Ecological Linkages: Marine and Estuarine Ecosystems of Central and Northern California

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Ecological Linkages:
Marine and Estuarine Ecosystems
of Central and Northern California

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I. Executive Summary

Three of California's four National Marine Sanctuaries, Cordell Bank, Gulf of the Farallones, and Monterey Bay, are currently undergoing a comprehensive management plan review. As part of this review, NOAA's National Marine Sanctuary Program (NMSP) has collaborated with NOAA's National Centers for Coastal Ocean Science (NCCOS) to conduct a biogeographic assessment of selected marine resources using geographic information system (GIS) technology. This report complements the analyses conducted for this effort by providing an overview of the physical and biological characteristics of the region. Key ecosystems and species occurring in estuarine and marine waters are highlighted and linkages between them discussed. In addition, this report describes biogeographic processes operating to affect species' distributional patterns. The biogeographic analyses build upon this background to further understanding of the biogeography of this region.

National Marine Sanctuaries of Central and Northern California

The study area includes three National Marine Sanctuaries (Cordell Bank, Gulf of the Farallones, and Monterey Bay), which encompass marine and estuarine habitats along the central and northern coast of California. Together, these contiguous national marine sanctuaries include more than 650 km of coastline, from Bodega Bay, north of San Francisco, to Cambria, near San Luis Obispo, and a total area of approximately 18,000 km^2.

Geographic Setting of the Study Area

The study region extends from Point Arena, a small peninsula on an elevated coastal plain in the southern portion of Mendocino County, to Point Sal, just south of Pismo Beach and the Nipomo Dunes area. The region consists of a multitude of diverse and important ecosystems that are very unique in their assemblages of marine organisms. Beginning near shore, the coast of California, especially north of Point Reyes and south of Point Pinos, is renowned for its strikingly beautiful, dramatic rocky cliffs. Pocket beaches occur along the coast where streams and rivers deposit sediment along the shore. Rivers that flow over broad, flat expanses of soft sediments into the ocean may be strongly influenced by tides and are frequently associated with upland and salt marshes, sandy beaches, intertidal flats, and estuaries. Estuaries and lagoons commonly form where rivers enter the ocean, mixing fresh and salt water. Rocky shores, which are more resistant to erosion than the sandy beaches, support a complex intertidal community, influenced primarily by the semidiurnal movements of tides. Moving offshore, subtidal communities are strongly influenced by sediment type, nutrient input, and depth. The majority of the continental shelf is sandy, but rocky outcrops cover a portion of it, forming submerged reefs, seamounts, and other features. Marine algae, unable to attach to the shifting sandy sediments, find more secure substrate on rocky reefs. At the shelf break, the continental slope drops precipitously to depths of over 3000 m. Sediments, transported down the continental slope and submarine canyons, collect in broad fans at the base of the slope. Below the rise, the abyssal plain is relatively flat, broken occasionally by such features as seamounts and small depressions. It is this array of ecosystems, combined with the oceanographic processes affecting the composition and abundance of marine organisms in them, which make this such a unique area.

Ocean Currents

The cold water California Current and comparatively warm water Davidson Current are major forces shaping the ecosystems in and around the study region. They affect upwelling and downwelling and, consequently, the amount of productivity seen along the coast. Additionally, where the two converge at Point Conception, a barrier is created that many species do not cross. The species north of Point Conception, encompassing the entire study region right up through Washington State, are a part of the Oregonian Province, while just south of Point Conception, they belong to the Californian Province. Although many species have ranges that end at the borders of these biogeographic zones under normal conditions, species of the subtropical Californian Province may occasionally extend their ranges to central and northern California during unusually warm oceanographic events, such as El Niño and the Pacific Decadal Oscillation. Other more localized oceanographic features, such as eddies, internal waves and bores, are also important factors influencing the distribution and abundance of marine species.

Oceanographic Seasons

While certain geological and biological features are evident along particular regions of coast, the same oceanographic processes and climatic phenomena are operating throughout the study region. Over a 12 month time-frame, the study area is exposed to three distinct oceanographic periods that vary with respect to prominence and location of ocean currents. These periods, described by upwelling (March to August), wind relaxation (August to November), and winter storms (November to March), are associated with different degrees of upwelling or downwelling. The amount of production in surface waters and the ability of organisms to disperse is directly impacted by these processes. In response to these periods, the abundance and type of organisms present in a given region changes throughout the year.

Natural Perturbations

Longer term climatic phenomena influencing the region include: El Niño, Pacific Decadal Oscillation, and global warming. Off the coast of California, El Niño events are characterized by increases in ocean temperature and sea level, enhanced onshore and northward flow, and reduced coastal upwelling of deep, cold, nutrient-rich water. During this period, survivorship and reproductive success of planktivorous invertebrates and fishes decrease with plankton abundance. Marine mammals and seabirds, which depend on these organisms for food, suffer food shortages, leading to widespread starvation and decreased reproductive success.

Every 20-30 years, the surface waters of the central and northern Pacific Ocean shift several degrees from the mean temperature. Such shifts in mean surface water temperature, known as the Pacific Decadal Oscillation, have been detected 5 times during the past century, with the most recent shift in 1998. The Pacific Decadal Oscillation impacts production in the eastern Pacific Ocean and, consequently, affects organism abundance and distribution throughout the food chain.

Ocean waters off the coast of California have warmed considerably over the last 40 years. It is not yet clear if this warming is a consequence of an interdecadal climate shift or global warming.

In response to these three phenomena some species have shifted their geographic ranges northward, altering the composition of local assemblages.

Ecosystems

The Land-Sea Interface

Rivers carry freshwater and sediments to bays, estuaries, and the ocean. Thirteen major watersheds are located along the central California coast. Historically, these supported large numbers of coho salmon, chinook salmon, steelhead trout, and sturgeon. Today, many native anadromous fish stocks throughout California are in danger of extinction. General degradation of upland watershed and freshwater ecosystems is a major factor in the decline.

Two major estuaries in northern and central California are San Francisco Bay and Tomales Bay. Several smaller estuaries and lagoons within the region, from north to south, are Estero Americano, Estero de San Antonio, Bolinas Lagoon, Drakes/Limantour Estero, and Elkhorn Slough (National Estuarine Reserve). Estuaries and bays are vulnerable to coastal development, pollution, introduction of invasive species, and commercial and recreational fishing for species that live in nearshore waters. Humans have modified and transformed about 90% of the wetlands in California. The existence and health of these coastal wetlands is critical to the survival of organisms that depend on these habitats for survival. One of California's wetland sites, Bolinas Lagoon, was designated as internationally important in this role under the Convention on Wetlands, signed in Ramsar, Iran, in 1971. The Convention on Wetlands is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. There are presently 136 Contracting Parties to the Convention, with 1,267 wetland sites designated for inclusion in the Ramsar List of Wetlands of International Importance.

Wetlands along the central California coast are sparse, but those present support millions of shorebirds and waterfowl during spring and fall migrations and the winter months. Migratory species require consistent sources of food and shelter along their migration route. If the distances between wetlands are too large, migrating birds may become exhausted and disoriented, increasing mortality.

Numerous marine species use embayments, lagoons, and estuaries as spawning and nursery grounds. Bat rays, leopard and smoothhound sharks, midshipman, Pacific herring, starry flounder, staghorn sculpin, surf perch of several species, jacksmelt, topsmelt, and pile perch mate and bear their young in estuarine habitats. Shallow, coastal waters of central and northern California also are critical habitat for Chinook, and especially coho salmon as they travel *en route* to spawning grounds in autumn and winter.

Geology and other physical forces influence the structure of the coastline. Energetic forces of water and wind erode the rocky coastline, creating the dramatic rocky intertidal habitat characteristic of the northern and central California coast. Small beaches form along the northern California coast where wind and waves erode granite and basalt cliffs. Further south, erosion of soft shale and sandstone bluffs creates the broad sandy beaches typical of southern California.

Sandy beach and rocky intertidal habitats are divided into distinct biological zones relative to height above mean high tide. In part, species' distributions are affected by their physiological tolerance to temperature, moisture, and salt. In response to these and other physical factors, the number of species of marine algae, gastropods, and fishes increases with depth in the intertidal zone.

Nutrients processed in marine systems are essential to communities using sandy beaches and rocky intertidal habitat. Waves carry and deposit plankton, macroalgae, and occasional corpses of fishes, birds, and marine mammals in the intertidal zone, providing an unpredictable and patchy source of food. Beach wrack attracts numerous mobile organisms, including amphipods, isopods, flies, beetles, and shorebirds. The sporadic deposition of food from the ocean sustains intertidal communities in habitats that are subjected to strong physical forces and relatively low local production.

Marine Ecosystems

Production in subtidal habitats depends on levels of light and nutrients, and exposure to physical forces. Sufficient light to support highly productive photosynthetic communities penetrates surface waters to approximately 30 m. Kelp, which can grow up to 10 cm per day, is among the most productive of marine plants. Primary productivity in kelp forests has been estimated at 350 to 2,800 grams of carbon per square meter.

Kelp provides substrate for numerous benthic and epibenthic invertebrates, as well as food and shelter for many fishes, seabirds, and marine mammals. Colonies of bryozoans grow on kelp fronds. Several species of snails, including purple ring top snail and blue top snail, feed on kelp, while kelp crabs cling to the underside of kelp fronds. During periods of low productivity, sea urchins may emerge from protective crevices in rocky reefs to graze on kelp. At the surface, floating kelp masses are important habitats for juvenile fishes, particularly rockfishes and kelp surfperch. Schools of blue, black, and kelp rockfishes and bocaccio are generally recorded in the midwater kelp canopy. Gopher, copper, black and yellow rockfishes, lingcod, cabezon and greenlings tend to associate with the bottom of the kelp fronds. In addition, the sea otter has been described as a "keystone species" for its role in structuring kelp forest communities through predation of herbivores, particularly sea urchins, resulting in increased kelp growth.

Productivity from seaweeds can also have less direct effects on coastal food webs. Particulate and dissolved organic carbon that results from fragmentation and decomposition of kelps and other seaweeds can be consumed by suspension-feeding zooplankton or benthic invertebrates, providing a trophic link between kelps and higher-level pelagic consumers, such as fish. A small portion of the drift algae may be transported off the reef, where it can contribute to production in submarine canyons and the deep sea.

Productivity is reduced on rocky reefs below 30 m, where light levels are low and kelp is unable to flourish. However, the physical structure of rocky reefs does provide shelter for numerous benthic invertebrates and fishes. Shortbelly rockfish (*Sebastes jordani*), the most abundant rockfish species on the continental shelf and upper slope off California, are often associated with rocky reefs between 30-80 m depth. Various seabirds and marine mammals rely on shortbelly rockfish for food. Sculpin (Cottidae) occur in shallow water and tidepools, as well as in deeper water around kelp forests, rocky reefs, and sand or mud bottoms on the continental shelf. Lingcod (Hexigrammidae), commonly associated with shallow rocky reefs, also occur in waters as deep as 300 m.

Soft bottom habitats on the continental shelf lack the physical structure and high biological production of kelp forests and rocky reefs. Species that live in soft sediments on the continental shelf are subjected to shifting sediments through wave action and near bottom currents. Some species that live in these habitats, such as crustaceans and mollusks, secure themselves in tubes and burrows. Other species, such as flatfishes, are camouflaged on sandy sediments of the seafloor by their color and shape.

Deep submarine canyons, such as Monterey, Ascension, Pioneer and Bodega, are remnants of riverbeds that deeply incised the continental shelf and slope during glacial periods. Because they cut into the continental shelf, submarine canyons support deep-sea communities relatively close to shore. Canyon walls are often steep and rocky, providing shelter for species, such as rockfishes and thornyheads, which are associated with complex physical structures. Canyon bottoms tend to slope gently and accumulate finer sediments, such as silt and mud, providing habitat for species such as flatfishes. In addition, the structure of submarine canyons affects the circulation of nearshore waters and the concentration of organisms in the water column.

Submarine canyons, submerged volcanoes, and other physical features under high pressure often concentrate gases and fluids beneath the sea floor. In some areas, where the sea floor is weak, these gases and fluids may be forced through the sediments, creating features known as cold seeps. Most cold seeps are found in the deep sea (600-3000 m) under conditions of low light, temperature, and oxygen, and high pressure. In spite of these difficult conditions, numerous organisms are adapted to life around cold seeps. Vesicomyid clams are the dominant species at cold seeps off central and northern California. These clams support chemoautotrophic bacteria in a symbiotic relationship. The bacteria use inorganic chemical compounds released by the cold seeps to produce organic compounds, which are used by their vesicomyid clam hosts.

Deep-sea communities depend on the distribution and quantity of primary production in surface waters, the rate of movement of organic material to the bottom, and the conditions of deposition and transformation of the organic matter in the sediment. A portion of dead organic matter produced in surface waters is transported to the sea floor either through passive sinking, or by active transport during vertical migration of the plankton. In the northeastern Pacific Ocean where production is particularly high, approximately 5-15% of the surface production eventually reaches the deep sea.

In a few places, extinct volcanoes or seamounts, disrupt the monotony of the abyssal plain. Off central California, several seamounts (Gumdrop, Pioneer, Guide, and Davidson) are located near the bottom of the continental slope. Seamounts provide physical structure, which supports complex deep-sea communities of benthic invertebrates and some fishes.

Offshore Islands

The California coast is a tectonic subduction zone, inhibiting the formation of offshore islands. The few that do exist are extremely important sites for breeding by seabirds and pinnipeds. The largest offshore islands in the study region are the Farallon Islands, west of San Francisco. The Farallon Islands support some of the largest colonies of breeding seabirds south of Alaska. Numerous marine mammals, including northern elephant seals, steller sea lions, harbor seals, and fur seals, haul out and breed on the Farallon Islands as well. Other important but much smaller breeding populations occur on rocks off Point Reyes, Año Nuevo Island, and on rocks off Big Sur. Subsurface features, e.g., the Farallon Ridge, Cordell Bank, and various seamounts, provide substrate and protection for diverse communities of benthic invertebrates and some fishes.

Biogeographic Distributions

The distribution of each species in the ocean is determined by a multitude of factors, including temperature, salinity, oxygen content, nutrient availability, current speeds and direction, species interactions, frequency of perturbation, and in general, food availability. Each species responds to these factors in slightly different ways. Despite these differences in individual responses, there can be similarities in species' distributions, which can be used to define biogeographic zones. The transitions between biogeographic regions are more distinct outside the study area than within this area, bounded by Points Arena and Sal (*Figures 9-13: Distributions of Selected Species*).

The geographic distributions of numerous marine organisms of the northeastern Pacific Ocean coincide with major oceanographic shifts (*Figures 9-13: Distributions of Selected Species*). The biogeographic boundary at the Gulf of Alaska occurs at the transition between sea and land along the south coast of Alaska. The biogeographic transition at Vancouver Island corresponds to the eastern portion of the North Pacific Drift, which bifurcates in this region with part diverted north into the Gulf of Alaska and part diverted south along the western coast of North America as the California Current. The biogeographic transition at Point Conception corresponds to a shift in the oceanographic regime. At Point Conception, the California coastline turns abruptly east and the cool water moving south in the California Current is diverted offshore.

The confluence of the California Current and the Southern California Countercurrent off Point Conception has been shown to affect the abundance and distribution of species. Waters north of Point Conception have been classified as the Oregonian Biogeographic Province, characteristic of the coast of central and northern California, Oregon, and Washington. Most of the organisms within this province have subarctic affinities. South of Point Conception, the marine species have been classified as the Californian Biogeographic Province, characteristic of warm subtropical waters off southern California and Baja California. These southern species occasionally extend their ranges to central and northern California during warm oceanographic events, such as El Niño and the Pacific Decadal Oscillation.

In addition to the changes in latitudinal distributions, the diversity of species changes with depth. The changes in species composition and abundance are associated with physiological tolerances for temperature, exposure, light and nutrient input, as well as a wide range of biological interactions among species. At all latitudes, the average number of species of algae and marine gastropods increased with depth from high to low intertidal and subtidal zones. In addition, species that occur across several depth zones are likely to have broader latitudinal distributions than species that occupy a single depth zone. In contrast to the patterns observed for marine algae and gastropods, the average number of fish species declined with latitude and depth. The greatest numbers of fish species occurred south of 50^{o}N latitude and shallower than 200 m.

For some species, the range of single individuals spans nearly the entire geographical distribution of the species. These species use local resources during long-distance migrations, but no individual resource supports a resident population. Examples of these species include baleen whales that feed at highly productive sites along their migration route, and seabirds that use estuaries along the coast as resting and feeding sites during their annual migrations.

For other species, the entire geographical range far exceeds the range of an individual. Many intertidal invertebrates and fishes have dispersal and sedentary phases during their life cycles. Examples of these species include barnacles, mussels, and clams that settle into intertidal habitats, and rockfish that settle into kelp forests or rocky reefs after a pelagic larval stage.

II. Introduction

Three of California's national marine sanctuaries—Cordell Bank, Gulf of the Farallones, and Monterey Bay—are currently undergoing a comprehensive management plan review. As part of this review, NOAA's National Marine Sanctuary Program (NMSP) is working with NOAA's National Centers for Coastal Ocean Science (NCCOS) to: (1) conduct a biogeographic assessment in a geographic information system (GIS) of selected marine resources, and (2) produce a report describing the important ecosystems, ecological processes and linkages in and around these three sanctuaries. This report supplements the biogeographic assessment being conducted by NCCOS. Together, these products will increase our understanding of marine and estuarine ecosystems, ecological processes, and the linkages between species and their habitats.

This report provides the background necessary for interpretation of patterns and relationships observed in the biogeographic analyses. This report identifies critical ecosystems and key species in the region. In addition, linkages between these ecosystems and species, and the effects of oceanographic conditions and anthropogenic influences on these linkages, are described. This report includes descriptions of estuarine and coastal areas, as well as the subtidal marine environment, whereas the initial GIS assessment is focused primarily on the subtidal marine environment.

III. Methods

This report was developed to meet the requirements established by the NCCOS Biogeography Program in consultation with the National Marine Sanctuary Program. The report summarizes oceanographic processes, including current patterns, eddies, freshwater plumes, and areas of upwelling that affect the distribution, dispersal, and production of marine and estuarine organisms. The report provides brief descriptions of the effects of larger-scale phenomena, such as major ocean currents, El Niño, and the Pacific Decadal Oscillation. Characteristics and locations of marine and estuarine habitats, such as bays and lagoons, sandy beaches, rocky intertidal areas, kelp beds, benthic, neritic, and pelagic habitats, continental shelf and slope, submarine canyons, cold seeps, seamounts, and offshore islands, are also described. San Francisco Bay is an important component of the study area, but the Bay itself is not a focal point of this report. Significant gaps in information are identified for each habitat. Key estuarine and marine species (including fishes, invertebrates, mammals, birds, reptiles, macrophytes, zooplankton and phytoplankton) are described within the context of the habitats they occupy and the linkages they form with other species and habitats. Rare or endangered species and those of significant commercial or recreational value are given special attention. Table 10 summarizes the status and distribution of species of particular concern. The authors conducted additional research to characterize biogeographic patterns. Summaries of the biogeographic patterns in the northeastern Pacific Ocean are provided at the end of the report. The authors included a brief summary of some of the most important anthropogenic impacts in order to provide accurate and fair representation of the ecological linkages among species, including humans, and marine and estuarine habitats. References are presented at the end of the report and are grouped by subject.

Information was gathered for the report using library and internet resources, as well as interviews with research scientists. Numerous electronic databases and catalogs were available to the authors (Table 1). In addition to the electronic resources, numerous hard-copy journals, housed in the collection at the Davidson Library at the University of California, Santa Barbara, were available to the authors (Table 2). Information from articles in over 80 academic journals was included in the report. The authors searched the electronic and hard-copy resources for information about an extensive list of topics that were identified in the scope of work for this project (Tables 3-6). Topics for research included physical oceanography, marine and estuarine habitats, key species, and the ecological linkages among different species and between species and habitats. Relevant information included descriptions of major habitat types and species of concern, including endangered and threatened species, keystone species, important predator or prey species, and species that are important for commercial or recreational purposes. For each species, information was gathered on distribution, status, population size, spawning location and time, feeding locations, and predator-prey relationships, as available in the literature.

Unpublished data were gathered to address specific issues. A database of distributions of over 830 species of marine benthic algae was provided by D. Sax (University of California, Santa Barbara). A database of distributions of over 770 marine benthic invertebrates was provided by G. Eckert (University of Alaska Southeast). Additional information on the distributions of 613 marine fishes, 131 shorebirds and seabirds, and 49 marine mammals was compiled by the authors. Literature records of species distributions are inherently variable in specificity. For many taxa, data on species distributions were available at a relatively coarse scale (>1^{o} latitude). However, for other groups, especially marine benthic invertebrates, distributional data were commonly available at a finer scale, including discrete boundary locations at the time of survey. A synthesis of information about biogeographic patterns of 460 species of benthic algae, 163 gastropod, and 234 fish species, along gradients of latitude and depth, was provided by C. Harley (Hopkins Marine Laboratory) and K. Smith (University of California, Santa Barbara). Data on biogeographic distributions are summarized at the end of the report.

In addition to the literature search, the authors interviewed over 20 scientists who have knowledge of marine and estuarine systems of central and northern California (Table 8). Interviews were initiated by a questionnaire provided to these scientists by email (Table 9) and many of these scientists continued to provide information through email and phone conversations. The scientists identified the habitats and/or species with which they were most familiar. The scientists provided lists of the most important references about the subjects of their expertise. The scientists also provided information on the status of habitats and/or species, and the likely role of habitats and/or species in structuring marine and estuarine communities. In some cases, scientists provided unpublished information about species' distributions and the factors that may limit species ranges. If the information was available, scientists described the dispersal patterns of study species. Several scientists reviewed one or several sections of the report and provided extensive comments to the authors. Comments were incorporated into the report under the guidance of the project team members in the National Marine Sanctuary Program and Biogeography Program.

IV. National Marine Sanctuaries of Central and Northern California

Three national marine sanctuaries, Gulf of the Farallones, Cordell Bank, and Monterey Bay, are located in coastal and marine habitats of central and northern California from Bodega Bay, north of San Francisco, to Cambria, near San Luis Obispo (*Figure 1: Study Region*). Together, these contiguous national marine sanctuaries include more than 650 km of coastline, and encompass a total area of approximately 18,000 km^2. Each sanctuary includes unique geological and biological features; however, all are strongly influenced by similar oceanographic processes.

The Gulf of the Farallones National Marine Sanctuary, established in 1981, includes an area of 3,250 km^2 off the northern and central California coast. The Sanctuary extends from Bodega Head, Sonoma County in the north, to Rocky Point, Marin County in the south. The Gulf of the Farallones extends beyond the Sanctuary's boundaries and is one of the broadest sections of the continental shelf off the U.S. West Coast. Besides the broad shelf, the major oceanographic feature that affects this coastal region is the San Francisco Bay Plume, which under certain conditions extends outwards to all areas of the Gulf. The Golden Gate, from which the plume emanates, lies midway along this section of coast. Offshore, the Gulf of the Farallones National Marine Sanctuary extends farther south to the waters west of San Mateo County. Habitats within the Gulf of the Farallones National Marine Sanctuary include rocky shores, sandy beaches, estuaries, lagoons and bays, as well as the Farallon Islands and the subsurface Farallon Ridge. The entire stretch of the broad shelf within the physical features described above is strongly influenced by coastal upwelling and the San Francisco Bay Plume. The upwelled waters, which support tremendous phytoplankton production, are advected offshore into the California Current as eddies and jets. These productive waters stimulate growth of organisms at all levels of the marine food web. In periods when upwelling is reduced, the nutrient input from the San Francisco Plume becomes important. The Farallon Islands, which are protected as a National Wildlife Refuge, are home to the largest concentration of breeding seabirds in the contiguous United States (12 species), as well as one of the richest assemblages of pinnipeds (5 species). About 163 species of marine, coastal, and estuarine birds and 36 species of marine mammals use the Sanctuary during breeding or migration. Further, white sharks are attracted to marine mammal colonies on the Farallon Islands, Point Año Nuevo, and Año Nuevo Island.

The Cordell Bank National Marine Sanctuary, designated in May 1989, includes an area of 1,362 km^2 off the coast of central California (*Figure 2: Northern Region*). Cordell Bank is located at the edge of the continental shelf, about 80 km northwest of the Golden Gate Bridge and 33 km west of Point Reyes. The main feature of the Sanctuary is an offshore granite bank, 7 km wide and 15 km long. The rocky bank emerges from the soft sediments of the continental shelf, reaching within 37 m of the ocean's surface. The base of the Bank is over 120 m deep. The combination of oceanographic conditions and undersea topography of Cordell Bank supports a diverse and productive marine ecosystem. A persistent upwelling plume projects southward and offshore from Point Arena and Point Reyes, transporting nutrients and organisms suspended in the water column into the bank's relatively shallow waters. Insolation fuels primary productivity and eventually influences the entire food web through direct and indirect trophic linkages. This high local productivity supports abundant populations of invertebrates, fishes (240 species), seabirds (69 species), and marine mammals (28 species), and attracts many migratory species.

The Monterey Bay National Marine Sanctuary, established in 1992, is the largest of 13 marine sanctuaries administered by the National Marine Sanctuary Program. The Sanctuary extends from the Rocky Point to Cambria Rock, encompassing nearly 450 km of shoreline and 13,780 km^2 of ocean, extending an average distance of 32 km from shore. At its deepest point, the Sanctuary reaches a depth of 3,250 m. The Sanctuary includes a variety of coastal and marine habitats, such as rugged rocky shores, lush kelp forests, and several underwater canyons, the largest of which is the Monterey Submarine Canyon. The northern portion of the Sanctuary includes a relatively wide and shallow continental shelf. This broad shelf extends through the northern reaches of the study area including the Gulf of the Farallones and Cordell Bank. South of Monterey Bay, the Sanctuary includes primarily deep ocean, owing to the consistently narrow continental shelf that extends south to Point Conception. The diverse array of habitats in the Sanctuary is home to 33 marine mammals, 94 species of seabirds, at least 345 species of fishes, and numerous invertebrates, and plants.

V. Geographic Setting of the Study Area

Study Region (*See Figures 1 & 5: Study Area & Rivers and Sediments*)

The coast of California, especially north of Point Reyes and south of Point Pinos, is renowned for its strikingly beautiful, dramatic rocky cliffs. Pocket beaches occur where coastal streams and rivers deposit sediment on the shore. Rivers that flow over broad, flat expanses of soft sediments into the ocean may be strongly influenced by tides and associated with upland and salt marshes, sandy beaches, intertidal flats, and estuaries. Estuaries and lagoons commonly form where rivers enter the ocean, creating a mixing of fresh and salt water. Rocky shores, which are more resistant to erosion than the sandy beaches, support a complex rocky intertidal community, influenced primarily by the semidiurnal movements of tides. Subtidal communities are strongly influenced by sediment type, nutrient input, and depth. The majority of the continental shelf is sandy, but rocky outcrops cover a portion of it, forming submerged reefs, seamounts, and other features. Marine algae, unable to attach to the shifting sandy sediments, find more secure substrate on rocky reefs. At the shelf break, the continental slope drops precipitously to depths of over 3000 m. Sediments, transported down the continental slope and submarine canyons, collect in broad fans at the base of the slope. Below the rise, the abyssal plain is relatively flat, broken occasionally with such features as seamounts and small depressions. A multitude of physical and biological variables interact to determine the composition and relative abundance of species in estuarine and marine ecosystems. This report provides a brief overview of the complex ecology of estuarine and marine systems along the central and northern coast of California.

Northern Region (*See Figure 2: Point Arena to southern San Francisco Bay*)

Point Arena, the northernmost point in the study area, is a small peninsula on an elevated coastal plain in the southern portion of Mendocino County. Point Arena extends northwest into the ocean along the San Andreas Fault, which is just east and landward of the point. The terrain on the point varies from gently sloping to moderately steep, and it is bisected by steep ravines. The Garcia River drains into the protected area between Point Arena and the coast north of the point. About 30 km south of Point Arena, the Gualala River travels several kilometers along the coast before reaching the ocean.

South of Point Arena, the Russian River drains the extensive watershed within Mendocino and Sonoma counties. Small freshwater and sediment plumes are carried directly into the open ocean from the Russian River. Establishment of dams and extraction of gravel from the Russian River have caused severe bank erosion and degradation, interrupting historical fish migration to prime spawning grounds in the river system.

Bodega Head, a small coastal peninsula, is located just south of the Russian River and about 105 km north of San Francisco. Various coastal habitats are found on and around Bodega Head, including grassland, exposed cliffs, freshwater and salt marshes, dunes and beaches, mudflats, and rocky intertidal habitats.

Bodega Harbor is southeast of Bodega Head, and protected from the open ocean by a narrow peninsula. The mudflats of Bodega Harbor support a diverse assemblage of intertidal invertebrates. In 1993, a small shallow tidal pond, Doran Marsh, was restored in Bodega Harbor to provide shorebird foraging habitat during high tides. The new habitat has attracted a significant portion of the harbor's shorebirds during seasonal migrations.

Bodega Bay, located about 100 km north of San Francisco, is bordered by rocky intertidal areas, low coastal bluffs, and short expanses of narrow, sandy beach. The bay attracts a variety of migrating shorebirds, waterfowl, and raptors. Esteros Americano and de San Antonio and the entrance to Tomales Bay are coastal estuaries located on Bodega Bay. Estero Americano, which drains into Bodega Bay at the Sonoma-Marin County line, is among the important biological areas off northern California. South of Estero Americano, Stemple Creek becomes the Estero de San Antonio, draining into Bodega Bay. Many different coastal habitats are found in the esteros including mudflats, marshes, rocky shores, coastal scrub, and grasslands. With the variety of habitats, the esteros are important feeding and resting areas for birds. The esteros support 31 marine and freshwater fishes, including Pacific herring, staghorn sculpins and starry flounder. The endangered tidewater goby breeds in the shallow waters of Estero de San Antonio.

Tomales Bay, located northeast of Point Reyes and about 80 km north of San Francisco, is an example of a fault-controlled valley along the San Andreas Fault. Movements of the fault impact the topography of the bay. Tomales Bay extends 24 km northwest from headwaters to mouth between Tomales Bluff and Sand Point at Bodega Bay. At the headwaters, Lagunitas Creek drains into Tomales Bay. Lagunitas Creek supports a run of approximately 10 percent of California's current coho salmon population. Dense eelgrass meadows are found in Tomales Bay, particularly in the vicinity of Hog Island. The eelgrass supports a diverse invertebrate community, including snails, shrimp, nudibranchs, and sea hares. Pacific herring use the extensive eelgrass beds in Tomales Bay for spawning. Tomales Bay also supports seasonal populations of salmon, steelhead, sardines, and lingcod. The shallow bay's sandy bottom attracts a variety of bottom-dwelling fish, including sole, halibut, skates, and rays. Leopard sharks are common in Tomales Bay and occasionally blue sharks are sighted. Over 41,000 shorebirds and seabirds, including loons, grebes, geese, cormorants, and ducks, spend the winter in Tomales Bay.

Point Reyes is a low but extensive peninsula, extending southwest from Tomales Point well out into the Pacific Ocean. Like Bodega Head, Point Reyes is on the Pacific Plate, separated from the rest of California by the San Andreas Fault. The southwest extension of Point Reyes into the Pacific Ocean influences local ocean circulation patterns. One of the strongest upwelling centers along the coast of California is located at Point Reyes. A plume of cold water forms offshore and south of Point Reyes when upwelled waters are displaced by coastal winds.

Drakes Estero and Estero de Limantour, located just east of Point Reyes, are open to the ocean, but protected from the coastal currents by the peninsula. Drakes Estero is a drowned river valley, created by rising ocean levels inundating the valley. Tidal channels and mudflats are exposed at low tide in the upper reaches of Drakes Estero, exposing a diverse assemblage of invertebrates that live under rocks and in the mud. Drakes Estero supports numerous shore and other birds during the fall migration and winter layover. A large harbor seal breeding colony (about 1,200 individuals) occurs at Drakes Estero. During the winter, a breeding colony of about 100 elephant seals congregates on sandy shores of Drakes Bay.

Offshore and west of Point Reyes is Cordell Bank, a prominent submerged feature that rises from the continental shelf. The bank rises from about 915 m on the sea floor to within 37 m of the ocean surface. Cordell Bank consists of a series of steep ridges and narrow pinnacles, about 15 km long and 8 km wide. The topography of Cordell Bank influences local ocean circulation. Strong upwelling of deep ocean waters consistently occurs to the north of Cordell Bank. Nutrients in the water support high phytoplankton productivity that stimulates growth of organisms at all levels of the marine food web.

Bolinas Lagoon is a small, shallow estuary located on the San Andreas Fault, about 25 km northwest of the Golden Gate Bridge. The lagoon is protected from the Pacific Ocean by a long spit, which terminates at the mouth of the lagoon. Covering less than 6 km^2, the triangular lagoon is 5.5 km long and 1.5 km across at it's widest. A diversity of habitats are found in the Bolinas Lagoon, including upland and salt marshes, mudflats, subtidal channels, eelgrass beds, and rocky intertidal habitats. The lagoon is a nursery for juvenile fish, many of which are important to commercial fishing industries, and which feed local seabirds and shorebirds. Harbor seals haul out onto the mudflats to rest, warm themselves, and give birth. Thousands of wintering waterfowl, shorebirds, and seabirds, including brown pelicans and endangered snowy plovers, forage and roost on the mudflats and marshes of Bolinas Lagoon.

The San Francisco Bay, at the confluence of the San Joaquin and Sacramento rivers, is the largest in the study area, encompassing an area of 177,699 km^2. Various coastal habitats are located in and around San Francisco Bay, including sandy beaches, mudflats, salt and freshwater marshes, rocky intertidal, reef, and shallow open water. Invertebrates are abundant in the muddy, bottom sediments of the San Francisco Bay. Estuarine fishes, such as the California halibut and leopard shark, occupy benthic habitats in San Francisco Bay, while other species, such as shiner surfperch and jacksmelt, live in the overlying waters. Hundreds of thousands of birds inhabit the bay waters year round and during migration forage on the mudflats, marshlands, and in the open water. The coast surrounding San Francisco Bay and the outer coast along San Mateo and San Francisco counties support the largest and most concentrated human population in the study area. As of 2001, approximately 6.9 million people live in the counties that border San Francisco Bay. The concentration of human inhabitants around San Francisco Bay contributes to coastal development, erosion, and input of pollutants into estuarine and marine ecosystems.

A large freshwater plume emanates from the mouth of San Francisco Bay as a consequence of freshwater input from the Sacramento, American, and San Joaquin rivers. The waters of the San Joaquin and Sacramento rivers once carried huge amounts of sediment, which were deposited in San Francisco Bay and offshore and subsequently transported by ocean currents to beaches and dunes along the coast. Patterns of sedimentation have changed as dams, which reduce sediment transport, were established on these rivers.

The Gulf of the Farallones lies offshore from San Francisco Bay. Here the broad continental shelf extends offshore 30-50 km before dropping steeply at the continental shelf break. This shallow sandy habitat supports a diverse community of fishes and invertebrates.

The Farallon Islands are located along the western edge of the Gulf of the Farallones near the continental shelf break. Only a few of the Farallon Islands chain (Southeast Farallon, West End, Middle Farallon, and North Farallon islands) emerge from the ocean. Many others, such as Noonday Rock, are subsurface. Southeast and West End islands are the largest, comprising an area of about 0.5 km^2. Middle Farallon Island, a small rock, is located 5 km northwest of Southeast Island. The North Farallon group, including seven steep rocky peaks (only four of which rise above the sea surface), is located 6 km northwest from Middle Farallon Island. The Farallon Islands support hundreds of thousands of seabirds year round and breeding colonies of 12 seabird species. Several pinnipeds, including northern elephant and harbor seals, California and steller sea lions, and northern fur seals, have established breeding colonies on the Farallon Islands.

Gumdrop, Pioneer, and Guide Seamounts are located about 120 km off the California coast, southwest of the Farallon Islands (*Figures 2-3: Northern and Central Regions*). These seamounts disrupt the monotony of the deep sea floor. The summit of Pioneer Seamount rises about 1,950 m and Gumdrop Seamount rises about 800 m above the deep sea floor. The physical structure of the seamounts provides substrate and protective cover for numerous invertebrates and some fishes that inhabit the deep sea.

<u>Central Region</u> (*See Figure 3: Point Año Nuevo to Point Sur*)

The San Mateo county coastline south of San Francisco consists of long stretches of sandstone cliffs with a few small beaches and estuaries created by coastal streams. These sandstone cliffs erode under the forces of ocean waves, coastal fog, and tectonic uplift, creating intricate caverns known as “tafoni.”

San Mateo and San Francisco counties support a large human population, estimated in 2001 at approximately 1.5 million people in the two counties. The population density of San Mateo County is estimated at 1,575 people per square mile. The concentrated urban population contributes to coastal development and erosion, and increased input of pollutants into coastal and marine ecosystems. Although several large towns are located south of San Mateo County, including Santa Cruz, Capitola, Moss Landing, Watsonville, Marina, Seaside, Monterey, Pacific Grove, and Carmel, the combined human population in Santa Cruz and Monterey counties is low (approximately 660,000 people) compared to San Mateo County. The population densities of Santa Cruz and Monterey counties are estimated at 574 and 121 people per square mile, respectively.

Point Año Nuevo is a low rocky point, located approximately 90 km south of San Francisco. Cool waters accumulate near an upwelling center off Davenport, southeast of Point Año Nuevo. High local productivity and moderate climate support diverse intertidal communities around Point Año Nuevo. More than 300 species of invertebrates have been recorded including clams, abalones, limpets, chitons, hermit crabs, and anemones. Elephant seals, sea lions, and other marine mammals form breeding colonies on Point Año Nuevo as well. Año Nuevo State Reserve protects the large breeding colony of northern elephant seals.

A small island (Año Nuevo Island) is located just offshore from Point Año Nuevo. The island supports nesting colonies of 6 seabird species, and serves as a breeding ground for northern elephant seals, harbor seals, and California and steller sea lions.

Monterey Bay is located between Point Santa Cruz to the north and a prominent granite headland, Point Piños, to the south. Monterey Bay, by far the largest bay along the central coast of California, covers an area of about 550 km^2 and is located about 80 km south of San Francisco between Davenport and the Monterey Peninsula. The northern coastline of Monterey Bay is composed of sand bluffs, mudstone terraces, and rocky intertidal areas. Sand beaches and cliffs extend from Soquel Point southward to Moss Landing. The Salinas Valley and the northern Santa Lucia Range are the dominant topographic features in the southern half of the Monterey Bay. To the south of Monterey Bay are the granite headlands of Point Pinos.

The Salinas River is the primary drainage into Monterey Bay. About 2.4 million cubic meters of sediment are deposited in Monterey Bay during the winter and spring months by the Salinas, San Lorenzo, and Pajaro rivers, and Soquel and Aptos creeks.

Elkhorn Slough opens into Monterey Bay at Moss Landing. The slough is a shallow estuary that extends inland from Moss Landing Harbor for approximately 6.4 km before curving north for 5 km. Elkhorn Slough is relatively shallow, with an average depth of 1.4 m. Elkhorn Slough encompasses a variety of habitats, including channels, mudflats, eelgrass beds, salt marsh, and hard substrate. The Elkhorn Slough supports a diverse and abundant biota, including numerous invertebrates, over 70 fish species, at least 265 bird species, sea otters, sea lions, and harbor porpoises.

Monterey Canyon bisects the floor of Monterey Bay, extending from the shore near Moss Landing across the continental shelf to a depth of over 3,200 m on the abyssal plain. There are two main branches of the Monterey Canyon: Soquel Canyon to the north and Carmel Canyon to the south.

In geologically active areas, such as submarine canyons off central California, high pressure under the sea floor may force fluids and gases through the seabed. These areas are known as cold seeps. Numerous cold seeps have been located in deep waters within and around the Monterey Canyon and in other geologically active regions near the edges of continents. Although cold seeps are found in cold, dark waters, under tremendous pressure, they support remarkably productive communities of bacteria, chemosynthetic clams, and vestimentiferan and pogonophoran tube worms.

South of the Monterey Peninsula, the Carmel River drains about 580 km^2 between the Sierra del Salinas and Santa Lucia Mountains. Near the coast, the river enters the Carmel Estuary and empties into Carmel Bay. Point Lobos, a conspicuous rocky outcrop, surrounded by protected sandy beaches and exposed gravel terraces, is the southern boundary of the bay. Carmel Bay drops steeply from Monastery Beach. Carmel Canyon continues to drop toward the northwest until it merges with Monterey Canyon at a depth of 1,970 m.

South of the Monterey Peninsula, the Big Sur coast is renowned for its steep cliffs and rocky headlands. Along the Big Sur coast, the western slope of the Santa Lucia Mountains drops steeply into the ocean. Many small streams and rivers drain the Santa Lucia Mountains between Big Sur and Morro Bay. The continental shelf off Big Sur remains narrow and highly dissected. Sur and Lucia Canyons transport sediments from the Santa Lucia Mountains to the deep abyssal plain (*Figures 3-4: Central and Southern Regions*).

Southern Region (*See Figure 4: Point Piedras Blancas to Point Arguello*)

Located seaward of the Sur and Lucia Canyons at a depth of 1,100 m, the Davidson Seamount rises from the ocean floor. The Davidson Seamount supports a diverse biological community relative to the surrounding deep water habitat, consisting mainly of invertebrates such as sponges and gorgonians and deep-sea fishes. The water above the seamount is a productive feeding ground for a variety of fishes, marine mammals, and seabirds.

Point Piedras Blancas is located approximately 18 km north of Cambria, near the southern boundary of the Monterey Bay National Marine Sanctuary. The sandy beaches south of Point Piedras Blancas have become one of the primary coastal breeding sites for the northern elephant seal. In 1990, fewer than 25 elephant seals were counted in the small cove just south of the Piedras Blancas lighthouse. In 1992, the first birth of a northern elephant seal occurred at Point Piedras Blancas. The total population of northern elephant seals at Piedras Blancas in 2001 was estimated to be around 8,000 and the number of pups born was about 1,950.

South of Cambria, fresh water from Chorro and Los Osos Creeks drains into Morro Bay, forming a small estuary. In shallow water, eelgrass beds and wetlands provide protected habitat for larvae and juvenile fishes. Chorro and Los Osos Creeks support breeding populations of steelhead trout. Morro Bay is located on the Pacific Flyway and supports numerous bird species over the winter and during spring and fall migrations. At low tide, about 6 km^2 of mudflats are exposed in Morro Bay, providing a vast feeding area for over 250 species of birds.

Pismo State Beach, along the coast of San Luis Obispo Bay, contains more than 8 km^2 of beach and sand dunes. Sediments accumulate on Pismo Beach, in part because longshore drift, which generally carries sediments south along the coast, is interrupted by a prominent feature (Point San Luis) just north of the beach.

At the southern end of the study area, the Santa Maria River deposits sediments along the coast, creating and maintaining the Nipomo Dunes. Sediments that comprise the dunes began to accumulate approximately 18,000 years ago at the end of the last glacial period. The dunes are now stabilized and covered with plants. Between the mesas and the beach, younger dunes form a series of sparsely vegetated ridges and hollows. The dunes support more than 200 species of resident and migratory birds, including one of the last nesting colonies of the federally endangered California Least Tern.

Three points are located near the southern end of the study area, Point Sal, Point Arguello, and Point Conception. San Antonio Creek and Santa Ynez River drain the coastal mountains between Point Sal and Point Conception. At Point Conception, the California coast turns eastward towards Santa Barbara. The geography of Point Conception influences oceanographic conditions and biogeographic distributions of coastal and marine species. Point Conception forms the southern and northern boundaries of the subarctic and subtropical zoogeographic regions, respectively.

VI. Ocean Currents

The California Current, the predominant current off central and northern California, moves water towards the equator along the west coast of North America. The California Current carries low salinity (31-34 ppt), cool (9-12^{o}C) water from the Subarctic Pacific and the North Pacific Drift. The core of the California Current is usually about 200-300 km offshore; however, the current is infused with nutrient-rich upwelled water, flowing as plumes and jets from upwelling centers near coastal promontories. The California Current generally flows about 5 to 10 cm/s, but may reach speeds up to 25 cm/s in some places.

The orientation of coastal peninsulas and points influences local and regional ocean circulation patterns. The California Current carries water south along the coast of central California to Point Conception, where the coastline turns abruptly east and the current continues southward and offshore. A large gyre forms in the Southern California Bight, with northward flow on the Southern California Countercurrent south of Point Conception. During the summer, a subsurface counter current, known as the Davidson Current, carries warm water through the Santa Barbara Channel and northward along the shelf break as far as Oregon. During winter, the Davidson Current is expressed at the surface.

The confluence of the California Current and the Southern California Countercurrent, which continues north as the Davidson Current, affects the abundance and distribution of species off Point Conception. Waters north of Point Conception have been classified as the Oregonian Province, characteristic of the coast of northern California, Oregon, and Washington. Waters south of Point Conception have been classified as the Californian Province, characteristic of warm subtropical waters off southern California and Baja California. Although many species are strongly separated by these biogeographic zones under normal conditions, species of the subtropical zone may occasionally extend their ranges to central and northern California during unusually warm oceanographic events, such as El Niño and the Pacific Decadal Oscillation.

The flow of the California Current is reduced during winter. From November through January, the northward-flowing Davidson Current is the dominant current below 100 m along the shelf break. The Davidson Current originates in the eastern equatorial Pacific as the Southern California Countercurrent and flows to the north within 100 km of the coast. The Davidson Current tends to be centered over the continental slope. Off San Francisco, the core of the Davidson Current is located about 800 m deep, and moving northwest and offshore at Point Reyes. The return of winds from the northwest in January slows the northward surface expression of the Davidson Current.

Coastal flows along the California coastline do not smoothly parallel the coastline. Rather, they are punctuated by jets, filaments and eddies that are typically associated with points, headlands or submerged features such as seamounts. Eddies are areas of circular water flow, moving clockwise off the California coast. The formation of eddies is influenced by prominent coastal and oceanic features, such as points and seamounts. There is a semi-permanent eddy northwest of Monterey Bay and in the Gulf of the

Farallones, known as the San Francisco Eddy. There is a semi-permanent eddy that extends out from Point Año Nuevo; another moves out from Point Arena and Point Reyes, projecting outward in the vicinity of the Farallon Islands. Eddies frequently form west and southeast of Monterey Bay and in the bay itself. In addition, eddies may form when currents move in opposite directions on different sides of seamounts or emergent rocky features, such as at Cordell Bank. Persistent eddies may retain zooplankton or ichthyoplankton.

Jets and filaments move water rapidly offshore, e.g., >1m/s, for a distance of up to several hundred kilometers. These oceanographic features affect the distributions of chlorophyll and plankton (*see neritic and epipelagic communities*). Collectively, the irregularities in coastal flows, such as eddies and jets, interact to concentrate, retain, or move production from upwelling centers to other locations.

Internal waves are waves that travel below the surface and can generate complex patterns of flow over the continental shelf and slope. Internal waves form as marine tides concentrate over the shelf break, particularly near irregular features such as submarine canyons. These internal waves produce turbulence, mixing, and up-canyon flow.

If internal waves become unstable, they can break and form internal bores. The bores commonly travel near the bottom across the continental shelf to shore, which can generate onshore flows of bottom waters. Internal bores may move sediments or organisms across the shelf into nearshore habitats.

Ocean currents and other oceanographic features such as eddies, internal waves and internal bores, strongly influence the distribution and abundance of marine species (*see biogeographic distributions*). Although many oceanographic processes have been described in great detail, our understanding of their linkages to ecological processes is just unfolding. In part, the lack of integration between oceanography and ecology has occurred because historically oceanographic and ecological processes were measured in different places and at different scales. Several programs that couple ecological and oceanographic studies are beginning to break this bottleneck.

VII. Oceanographic Seasons

Each year, there are three distinct oceanographic periods characterized by persistent upwelling, frequent wind relaxation, and winter storm conditions. These periods overlap and do not follow a strict cycle.

The upwelling season generally occurs between mid-March and mid-August. Strongest upwelling occurs during May and June (*Figure 6: SST and Chlorophyll*). During this season, strong northwest winds, combined with the Coriolis force, move surface waters offshore and southward. Cool, nutrient-rich water from depth replaces the displaced surface water. Upwelling areas can be observed as cool sea surface temperatures in satellite images. Although the duration and intensity of upwelling is variable, upwelling episodes are commonly sustained for 7-10 days, punctuated with periods of relaxation. The upwelling-favorable winds generally subside by late July. El Niño and other warm water events may reduce the intensity by which deep waters are upwelled to the surface (*Figure 7: SST during El Niño and non-El Niño year*).

A period of frequent wind relaxation generally occurs between mid-August and mid-November (*Figure 6: SST and Chlorophyll*). During this time, winds are light and variable, and the seas can remain calm for extended periods (up to a week or two). When upwelling is not active, offshore waters move inshore and surface water is heated by sunlight and becomes warmer. When upwelling-favorable winds relax, larvae found in surface waters may be transported back to shore, where some larvae eventually settle. Periods of wind relaxation lasting approximately 2-6 days and may alternate with upwelling-favorable conditions during the spring. Periods of relaxation may persist longer during the late summer and early fall. The period of wind relaxation quickly disappears after the onset of upwelling winds or the return of winter storms.

The winter storm period generally occurs between late November and mid-March (*Figure 6: SST and Chlorophyll*). During this period, low pressure systems moving south of the Gulf of Alaska generate southerly winds off California, along with large waves. Under the influence of these processes, the northward flow of the Davidson Current is enhanced.

Upwelling is closely associated with coastal morphology. Upwelling tends to occur off points along the eastern boundary of the North Pacific Ocean. Major upwelling centers are located near Points Arena, Reyes, Año Nuevo, and Sur. Particularly strong upwelling occurs in the area between Point Arena and Point Reyes. Coastal mountains concentrate and intensify winds in this area, increasing the offshore movement of water. During upwelling, cool, nutrient-rich water rises to the surface near Point Reyes, moving offshore and southward across the Gulf of the Farallones. Cool waters may accumulate off central California as well, especially near Point Año Nuevo and Point Sur. These waters and associated nutrients can then be transported to Monterey Bay via surface currents.

Phytoplankton, which support the complex web of marine life, thrive on nutrients in upwelled waters (*see neritic and epipelagic communities*). Upwelled waters in some regions of the world are high in nutrients, but do not stimulate large blooms of phytoplankton as other micronutrients, such as iron, can limit productivity. In the central coast region of California, iron is commonly resuspended from bottom sediments into the cold bottom water that is ultimately brought to the surface by upwelling. By comparison, in this region rivers appear to be a relatively minor source of these nutrients and micronutrients. High phytoplankton production in areas of strong upwelling stimulates growth of organisms at all levels of the food web. The higher trophic levels, including invertebrates, fishes, marine mammals, and seabirds depend on nutrient input from upwelling (*see neritic and epipelagic communities*).

Off central and northern California, near-surface chlorophyll concentrations tend to be higher nearshore than offshore. At some upwelling centers, plankton populations are carried offshore in eddies, jets, and filaments. These plankton populations may be transported back toward the shoreline if coastal winds reverse or as eddies return water and plankton to their points of origin. For example, many invertebrate and fish larvae, which may be moved far offshore during persistent periods of upwelling, can return to shore and settle in shallow coastal reefs during periods of wind relaxation.

VIII. Natural Perturbations

A. El Niño-Southern Oscillation

El Niño-Southern Oscillation is one of the strongest recurring patterns in the ocean-atmosphere system (*Figure 7: SST during an El Niño and non-El Niño year*). El Niño is defined by relaxation of the trade winds in the central and western Pacific, which can set off a chain reaction of oceanographic changes in the eastern Pacific Ocean. Off the coast of California, El Niño events are characterized by increases in ocean temperature and sea level, enhanced onshore and northward flow, and reduced coastal upwelling of deep, cold, nutrient-rich water.

Figure 7 shows the sea surface temperature during El Niño (1997-98) and non-El Niño periods (1996-97). Each image shows the average sea surface temperature during the indicated month: April, August, and December. During El Niño, upwelling, which is indicated by the dark blue shading in *Figure 7*, may be particularly strong in the spring. During the summer, upwelling is greatly reduced and warm surface waters, indicated by the yellow and red shading in *Figure 7*, move northward and toward the coast. The effects of El Niño are especially noticeable in the late fall or early winter, when the warm surface waters persist.

Since 1800, there have been approximately 48 El Niño events, with a mean frequency of one event every 4.1 years. Although El Niño events occur frequently, they are difficult to predict and highly variable in intensity. Some El Niño events are relatively weak, whereas others may affect the entire Pacific Basin. Particularly strong El Niño events occurred during 1957-1958, 1982-1983, and the strongest El Niño on record occurred in 1997-1998.

Temperature changes and other environmental variables associated with El Niño events may directly affect the composition and structure of biological communities. El Niño events are accompanied by large reductions in plankton, fish, seabirds, and marine mammals in many upwelling regions of the eastern Pacific Ocean. The thermocline separating warm, nutrient poor surface waters from colder nutrient rich waters below commonly occurs much deeper below the surface. As a result, when upwelling winds bring deeper water to the surface, it is still relatively warm and nutrient poor. Without the fertilizing effects of high nutrients, the blooms of phytoplankton production do not occur. For example, primary production (*see neritic and epipelagic communities*) was 5- to 20-fold lower during the 1982-1983 El Niño event than during previous years. In addition, the onset of phytoplankton blooms may be delayed several months during El Niño events.

Without this flush of phytoplankton production, zooplankton (*see neritic and epipelagic communities*) biomass declined during the strong El Niño events of the last century. Changes in the density and abundance of zooplankton are thus secondary consequences of changes in concentrations of dissolved nutrients and biological productivity.

During El Niño, upwelling favorable winds are often reduced in the central California region. As a result, larvae in surface waters, which typically are carried offshore during upwelling, may be retained near the coast. High nearshore retention of larvae may contribute to increases in their successful recruitment back to coastal adult habitats. For example, average recruitment of barnacles (*Chthamalus fissus/dalli* and *Balanus glandula*) during El Niño was nearly two orders of magnitude greater than during the following year. During the 1997-1998 El Niño event, sea urchin larvae settled during relaxation of upwelling-favorable winds. Similarly, the recruitment success of Pacific hake is reduced during years when cold waters are upwelled (contributing to offshore transport of larvae). Strong recruitment of Pacific hake resulted only from spawning in warmer than average years.

Decreased food supply during El Niño events contributes to mortality and decreased reproductive success of fishes. Rockfish species that enter parturition during the months of January and February (blue, black, widow and yellowtail rockfish) may suffer reduced parturition success because of food shortages during El Niño events. Growth rates were slower, and the condition of rockfish deteriorated during the 1982-1983 El Niño event as compared to previous or subsequent years.

During El Niño events, seabirds also suffer a serious reduction in sources of food, contributing to breeding failure and mortality. Species that feed locally on benthic prey (e.g., Pigeon Guillemots and Pelagic Cormorants) are particularly vulnerable to food shortages. For example, seabirds on the Farallon Islands delayed their reproductive effort, and mortality was higher than normal during the 1982-1983 and other recent El Niño events. Fewer chicks were fledged, and those that survived exhibited longer times to fledging and lower fledging weights.

Breeding success among seabirds at the Farallon Islands depends on multiple variables, including the strength of the California Current, the intensity of upwelling, and interannual and interdecadal fluctuations. The numbers of warm-water species (including Black-vented Shearwater, and Black and Least Storm-petrels) off southern and central California increase during periods of sea surface warming associated with El Niño events. Cool-water species (such as Sooty Shearwater) decline during periods of sea surface warming, either due to northward migration or local declines in abundance.

Pinnipeds exhibit increased mortality and reduced breeding success in central and northern California during El Niño events. However, the impacts of El Niño events on pinnipeds off central and northern California are lower than those closer to the equator, where the changes in temperature and climate are more intense. Some pinnipeds may respond to changes in food supply by moving to a more productive area, or shifting their diets to accommodate changes in prey species composition and density.

Changes have also been reported in cetacean populations off the coast of California in relation to El Niño. In 1997-98, odontocete diversity increased as southern species moved northward off California. Rorqual whale densities declined in areas where their euphausiid prey became less abundant and increased around coastal upwelling regions where zooplankton biomass was also concentrated. These trends reversed with the 1999 La Niña conditions and the return of the euphausiids.

Humpback whales may be better able to cope with stressful environmental conditions than other rorqual whales, because they are capable of switching their primary prey between euphausiids and fish.

Numerous northern range extensions and increases in abundance of southern species have been associated with El Niño events. For example, pelagic red crabs (*Pleuroncodes planipes*), normally found off the central and southern coast of Baja California, are commonly found as far north as Monterey during El Niño events. Spawning populations of northern anchovy (*Engraulis mordax*) moved further offshore and to the north during the 1982-1983 El Niño event than during previous years (*see neritic and epipelagic, and offshore island communities*). Eastern tropical Pacific fishes (e.g., tropical triggerfish, blue-banded goby, lumptail searobin, and Pacific cutlassfish) have been observed in warm-temperate waters off southern California during El Niño events. Pelagic fish species (including northern anchovy, sardine, Pacific mackerel, jack mackerel, and Pacific whiting) tend to move into cooler waters offshore and north of their normal ranges during El Niño events. Cool water seabird species (e.g., Black-legged Kittiwake and Sooty Shearwater) migrate further offshore and north of their usual northern limit during the El Niño events. However, cold-water species return to the California coast with the onset of La Niña conditions and displace warm-water species prevalent during El Niño events.

B. Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is a recurring pattern of climate variability that is characterized by parallel interdecadal fluctuations in sea surface temperature and sea level pressure. There is growing evidence of reversals in the prevailing oceanographic conditions around 1899, 1925, 1947, 1977, and 1998. The northeastern Pacific was unusually cool from 1900-1924 and from 1947-1976, and unusually warm from 1925-1946 and from 1977-1998. The primary cause of these interdecadal oscillations is currently unknown.

Numerous changes in terrestrial and marine ecosystems are associated with the Pacific Decadal Oscillation. Zooplankton biomass in the Gulf of Alaska and the California Current declined after a shift to warmer waters in 1976-1977. In the California Current, the biomass of macrozooplankton decreased by 70% between the mid 1970s and the early 1990s. The lowest macrozooplankton biomass of central California was recorded in 1998, when the strongest El Niño event recorded occurred during the late stages of the warm phase of the PDO.

An anomalously warm water regime in the central and north Pacific Ocean persisted from 1977 to 1999. Since the apparent return of cooler waters in 1999, macrozooplankton rebounded to the long-term mean for the period of 1951-1984. The changes in zooplankton abundance undoubtedly impact species that rely on zooplankton as food and their predators. The reduced supply of the euphausiid *Thysanoessa spinifera* since the mid-1970s, associated with the warm phase of the Pacific Decadal Oscillation, likely contributed to the decline of Cassin’s auklets and sooty shearwaters and some pinnipeds, including steller sea lions and fur seals. The severe decline of sardines during the 1940s and 1950s undoubtedly affected the breeding success of certain species, including steller sea lions, common murres, tufted puffins, and California brown pelicans.

Since the 1950s, Alaskan salmon abundance has fluctuated widely with interdecadal oscillations that parallel the PDO. Catch of Alaskan sockeye and pink salmon was relatively low and stable during the 1950s, 1960s and 1970s, but increased dramatically since the late 1970s. The increase corresponds to the shift to the warm phase of the PDO. Catch of chinook and coho salmon from the Pacific Northwest and California was out of phase with the long term oscillations in Alaska. Peak catch of these species occurred during the cool phase of the PDO during the 1950s, 1960s, and early 1970s. Catch generally declined in this region throughout the warm phase of the PDO (Mantua et al. 1997). Such regional variations in catch parallels regional differences in climatic responses to different phases of the PDO. For example, on average precipitation increases during the warm phase of the PDO in Alaska, but decreases during this phase in Washington, Oregon and Northern California.

C. Global Warming

Ocean waters off the coast of California have warmed considerably over the last 50 years. These changes appear to be driven by a complex interaction between natural climate cycles, such as Pacific Decadal Oscillation, and global increases in average temperature. Warming expands the surface layer of the ocean. As a consequence of recent warming, the sea level off California has risen an average of 0.9 (+/- 0.2) mm per year for the last 50 years. This rise in sea level is substantially lower than the average global sea level rise of 2 mm/year.

Plants and animals may respond directly to increases in temperature, or indirectly to other environmental factors associated with the climate shift (e.g., altered current directions and speeds or altered nutrient dynamics). Some species appear to have shifted their geographic ranges north in response to increased water temperatures. During the last decades, an assemblage of rocky intertidal invertebrates from central California shifted to include a greater dominance by southern species relative to northern species. An assemblage of reef fishes in southern California shifted to include more individuals of warm-water species and fewer individuals of cold-water species. Bottlenose dolphins moved north into Monterey Bay, and several coastal seabird species have extended their breeding ranges into California (including central California) as well. Seabird abundance within the California Current system declined by 40% from 1987 to 1994. The decline in overall bird abundance is driven largely by the decline of the Sooty Shearwater, a cold-water species that relies on euphausiids and small fishes. Global warming and other long-term climate variations, such as the Pacific Decadal Oscillation, may contribute to these biological changes.

IX. Ecosystems

A. Lagoon and Estuarine Communities

Lagoons and estuaries are among the most productive natural systems. There are many reasons for this high productivity, including the availability of protected, shallow, warm water, abundant light, and high nutrient input. In addition, bays and estuaries provide a variety of different habitats, including shallow regions such as flats, brackish water, eelgrass beds, salt marshes, and tidal creeks.

Estuaries form where rivers and streams mix with salt water from the ocean, creating a zone of brackish water. The mean annual salinities of the estuaries of central California generally are greater than 25 parts per thousand (ppt) because of the typically low volumes of freshwater leaving the watershed. San Francisco Bay and Tomales Bay are the only estuaries along the coast that receive sufficient volumes of fresh water to generate lower estuarine salinities (0-24 ppt).

Shallow intertidal flats form the transition between terrestrial and marine habitats. These habitats are flooded and drained with daily tides. The sun can quickly warm the shallow waters of intertidal flats; organisms in these habitats must be able to withstand broad temperature fluctuations. When the tides recede, they often expose the resident organisms to greatly altered temperatures and reduced levels food. Ironically, exposure to air is also commonly associated with reduced levels of oxygen within the sediments as the resident animals respire. Renewed supplies of food and oxygen are returned to the flats when they are bathed with new seawater at high tide.

A diverse group of photosynthetic organisms exploits the shallow margins of wetlands where they receive high levels of sunlight and nutrients. Many unicellular algae grow in intertidal flats, the most numerous of which are diatoms. Larger multicellular algae, such as *Ulva* and *Enteromorpha,* grow in the high intertidal flat, especially in tidal pools. Eelgrass (*Zostera* spp.) occurs in protected waters, including all larger bays and estuaries off central and northern California. Eelgrass is commonly found in semi-sheltered areas of soft sediment in the intertidal and subtidal zones. The greatest density of eelgrass is typically below mean low water. Eelgrass does not generally grow in waters that carry substantial sediment loads due to the reduced light conditions.

Salt marshes develop along the shores of some protected river mouths and estuaries, particularly where fine-grained sediments are bathed by tides and fresh water. Some areas in a salt marsh may develop high salinity due to rapid evaporation of seawater, while other areas that are regularly inundated by tides have lower salinity. A variety of herbaceous plants grow in salt marshes, including pickleweed, saltgrass, cattails, sedges, and rushes. A healthy salt marsh supports extremely high productivity, approximately five to ten times as much per acre as a wheat field. In addition, salt marshes provide ecosystem services, such as filtration of sediments and pollution that enter coastal systems. In California, a number of listed species (plants, invertebrates, birds, and mammals) are found in the ever-diminishing salt marshes (*Table 1*).

Tidal creeks generally flow into estuaries and bays; some tidal creeks flow directly into the ocean (e.g., Elkhorn Slough, Estero Americano, and Estero de San Antonio) where they are strongly affected by daily tide changes. Because they are a source of fresh water, tidal creeks are among the lowest salinity habitats associated with estuaries and bays. However, brackish water may extend into the creeks during high tides. Tidal creeks form channels in the soft sediments of intertidal flats, creating structure that attracts many marine organisms. At high tide, organisms may venture out of tidal creek channels onto the submerged intertidal flats in search of prey. As the water recedes with the low tide, these organisms again become concentrated in tidal creek channels.

Unique lagoons and estuaries

Estuaries are not common along the California coast, relative to other parts of the world, owing to the steep coastal topography. Two major estuaries are found in northern and central California: San Francisco Bay and Tomales Bay. The San Francisco Bay (1,250 km^2) and the San Joaquin Delta (3,000 km^2) comprise the largest of the estuaries of the California coast. The Sacramento and San Joaquin Rivers carry large volumes of water into the San Francisco Bay from a watershed area of approximately 153,000 km^2 in the Central Valley of California. Tomales Bay is much smaller than San Francisco Bay, covering an area of approximately 550 km^2. Most of the runoff into Tomales Bay is from creeks and small rivers.

In addition to these, a few smaller estuaries and esteros occur along the coast: Estero Americano, Estero de San Antonio, Abbott's Lagoon, Drakes Estero and Estero de Limantour, Bolinas Lagoon, and Elkhorn Slough (Figures 2 and 3). The Esteros Americano and de San Antonio are coastal estuaries located on Bodega Bay, north of San Francisco, California. Estero Americano includes approximately 1.6 km^2 of open water and another 1.6 km^2 of wetlands. Estero de San Antonio, just south of Estero Americano, includes approximately 0.4 km^2 of open water and 0.8 km^2 of wetland habitats. The esteros become hypersaline when sand bars reduce the freshwater flow. Drakes Estero, located just south of Point Reyes, is a drowned river valley, which formed during the Pleistocene glacial epochs when sea level was much lower than it is today. Following the glacial epochs, sea levels rose and inundated coastal valleys forming estuaries such as Drakes Estero. Estero de Limantour, located just south of Drakes Estero, extends about 3 km southeast and parallel to the ocean, along sandy dunes and beaches. Bolinas Lagoon is a small shallow estuary located directly along the San Andreas Fault, 25 km northwest of the Golden Gate Bridge. The mudflats of Bolinas Lagoon cover approximately 2.4 km^2 and support a productive food web. Elkhorn Slough, which covers an area of approximately 182 km^2 along the coast in the middle of Monterey Bay, is the largest tract of tidal salt marsh in California outside of San Francisco Bay. The watershed around the slough includes dunes, coastal marsh, oak, woodlands, and maritime chaparral, supporting a variety of rare plants and animals.

Numerous bays, including Bodega, Drakes, Bolinas, Half Moon, Monterey, Carmel, Morro, and San Luis Obispo, are totally marine but somewhat protected from the open ocean by the surrounding landscape. Bodega Bay is located in the protected area between Bodega Head and the coast, approximately 113 km north of San Francisco. Drakes Bay is located approximately 29 km north of the mouth of San Francisco Bay, in the sheltered waters between Point Reyes and Double Point. Bolinas Bay is a small bay with restricted tidal flow south of Duxbury Reef in Marin County. Half Moon Bay is a crescent-shaped bay south of San Francisco in San Mateo County. Monterey Bay, which is bisected by the Monterey Canyon system, marks the transition zone from the wide continental shelf in the north to the narrower shelf in the south. Carmel Bay is protected in the waters between Point Pinos and Point Lobos. The Carmel Bay is bisected by Carmel Canyon, which extends southwest from the Carmel River until it joins the submarine canyon in Monterey Bay. A small (9.2 km^2) estuary in Morro Bay is fed by Chorro and Los Osos Creeks and is protected from the Pacific Ocean by a sand spit. Morro Bay was designated as California's first State Estuary in 1994 in order to protect the creeks, wetlands, salt marshes, mudflats, sand dunes, and open water that support a diversity of wildlife around the bay. San Luis Obispo Bay is located in the protected waters between Port San Luis and Guadalupe. San Luis Obispo Bay is known for the extensive sandy beach (Pismo Beach) located along its coast.

Ecological linkages in estuaries and lagoons

Estuaries and lagoons support unique biological communities with both aquatic and terrestrial characteristics. The organisms that live in estuaries must be able to tolerate high salinity, periodic inundation and desiccation, and those that are aquatic must be able to survive low concentrations of dissolved oxygen.

Plants in the lower salt marsh are subjected to regular inundation by saltwater. Halophytic vegetation, such as pickleweed, grows higher in the marsh where flooding occurs less frequently and salt may become concentrated. However, little vegetation can grow in areas characterized by high evaporation and soil salinity (e.g., 1000 ppt). A diverse assemblage of wetland plants grows in areas near tidal creeks where fresh water input is high. As the plant matter breaks down into detritus, it is consumed by various filter feeders, deposit feeders, and other omnivores and scavengers.

Habitat and salinity strongly influence fish species composition and abundance in bays and estuaries. Brackish water supports a distinctive assemblage of invertebrate and fish species, including the endangered tidewater goby, *Eucyclogobius newberryi,* the Delta smelt, *Hypomesus transpacificus,* and the stickleback, *Gasterosteus aculeatus leiurus*. Stenohaline species, including jacksmelt, Pacific sardine, and several rockfish, are found in estuaries of the central coast. Other species, including salmonids, clupeids, and embiotocids, are found in estuaries of northern California. Tidal creeks support distinctive fish and invertebrate communities that tolerate high input of fresh water. The aquatic ecosystems of central California support numerous fish species with anadromous life history patterns, such as coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*), steelhead trout (*O. mykis*), and sturgeon (*Acipenser* spp.). The eggs and juveniles of these fishes can be found in fresh water. The juveniles mature at sea (*see neritic and epipelagic communities*), and return as adults to rivers for reproduction.

Eelgrass beds are highly productive habitats that support a unique assemblage of invertebrates and fishes. Many fishes, including Pacific herring (*see neritic and epipelagic communities*), spawn in eelgrass beds, among other habitats. The structure of eelgrass beds provides protection from predation for juvenile invertebrates and fishes. Large numbers of shorebirds (*see sandy beach, rocky intertidal, and offshore island communities)* are attracted to eelgrass beds where they feed on the eelgrass, fish and invertebrate eggs and young.

A unique, but species-poor assemblage of resident birds frequent California's coastal lagoons, estuaries, and salt marshes. Most are listed as endangered or threatened: clapper rail, black rail, saltmarsh common yellowthroat, and saltmarsh song sparrow (*Table 1*). Among other avian species, few are year-round residents of coastal wetlands, but many use salt marshes, shallow intertidal flats, and lagoons during their annual migrations. The estuaries and bays of coastal California are part of the Pacific Flyway, one of the four principal bird migration routes in North America. San Francisco Bay supports the greatest number of migratory and resident birds. Also important are Tomales Bay, Bolinas Lagoon, and Elkhorn Slough. Bolinas Lagoon was designated a wetland of significant international importance under the Convention on Wetlands, signed in 1971.

Marine mammals, including harbor seals, harbor porpoises, sea otters, and northern elephant seals, are common in California's bays (*see sandy beach, rocky intertidal, kelp forest, and offshore island communities*). An occasional gray whale may enter San Francisco Bay, given its deep waters.

Ecological linkages between estuaries, lagoons, and other marine ecosystems

Estuaries and bays are the links between freshwater and marine systems. Rivers carry sediment and other suspended or dissolved materials from sources upstream to the coast. Some of these materials are deposited in large deltas at river mouths. Rivers carry a portion of the sediments and other materials, through estuaries and bays, into the open ocean. The structure of beaches around estuaries and bays depends, in part, on the types of sediments carried by rivers to the coast. Disturbance to land around streams and rivers may cause excessive sedimentation. In some cases, fine sediments may be transported to and deposited in marine habitats, reducing the light and oxygen available to organisms that live there.

Estuarine vegetation may influence the productivity of other nearby habitats. For example, macroalgal mats, composed primarily of *Ulva* and *Enteromorpha* spp., may be carried on tides or currents to the open ocean where they provide shelter and food for numerous organisms, notably juvenile fishes. Eventually, these mats may wash up on shore where they provide nutrients to sandy beach and rocky intertidal communities.

Estuaries are used by many marine species during portions of their life cycles. Several factors make estuaries a suitable habitat for survival and rapid growth of young animals: high food availability, elevated water temperature, and limited access for some predators.

Numerous larvae and juvenile marine fishes settle in lagoons and estuaries to grow before moving into deeper waters as juveniles and adults. Many species that live as adults on the continental shelf and slope or in submarine canyons (e.g., sole, sablefish, hake, and rockfish) produce pelagic larvae that recruit to estuaries, bays, intertidal habitats, kelp forests, rock outcrops, and cobble fields. Anadromous species travel through estuaries and bays in order to reach the open ocean where they grow until their return to natal streams for breeding. As the young fishes grow, they may return to deeper habitats where they remain as adults.

Some species, including many shorebirds and waterfowl, use the network of bays and estuaries along primary migratory routes, including the Pacific Flyway. These migratory birds require shelter and food provided by bays and estuaries during their long migration from South America, Central America, or Mexico to Canada and Alaska. As wetlands developed into farms, and residential and industrial lands, many estuaries and bays have become partially filled and migratory birds are forced to fly farther between suitable resting and feeding habitats.

Relative status of lagoons and estuaries

Humans have impacted estuaries and bays through changes in hydrology and water quality, changes in estuary size through intentional fills, biological invasions, harvesting, oyster culturing, and recreational activities such as fishing, hunting, and boating. During the last century, coastal California was highly modified by coastal development. Human activities, such as diking, mining, dredging, filling, and reclamation, have substantially reduced the area of coastal wetlands. Sedimentation has increased in estuaries and bays from dredging to maintain vessel access and from activities upstream, such as building of roads, logging, ranching, and agriculture (e.g., Bolinas Lagoon). Diversion and channelization of rivers to control floods has altered the flow of fresh water into coastal and marine systems. The decreased freshwater input to some estuaries, and increased marine influence on others, has impacted the conditions in salt marshes, brackish water, and eelgrass meadows.

Many factors, including urban runoff, septic systems, agriculture, forestry, and grazing, contribute to the input of nutrients to the ocean. Millions of gallons of treated sewage flow into marine and estuarine waters every day. Bacteria, viruses, and nutrients may be transported into watersheds from faulty sewage and septic systems and from domestic animal waste products. Persistent agricultural pesticides can remain in the soil for over 25 years and may be washed into rivers, estuaries, and the ocean during heavy rains. In some places, the elevated nutrient content of the water has caused harmful algal blooms and reduced oxygen concentrations. However, unlike other changes in estuaries, nutrient additions may have fewer lasting ecological impacts on marine communities if the source of nutrients is eliminated.

Harvesting may be a major factor in the decline of invertebrate species diversity and abundance in estuaries and bays. For example, several native bivalve species harvested by humans (*Tresus nuttallii, Clinocardium nutallii, Protothaca staminea,* and *Saxidomus nuttallii*), and the blue mud shrimp (*Upogebia pugettensis*) are no longer common at Elkhorn Slough. Grass shrimp and the native oyster, once abundant in San Francisco Bay, are now rare.

Invasive species have altered community composition and displaced native species in estuaries and bays throughout coastal California. For example, the majority of species (97%) in the San Francisco Bay and the majority of the biomass (99%) are introduced. The introduction of exotic fish species has led to the extinction of at least one native species, the thicktail chub (*Gila crassicauda*), and the listing of one endangered species, the delta smelt (*Hypomesus transpacificus*). Commercial shipping, especially ballast water release, is probably the most important vector for moving species between bioregions, while local factors, such as boat traffic, are probably more important vectors on a local scale.

Gaps in ecological knowledge about lagoons and estuaries

Estuaries and bays are strongly affected by human activities. Because of these impacts, habitats within estuaries and bays, and the composition and abundance of species within those habitats, have been altered dramatically. In many cases, historical information about the ecology of particular bays and estuaries is not available and their ecology has changed significantly. Temporal and spatial variation in ecological processes is poorly known, because most estuaries and bays no longer support the communities that once thrived within their productive waters. The effects of some invasive species have been documented, particularly in San Francisco Bay and Elkhorn Slough, but relatively few studies examine the competitive and trophic interactions between native and invasive species. An understanding of the extent and effects of habitat modification, pollution, and invasive species in estuaries and bays is critical to elucidate the status of these habitats and the potential to restore them to their former productivity.

B. Sandy Beach Communities

Sandy beaches are constantly changing under the influence of wind and waves. Marine systems strongly influence beaches through the annual deposition and erosion of beach sediments. Sandy beaches tend to be wide and gently sloping in the summer, when sand is deposited on the shore. However, large waves generated by winter storms may remove sand from beaches and deposit it offshore. During the winter, beach communities may be completely transformed when sand is removed, leaving cobble or shale. As the calm summer conditions return, the gentle swells pick up the sand and return it to the beach.

Rivers carry sediments to the ocean where they are resuspended and eventually deposited on the shore. These sediments are carried along the coast by the alongshore current, or onshore and offshore by breaking waves. Beach characteristics are strongly influenced by the types and amounts of sediments that are carried to the coast by rivers and ocean currents. Since the damming of almost all the major rivers along the West Coast, sediment is now far less available than it was before the 1930s.

Beaches have different characteristics associated with coastal geology and prevalent winds. Rivers deposit sediments in the ocean, forming barrier beaches and sand spits, such as those at the Salinas, Pajaro, and Santa Maria River mouths. Cove (or pocket) beaches form along the northern coast, where wind and high-energy waves erode the steep granite and basalt cliffs. Many of the pocket beaches along the coast from Santa Cruz to San Francisco disappear completely during the winter months, replaced by cobbles (south coast) or shale shelves (Waddell bluffs). Broad sandy beaches form in southern California where shale and sandstone bluffs continuously crumble under the influences of wind and waves.

Ecological linkages on sandy beaches

The distribution of organisms on sandy beaches is strongly influenced by the amount of tidal inundation and the seasonal cycle of deposition and removal of sand. The upper intertidal beach is submerged for a short time and exposed to the widest range of temperatures. The mid-littoral beach is alternately submerged and exposed for moderate periods of time. The swash zone is submerged for approximately 12 hours per day. The low intertidal zone is exposed for brief periods of time during the lowest tides, and the surf zone is constantly submerged and subjected to the motion of breaking waves.

Animals on the upper intertidal beach rely on unpredictable and patchy food sources. The primary food sources on the sandy beach include plankton, macroalgae, and occasional corpses of invertebrates, fishes, birds, and marine mammals that are washed ashore (*see sections on kelp forest, neritic, and epipelagic communities*). Scavengers on this "beach wrack" dominate the high intertidal fauna. The first colonists on beach wrack are kelp flies (Diptera) and talitrid amphipods; eventually, coleopteran beetles and terrestrial isopods colonize wrack as well. The pill bug, *Alloniscus perconvexus*, burrows into the sand just beneath the surface and emerges at night to feed on beach wrack. Beach hoppers, *Megalorchestia* spp., dig burrows or remain under piles of wrack during the day, emerging at night to forage on algae and other detritus. Numerous oligochaetes and nematodes are found under decaying wrack. The concentration of food associated with macrophyte wrack attracts numerous coastal birds, including gulls, plovers, and turnstones.

The upper beach communities are used as breeding habitats by a variety of birds and pinnipeds (*see also sections on lagoon and estuarine, rocky intertidal, and offshore island communities*). Endangered western snowy plovers, *Charadrius alexandrinus nivosus*, nest in coastal dunes. Endangered California least terns, *Sterna antillarum browni*, nest in colonies on sandy beaches associated with river mouths or estuaries. Breeding populations of various pinniped species, including California sea lions (*Zalophus californianus*), northern elephant seals (*Mirounga angustirostris*), and harbor seals (*Phoca vitulina*), are found on secluded sand beaches off central and northern California.

The mid-littoral beach fauna is dominated by species with high mobility, such as cirolanid isopods (*Excirolana* spp.). The annelid worm (*Euzonus mucronata*) is abundant in damp soil in the mid-littoral zone. The polychaete *Nephtys californiensis*, which is found in the same region, may be a predator on *Euzonus*. Various shorebirds, including sandpipers and plovers, enter the mid-littoral zone to prey on isopods, worms, and other invertebrates.

Various herbivores, including sand crabs, harpactacoids, polychaetes, and nematodes, serve as the basis for the food web characteristic of sandy intertidal communities. The dominant macrofaunal herbivore in the swash zone is the sand crab, *Emerita analoga*. At high tide several fishes, including croakers (Scianidae) and surfperch (Embioticidae), prey on sand crabs. In addition, sand crabs are a primary source of food for shorebirds including plovers, sandpipers, sanderlings, willets, and surf scoters, as well as sea otters.

Animals of the low intertidal zone of sandy beaches tend to burrow into superficial sediments for protection. The dominant crustaceans of the low intertidal include burrowing amphipods (Phoxocephalidae and Haustoridae). One efficient burrower, the spiny mole crab (*Blepharipoda occidentalis*), is typically found on beaches with sand crabs, which comprise a substantial portion of its diet. Some fishes, including surfperch (Embiotocidae) and bat rays (*Myliobatis californica*), consume spiny mole crabs.

Some invertebrates of the low intertidal zone remain active on the surface in spite of the constantly changing landscape of waves and shifting sediments. Cumaceans and ostracods are active on the surface sediments of the low intertidal zone. Euphilomedid ostracods (*Synchelidium shoemakeri* and *Monoculodes spinipes*) are among the common crustaceans in this zone.

Small pelagic fishes, including grunion and smelt, use sandy intertidal areas for spawning. Grunion (*Leuresthes tenuis*) spawns on sand beaches of southern and central California during the spring. Surf and night smelt (Osmeridae) spawn on beaches of central and northern California during the spring and summer.

Animals in the surf zone are subjected to nearly constant and intense physical agitation. Bivalve mollusks, crustaceans, and tube-building worms must burrow and anchor themselves in beach sediments to reduce the impacts of waves, desiccation, and predation. Bivalves, including Pismo (*Tivella stultorum*), razor (*Siliqua patula*), surf (*Spisula solidissima*), and coquina clams (*Donax spp.*), are found in the low intertidal and surf zones of sandy beaches in California. At low tide, these bivalves filter millions of microscopic diatoms and zooplankton from water that is retained between sand particles. Predators such as boring snails (*Euspira* sp.), sea otters (*Enhydra lutris*), and humans prey on Pismo clams and other bivalves that live in the low intertidal beach and surf zone.

A few species, including sand dollars (*Dendraster excentricus*), live at the seaward border of the surf zone under constant agitation by ocean waves. Sand dollars are able to survive below the surf zone by consuming detritus and diatoms filtered from the water. Bottom feeding fish (e.g., starry flounder) and seastars (*Pisaster brevispinus* and *Pycnopodia helianthoides*) prey on these sand dollars. Wolf eels (*Anarrhichthys ocellatus*) and other fishes are attracted to sand dollar beds where they prey on *Cancer* crabs that seek refuge in the spaces between these sand dollars.

Ecological linkages between sandy beaches and other marine ecosystems

Sandy beaches are dynamic environments, constantly changing under the influence of the physical processes in the ocean. During the summer months, ocean waves deposit sediment on beaches. In the winter, storms generate large waves that remove sand from beaches and deposit the sediments offshore. Thus, physical processes connect sandy beaches with rivers, which carry sediments to the ocean, and marine systems, which deposit and remove the sediments from the coast.

Sandy beaches are strongly influenced by production from marine systems that is transported to and deposited on the shore. Detached plant and algal debris, and corpses of fishes, seabirds, and marine mammals influence the structure of sandy beach communities by providing food and shelter that are otherwise not available.

Relative status of sandy beaches

Development of the California coast has altered the natural processes of beach building and erosion. Because many rivers have been dammed or channelized to control floods, they carry much less sediment to the ocean, substantially reducing the supply of sediments to sandy beaches. Each fall, large amounts of sand are moved to the upper beach to reduce losses during the winter months. Construction of offshore breakwaters, groins, and jetties, and shoreline hardening structures such as riprap, alters the deposition and movement of sand along the coast. These structures occasionally retain sediments on sandy beaches, but often they simply redistribute sediments offshore.

Numerous factors have caused the degradation and loss of dune habitats, including urbanization, recreational use, and invasion of non-native beach grasses. The degradation and loss of dune habitats, and increase in predators associated with urban landscapes, such as domestic and feral dogs, feral cats, red foxes, striped skunks, Virginia opossums, and raccoons, caused significant declines of two endangered species: California Least Tern and Western Snowy Plover.

Harvesting of beach organisms has contributed to declines of some beach species. At the beginning of the last century, a substantial fishery developed for Pismo clams. From 1916 to 1947, commercial clam diggers collected an average of 50,000 clams per year, with the harvest exceeding 350,000 clams in the 1930s. Human harvest, combined with sea otter predation, has decimated populations of Pismo clams in central California. In addition to the harvest of invertebrates, there is a large (and generally unreported) recreational fishery for surf and night smelt. Surf smelt are particularly vulnerable to fishing because their life cycle is short and overfishing of a single cohort can have catastrophic consequences.

Some gaps in ecological knowledge about sandy beaches

The ecology of sandy beaches is fairly well known, because this habitat is accessible. Scientists have identified many of the factors that influence the deposition or removal of sediments on beaches and the structure of beach communities. However, long-term changes in the distribution and structure of beach and dune systems are not particularly well known. These long-term changes may have important implications for zoning of coastal land use, particularly if certain habitats accumulate or disappear over time. Many of the natural beach dynamics may not be detectable under the influence of human activities. More information is needed to determine the consequences of constant perturbation of sandy beaches by commercial and recreational activities.

C. Rocky Intertidal Communities

Rocky intertidal communities form along the shoreline between high and low tide marks. Four zones of rocky intertidal organisms are traditionally associated with different tidal heights, similar to the ecological zonation characteristic of sandy beaches. The splash zone is almost always exposed to air, with spray from waves breaking on the beach adding moisture to the splash zone. The high intertidal zone is exposed to air for long periods of time, and submerged for short periods twice each day. The middle intertidal zone is exposed to air once or twice each day and can spend comparable amounts of time submerged in seawater versus exposed to air. The low intertidal zone is only exposed for short periods of time and only during the lowest tides.

<u>Ecological linkages in rocky intertidal habitats</u>

The distribution of organisms in the rocky intertidal zone is strongly influenced by the amount of tidal inundation, exposure to air, and intensity of disturbance. Some areas of the coast, particularly rocky headlands and the exposed outer coast, are subjected to high wave action, organisms in rocky intertidal habitats must be capable of surviving these extreme conditions. Wave shock is reduced in areas that are protected by offshore rocks, reefs, or islands. In addition to their exposure to wave shock, organisms in rocky intertidal habitats are exposed to drying and heating or cooling during low tides. Physiological characteristics of intertidal species influence vertical distributions of these organisms along the gradient of exposure.

The splash zone supports relatively few species. Lichens and algae survive in the splash zone, because they require little fresh water or nutrient input, and they are tolerant of seawater. Isopods, related to the pill bug, are scavengers on fragments of plants and animals that are deposited in the splash zone. The harpacticoid copepod *Tigriopus californicus* is abundant in tide pools in the splash zone of the rocky intertidal zone along the Pacific Coast from Alaska to Baja California. Few competitors and almost no predators coexist with *Tigriopus* in pools above mean high water. Experiments have shown that *Tigriopus* can survive and reproduce in pools below the splash zone. However, in nature, effective predation by intertidal fish (primarily tidepool sculpin) and invertebrates (including sea anemones) excludes *Tigriopus* from pools below mean high water.

Marine mammals occasionally haul out into the splash zone to rest. Harbor seals (*Phoca vitulina*) are found on rocky intertidal habitats and offshore rocks, as well as sand and mudflats (*see lagoon and estuarine, sand beach, kelp forest, and offshore island communities*). Steller sea lions (*Eumetopias jubatus*), which are listed as a threatened species, haul out to breed on rocky platforms at Año Nuevo Island and the Farallon Islands. During the winter, the sea lions haul-out at Point Reyes and on the rocky islands off the Sonoma coast (*see rocky intertidal, neritic and epipelagic, and offshore island communities*).

The high intertidal zone is exposed for long periods during the tidal cycle. Fucoid algae commonly dominate the high intertidal zone of much of central and northern California with the exception of the Farallon Islands. Invertebrates of the high intertidal zone, such as barnacles, limpets, crabs, and snails, often retreat into protective shells or crevices during the long periods of exposure. In northern and central California, the barnacle, *Balanus glanula*, and the red algae, *Endocladia muricata* and *Mastocarpus papillatus*, are used as indicators of the high intertidal zone. Periwinkles (*Littorina keenae*) are commonly found in the high intertidal zone. Invertebrates in the high intertidal zone attract various shorebirds. Black Oystercatchers feed heavily on mussels and limpets; Black Turnstones feed on barnacles, periwinkles, limpets, isopods, and amphipods in the lower splash zone and high intertidal zone.

A small group of specialized fishes is found in tide pools of rocky intertidal habitats. Representative species include the monkey-face eel (*Cebidichthys violaceus*), rock eel (*Pholis gunnellus*), rockweed gunnel (*Xererpes fucorum*), blackeye goby (*Coryphopterus nicholsii*), dwarf surfperch (*Micrometrus minimus*), juvenile cabezon (*Scorpaenichthys marmoratus*), tidepool sculpin (*Oligocottus maculosus*), tidepool snailfish (*Liparis florae*) and blennies.

Organisms that live in the middle intertidal zone must be able to tolerate nearly equal periods of exposure to air and inundation by water. Dense patches of coralline algae, mussels, and barnacles typically dominate the middle intertidal zone. Mussels, particularly *Mytilus californianus*, can be so numerous in the middle intertidal that it is often called the "mussel zone." Intertidal species tend to be active when they are submerged in seawater, which carries their primary food source. However, those that can (such as mussels and barnacles), retreat into protective shells during periods of exposure. Honeycomb tube worms (*Phragmatopoma californica*) form large colonies under crevices and on rocky ledges of the middle intertidal zone. Black abalone (*Haliotis cracherodii*), once common in this habitat, is primarily an intertidal organism, but this species may be found as deep as 6 m in southern California. Abalone feed on algae, mostly on pieces of subtidal brown kelps (such as *Macrocystis pyrifera* and *Nereocystis luetkeana*) that drift into the intertidal zone (*see kelp forest communities*). Higher-level predators, such as seastars, octopus, lobster, several species of crab, and sea otters, are attracted to abundant prey in the intertidal zone during high tides. However, many of these marine predators retreat with the tides to deeper waters. Such restrictions on the time that predators have access to mid intertidal species can play an important role in setting their vertical distribution on the shore. The refuge of mid intertidal habitats can be critical to species that cannot persist in the face of higher predation below.

Species of the low intertidal zone, including the southern sea palm, *Eisenia arborea,* the brown alga *Halidrys dioica,* and seastars are not capable of surviving extended periods of exposure. Sea urchins (*Strongylocentrotus* spp.) are found from the rocky intertidal to subtidal zones, particularly in regions of abundant drift algae (*see sections on kelp forest, and neritic and epipelagic communities*). Where it occurs, the ochre seastar, *Pisaster ochraceus,* is one of the principal predators in low rocky intertidal communities from central California to Washington. Dogwhelks are also key predators on rocky intertidal shores. When predators such as seastars and dogwhelks are removed from the low intertidal zone, mussel beds often expand, relative to areas where these predators are not removed.

Ecological linkages between rocky intertidal habitats and other marine ecosystems

Many organisms in the intertidal zone depend on tides to bring food, such as drift algae, plankton, or dissolved nutrients. Few species can survive in the splash zone, which receives inconsistent nutrient and plankton input from the ocean. Nutrients and plankton are regularly carried into middle and low intertidal habitats that support greater diversity and biomass. In general, diversity of marine benthic algae and invertebrates increases with depth in intertidal habitats. The rates of delivery of plankton and nutrients to reefs can vary dramatically along the shore reflecting corresponding variation in oceanographic conditions offshore.

The maintenance and growth of populations of many intertidal animals, such as mussels, barnacles, and honeycomb tubeworms, depend on recruitment of young from the plankton. During their planktonic stage, larvae of many species may be carried far offshore on ocean currents. To become an adult, these larvae must return to shallow coastal habitats. Several mechanisms, including upwelling and wind relaxation, appear to play a key role in the process of recruitment. During planktonic development, larvae are also carried along shore. The production of young by adults at one location seeds recruitment elsewhere, thereby connecting rocky reef habitats along the shore. Nearshore settlement varies dramatically among species. Some successfully recruit only sporadically. For example, in 1992 sea urchins settled primarily during a single, unusual relaxation event. Others recruit more regularly with repeated bouts of recruitment to intertidal areas each year [e.g., crabs (*Cancer* spp.)]

Predation by planktivorous fishes, including rockfishes, influences the survival and distribution of organisms that settle in the rocky intertidal zone. Juvenile rockfishes associated with kelp forests in Monterey Bay may consume over 98% of the barnacle larvae that are carried through kelp forests on tides, waves, and surface currents. High barnacle settlement is inversely correlated with the distribution of juvenile rockfish in kelp forests nearby.

Relative status of rocky intertidal habitats

Introduction of nutrients, pollutants, and other substances along the coast may cause substantial changes in species composition and productivity. Many common intertidal organisms, including fishes, crustaceans, limpets, snails, sponges, ascidians, foliose red algae, and surf grasses, cannot live in areas exposed to high levels of sewage. Regions around municipal and private wastewater outfalls may support depauperate communities of diatoms and coralline algae. Some intertidal habitats require 20 years or more to recover from the effects of dumping sewage.

Rocky intertidal communities are particularly prone to damage following oil spills since oil is readily deposited and retained on the reef. Numerous rocky shore species, including barnacles, snails, mussels, clams, crabs, amphipods, polychaetes, and attached algae, may be coated in spilled oil. Other species, such as mussels, clams, and oysters, may accumulate oil in body tissues through filter feeding.

Rocky intertidal habitats are vulnerable to trampling and harvesting of intertidal organisms. Increasingly, humans visit rocky shores as sightseers and naturalists, or to collect food and bait. Commercial and recreational fisheries target numerous intertidal invertebrates, including abalone, crab, snails, mussels, and barnacles, and some seaweeds. Studies of the intertidal zone have detected changes in density and species composition associated with human use (harvesting and trampling).

Large-scale climate and oceanographic changes may influence the composition, abundance, and distribution of intertidal organisms. It is likely that climate warming has contributed to shifts in the composition of the central California rocky intertidal zone. During the last century, the upper and middle intertidal zones of one study site in Monterey Bay changed substantially. Algal cover characteristic of the middle intertidal zone (including *Endocladia muricata* and *Mastocarpus papillata*) increased in the upper intertidal zone. By 1994, several warm-temperate algae (including *Endocladia muricata*, *Mastocarpus papillata, Gelidium coulteri, Rhodoglossum affine,* and *Gigartina canaliculata*) displaced the cold-temperate species (*Fucus distichus* and *Pelvetia fastigata*) as the dominant species of the middle intertidal zone in the Monterey Bay. Similarly, comparisons of changes in invertebrates at one site in southern Monterey Bay showed a shift in dominance over a 60 year interval from species with more northern distributions to species with more southern distributions. These changes may be associated with a long-term global warming trend and increasing occurrence and intensity of El Niño events (*see natural disturbances*).

Some gaps in ecological knowledge about rocky intertidal habitats

The ecology of rocky intertidal communities is fairly well known, because this habitat is accessible and the species are relatively immobile and easily manipulated experimentally. It has been a popular subject of ecological study for decades. Scientists have identified many of the factors that influence the composition of rocky intertidal communities. However, scientists have just begun to understand the temporal scale of changes in the structure of rocky intertidal communities. Long-term changes in the species composition of rocky intertidal habitats have been attributed to such factors as shifts in climate, changes in the abundance of key predators, disease, and intense harvesting or other forms of human disturbance. Teasing apart the influences of these disparate factors will require long-term studies and experiments.

D. Kelp Forest Communities

Macroalgae are marine plants that grow in shallow coastal waters of oceans throughout the world. Macroalgae use photosynthesis to harvest solar energy to fuel their growth and reproduction. Because they require light, most macroalgae are restricted to shallow water, and they rarely occur deeper than about 40 m. Kelp (a form of brown macroalgae) form dense forests that exhibit extremely high rates of primary production.

Numerous factors influence the distribution of kelp, including substrate type, light, water motion, sedimentation, nutrients, salinity, temperature, and the abundance of herbivores. Almost all kelp grows on hard substrates. Nutrients, including dissolved nitrogen, phosphate, and other trace compounds are critical for development and growth. Water motion also influences the distribution of kelp. Some species, such as giant kelp (*Macrocystis pyrifera*), grow in calm waters, whereas others, such as bull kelp (*Nereocystis luetkeana*), grow primarily in habitats with high wave energy. Many of the factors that affect the distribution of kelp species are interdependent, and therefore it is difficult to isolate the effects of each factor. For example, nutrient levels are closely associated with variation in light, temperature, and water motions that simultaneously affect kelp physiology, growth and survival. During El Niño years, the combination of warmer, less nutrient rich waters with more frequent large storms can lead to dramatic declines in kelp productivity and biomass.

Ecological linkages in kelp forests

Dense forests of kelp grow in rocky nearshore habitats along the entire California coast (*Figure 8: Kelp distribution*). In general, south of Santa Cruz, the predominant species is giant kelp, a perennial species found in moderately calm waters. Shallow waters off Point Sur, Point Lopez, Piedras Blancas, and Pfeiffer Point support productive forests of giant kelp. In the area north of Santa Cruz, bull kelp, an annual species found in areas of high water motion, becomes more common.

Patches of stipitate kelps (*Pterygophora californica* and *Eisenia arborea*) and several species of *Laminariales* are found beneath the kelp forest canopies along with a rich diversity of red algal blades and turfs. Nongeniculate (encrusting) coralline algae (*Lithothamnium* spp. and *Lithophyllum* spp.) and upright geniculate (articulated) coralline algae (*Bossiella* spp. and *Calliarthron* spp.) are intermingled with blades and turfs of a rich diversity of other seaweeds in kelp forests throughout central California. Shallow areas inshore of kelp forests often support patches of feather boa kelp (*Egregia menziesii*), the low intertidal giant kelp (*Macrocystis integrifolia*), and Fucalean algae (e.g., *Cystoseira osmundacea*).

Sea urchins (*Strongylocentrotus* spp.) play an important ecological role in the structure of kelp forest communities (*see sections on rocky intertidal, and neritic and epipelagic communities*). Although sea urchins are omnivorous, they primarily eat foliose algae. When drift algae are abundant, urchins remain in intertidal or shallow subtidal habitats where they forage on drift algae. When drift algae are scarce, urchins may move together across the seafloor in search of remnant stands of kelp. Urchins can remove entire kelp plants by grazing through their holdfasts. Some areas are periodically denuded of macroalgae by sea urchins, creating "urchin barrens," particularly in southern California. In central California, urchin populations are reduced by sea otter predation. Consequently, kelp forests and associated species flourish within the geographical range of sea otters.

Kelps provide a variety of distinctly different microhabitats associated with an abundant and diverse community of invertebrates. The most common invertebrates found within kelp holdfasts include polychaetes, amphipods, decapods, gastropods, and ophiuroids. The most common sessile invertebrates found under kelp canopies include sponges, tunicates, anemones, cup corals, and bryozoans. Diverse assemblages of planktonic species, such as jellyfish, crustaceans, and fish larvae, are seasonal inhabitants of kelp forests.

The invertebrate diversity and physical structure associated with kelp forests attract a variety of higher-level predators. Kelp provides cover for newly born or recently settled young fish. Midwater fishes of the kelp canopy, such as señorita (*Oxyjulius californica*) and the surfperch (*Brachyistius frenatus*) browse on the small crustaceans associated with both the kelp fronds and canopies. Other midwater predatory fishes include the common planktivorous blue rockfish (*Sebastes mystinus*), blacksmith (*Chromis punctipinnis*) and juveniles of the predatory kelp rockfish (*S. atrovirens*), olive rockfish (*S. serranoides*) and black rockfish (*S. melanops*). Blue rockfish prey on gelatinous zooplankton whereas juvenile and adult black rockfish primarily consume megalopae, amphipods, isopods, and other fishes, including young-of-the-year rockfishes.

Kelp forests harbor a large potential source of prey that attracts piscivorous birds. Gulls, terns, Snowy Egrets, Great Blue Herons and cormorants are commonly associated with kelp forests. Other species, such as phalaropes and Black Turnstones, feed on the plankton and fish larvae associated with kelp and drift algae.

The sea otter has been described as a "keystone species" for its role in structuring nearshore marine communities (*see lagoon and estuarine, sandy beach, and rocky intertidal communities*). Sea otters are important predators in the kelp forest, consuming sea urchins and other invertebrates. Numerous studies indicate that sea otters reduce herbivore densities and indirectly increase the abundance of macroalgae. As the densities of macroalgae increase, the habitat structure becomes more complex and supports a greater diversity of fishes.

In addition to sea otters, several other marine mammals find food in kelp forests. Harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*) are common in and around kelp forests (*see lagoon and estuarine, sandy beach, rocky intertidal, neritic and epipelagic, and offshore island communities*). Harbor seals feed on fishes in the kelp forest whereas California sea lions probably limit their use of the kelp forests to transitory feeding. Gray whales (*Eschrichtius robustus*) have been observed in kelp forests, where they feed on invertebrates and escape predation from killer whales, *Orcinus orca* (*see neritic and epipelagic communities*).

Ecological linkages between kelp forests and other marine ecosystems

Drift algae may be carried to the shore on tides, currents, and storm-generated waves (*see sandy beaches and rocky intertidal communities*). The drift algae provide important nutrients to beach communities. Mobile insects and birds are among the first to detect drift algae on beaches. As the algae decompose, nutrients are mixed into the beach sediments and consumed by burrowing invertebrates. During high tides, pieces of drift algae are transported into rocky intertidal habitats, where a variety of herbivores, including abalone and sea urchins, trap and consume the drift algae. Sea urchins and abalone feed on drift algae carried into intertidal areas by waves and currents. Floating kelp masses are important habitats for juvenile fishes. Fishes are attracted to the floating kelp because it provides a source of food (primarily amphipods) and shelter.

A small portion of the drifting kelp sinks through the water column and provides nutrients to organisms on the continental shelf and slope. Scientists have documented the movement of drift algae into Monterey Submarine Canyon. Some drift algae decomposes and sinks through the water column to the meso- and bathypelagic zones, contributing to production in the deep sea.

Relative status of kelp forests

Kelp is harvested during the late summer and early fall along the Big Sur coast north to the Monterey Peninsula. The primary reason for harvesting kelp is to extract chemical compounds, called alginates, which are used in common products such as toothpaste and ice cream. Kelp also is used to feed farmed abalone, and for various recreational, educational, and scientific purposes. The total volume of kelp extracted from the central and northern California coast varies widely, from less than 500 wet tons in 1987, 1991, and 1993, to over 10,000 wet tons in 1996. Around the Monterey Peninsula, the kelp harvest has declined from 664 tons in 1996 to 142 tons in 1999. The decline in kelp harvesting may be associated with social pressures to harvest elsewhere, oceanographic conditions, failure of farmed abalone business, and development of a management cooperative.

Few studies examine the potential ecological impacts of intensive and repeated harvesting of kelp. Of available studies, most conclude that harvesting does not have a significant effect on the kelp canopy, particularly when interannual variation is considered.

A few studies suggest that kelp harvesting may affect populations of marine algae, invertebrates, and fishes. Removal of the kelp canopy may enhance the growth rate of subsurface algae by allowing light to penetrate the water column to the sea floor. Some studies estimate that harvesting kelp may remove up to 25-35% of the motile invertebrates that live in the harvested kelp canopies. However, no studies have quantified whether removal of these invertebrates has significant ecological effects. Fish, marine mammals, and seabirds are less likely than invertebrates attached to or associated with the kelp canopy to be killed during kelp harvesting, because they move in response to physical disturbance and noise. However, some have suggested that kelp harvesting may affect juvenile fish, notably rockfish, which aggregate in kelp canopies.

Kelp is strongly affected by the intensity of predation by sea urchins and other invertebrate herbivores, as well as humans. When sea urchins are scarce, kelp tends to be plentiful. Sea urchin populations are consistently small where their primary predators are common. Sea otters, seastars, lobster, California sheepshead, and wolf eel are known to eat sea urchins. Urchin populations can grow when these predators are reduced or removed from the system. Large urchin populations can decimate entire forests of kelp. Human activities have altered these trophic relationships between predators and herbivores in various ways. In the past, humans hunted sea otters to near extinction, and other urchin predators in southern California (such as lobster and sheepshead) are still being caught. The reduction or removal of these predators can allow urchin populations to grow, leading to a decline of kelp. However, humans also commercially harvest some urchin species, and may control the size of urchin populations in places where the fishery is large.

Some gaps in ecological knowledge about kelp forests

The ecology of kelp forest communities is comparatively well known, because this habitat is extremely productive and has been used and studied by humans for many years. Scientists have identified a large number of physical and biological factors that influence the structure of kelp forest communities. However, the impacts of human use (e.g., kelp harvesting) are not fully understood. Kelp harvesting may have significant impacts on invertebrates attached to kelp fronds (e.g., gastropods and crustaceans). Additional study is needed to determine the effects of kelp harvesting on juvenile and adult fishes. Kelp provides habitat for prey of seabirds and marine mammals and the potential impacts of harvesting kelp on these predators are unknown. The impacts of harvesting kelp may vary depending on the technique (e.g., machine or hand harvesting), but no studies have determined the extent of these potential differences.

E. Neritic and Epipelagic Communities


Cordell Bank Expeditions

The vast majority of the three marine sanctuaries consist of open ocean habitats. These waters are classified into two primary zones, neritic and oceanic, based on their proximity to the continental shelf and the sea floor. The neritic zone overlies the continental shelf. The oceanic zone is the region of open water that overlies the shelf break and abyssal depths. Generally, the oceanic zone is divided by depth into three regions: the epi-, meso-, and bathypelagic zones. The epipelagic zone includes the upper 200 m of the water column.

Both the neritic and epipelagic zones receive high levels of light and are subjected to seasonal variations in temperature and salinity. The neritic, epi-, and mesopelagic zones support a diverse and complex food web of plankton, invertebrates, fishes, and mammals. The bathypelagic zones are characterized by reduced or no light, cold temperature, and high pressure. Organisms that live under these conditions require specialized characteristics for hunting and locating mates.

Ecological linkages in neritic and epipelagic communities

Most marine food webs are supported almost entirely by phytoplankton that live in open water. In general, the highest phytoplankton biomass occurs in surface waters near the shore. The maximum phytoplankton production occurs during the spring and summer upwelling season, when the nutrient content of surfaces waters is relatively high (*see oceanographic seasons*). During upwelling, coastal winds may displace waters, nutrients, and phytoplankton production offshore. Throughout the year, phytoplankton are important food for protozoans, zooplankton, bivalves, and larval fishes, such as anchovies and sardines.

Zooplankton depend on phytoplankton production for food, and in turn, microzooplankton contribute to the food supply of macrozooplankton. Zooplankton production varies with physical factors, including oceanographic conditions, temperature, currents, and eddies, and biological factors, including biomass of the adult stock and the reproductive effort for the year. Large populations of zooplankton are associated with high productivity in upwelling centers along the central coast of California. Zooplankton abundance decreases from north to south and from inshore to offshore with changes in temperature and nutrient availability. Zooplankton biomass in the California Current is highest in late spring, summer, and early fall, in part because of a peak in spawning of rockfishes, myctophids, and bathylagids.

Crustacean larvae, including euphausiids and copepods, are dominant groups in the epipelagic zone. Two species of euphausiids, *Euphausia pacifica* and *Thysanoessa* *spinifera*, are abundant in the epi- and mesopelagic zones. Euphausiids often are concentrated near Cordell Bank, the Farallon Islands and in Monterey Bay, due to high local productivity and oceanographic and geologic characteristics (*see submarine canyon and offshore island communities*). Copepods are found in a variety of marine habitats, including open water, sea floor sediments, tidal flats, and deep-sea trenches (*see neritic and epipelagic communities*).

Gelatinous zooplankton, including Hydromedusae, Siphonophora, Scyphomedusae, Ctenophora, Heteropoda, Pteropoda, Thaliacea, and Appendicularia, are abundant in the epi- and mesopelagic zones. Gelatinous zooplankton play a significant role in processing and transporting nutrients throughout the oceans. Pteropods, salps, and appendicularians are filter-feeders; they collect, concentrate, and transport particulate organic matter using mucous sheets, nets, strands, and filters.

Numerous fish species of the continental shelf and slope and submarine canyons have pelagic larvae. The duration of the pelagic larval and juvenile stages of many fish species is typically several weeks to months, but may be more than one year. After the pelagic phase, juveniles of many species settle into shallow waters near the coast and move into deeper waters as they grow.

Seasonality, turbidity, light levels, and predator or competitor distributions affect depth distributions of larval fishes. Species that remain in surface waters (e.g., some *Sebastes* spp.) may be carried offshore on surface currents, thus affecting their distribution and their recruitment success. However, vertical migration may be used as a mechanism to avoid predators and to recruit to nearshore settlement areas. Species that migrate below the thermocline (e.g., *Citharichthys* spp.) are less likely to be affected by surface currents and may be retained near the coast.

Spatial and temporal distribution of plankton affects the distributions of planktivorous fishes, marine mammals, and seabirds. In particular, marine mammals and seabirds aggregate in regions with extremely high plankton density, such as Cordell Bank, the Gulf of the Farallones, parts of Monterey Submarine Canyon, and certain areas around the Channel Islands.

Squid, which commonly inhabit the water column over sand bottom, are an important food source for numerous fishes, seabirds (including one of the most abundant pelagic seabirds, sooty shearwater), and marine mammals (including sea lions, seals, dolphins, orcas, and sperm whales). The most important squid species along the California coast is *Loligo* spp., which concentrates in relatively shallow waters over the shelf, especially in Monterey Bay. Other squid live in deeper waters where they consume euphausiids and copepods, and a variety of other crustaceans, gastropods, and polychaete worms. Spawning squid, including *Loligo* spp., tend to congregate in protected bays, usually over sandy bottoms with rocky outcroppings.

The composition of fish species in the neritic and epipelagic zone varies throughout the year with migration and spawning, and from year to year with environmental fluctuations. A small number of migratory species dominate the fisheries of central and northern California, including northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), Pacific hake (*Merluccius productus*), and jack mackerel (*Trachurus symmetricus*). These species spawn in the Southern California Bight and subsequently migrate into waters off northern California, Oregon, and Washington. During warm water conditions, the center of spawning may shift northward and continue longer. Northern anchovy and Pacific sardine can spawn throughout the year, but the peak in sardine spawning occurs in April and May. Pacific hake spawn in the winter whereas jack mackerel spawn between March and June. These fish are an important linkage in the marine food web, supporting a wide variety of higher-level predators, including other fishes, seabirds such as pelicans, gulls, and cormorants, and marine mammals such as seals and sea lions, dolphins and porpoises, and sperm and humpback whales.

Numerous sharks, including the blue shark (*Prionace glauca*), common thresher shark (*Alopias vulpinus*), mako shark (*Isurus oxyrhinchus*), basking shark (*Cetorhinus maximus*), and spiny dogfish (*Squalus acanthias*), are common residents of the neritic and epipelagic environment. Occasionally, the bigeye thresher shark (*Alopias superciliosus*), salmon shark (*Lamna ditropis*), and soupfin shark (*Galeorhinus galeus*) are taken in fishing gear. The white shark (*Carcharodon carcharias*) hunts in shallow open waters, often in the vicinity of Point Reyes, the Farallon Islands, and Año Nuevo Island where pinnipeds aggregate to molt and mate.

Concentrations of pelagic invertebrates and fishes attract seabirds to the open ocean over the continental shelf. Over 80 species of migrant seabirds and shorebirds, including Pacific and red-throated loons, California brown pelican, red-necked, western, and Clark's grebes, black-footed albatross, pink-footed, sooty, Buller's, and black-vented shearwaters, herring and glaucous-winged gulls, and white-winged and surf scoters, are regular visitors to waters around the Farallon Islands.

The most important types of prey for many seabirds are euphausiids, squid, juvenile rockfish, subadult sardine, and anchovy. Sooty shearwaters (*Puffinis griseus*), which are among the most numerous seabirds in the study area, migrate to the North Pacific during their non-breeding season to forage on fish, squid, and euphausiids. Shortbelly rockfish, anchovy, and sardine are among the primary foods of common murres (*Uria aalge*), Brandt's cormorants (*Phalacrocorax penicillatus*), and rhinoceros auklet chicks (*Cerorhinca monocerata*). Murres and other seabirds feed principally on euphausiids in the spring, before juvenile fish and anchovies are available. Adult rhinoceros auklets consume sablefish and juvenile lingcod found in deep waters far offshore. California brown pelicans (*Pelecanus occidentalis californicus*) feed primarily on northern anchovy, Pacific sardine, and Pacific mackerel. Cassin's auklets (*Ptychoramphus aleuticus*) depend on euphausiids and mysids as their primary food supply. Rhinoceros auklets and ashy storm-petrels (*Oceanodroma homochroa*) frequent waters of the continental slope, where they feed on epipelagic invertebrates, including euphausiids and oceanic squid. and fishes, including lanternfishes and Pacific saury.

Although pinnipeds use sandy beaches, mudflats, and rocky shores for resting and breeding, they forage in neritic, epipelagic, and mesopelagic waters, especially of the continental slope. California sea lions (*Zalophus californianus*) and steller sea lions (*Eumetopias jubatus*) forage over the entire continental shelf and slope on a variety of invertebrates and pelagic fishes. Northern elephant seals (*Mirounga angustirostris*) feed on or near the bottom along the slope and deeper waters, where they hunt for fishes and invertebrates, including squid, octopus, hagfish, ratfish, hake, and rockfish. Female and juvenile elephant seals remain off the coasts of California and Oregon, whereas males travel as far northwest as the Aleutian Islands and the Gulf of Alaska. During their non-breeding season, northern fur seals (*Callorhinus ursinus*) are the most abundant pinnipeds over the continental slope off California, where they hunt sablefish, rockfish, anchovy, squid, crabs, and various other types of prey. Harbor seals, which are found only in coastal habitats, occasionally travel 300-500 km to find food. Generally, they feed on coastal species such as anchovy, jacksmelt, and herring.

Dolphins and porpoises are residents of neritic and oceanic waters, with occurrence patterns stratified by depth. Common dolphins (*Delphinus* spp.) are the most abundant cetaceans off California, but almost all occur far seaward of sanctuary boundaries. The Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) is the second most abundant cetacean off California, with its greatest concentrations off central California. Pacific white-sided dolphin, northern right whale dolphin (*Lissodelphis borealis*), and Risso's dolphin (*Grampus griseus*) are found primarily in pelagic waters of the slope and beyond. They move north into Oregon and Washington as water temperature increases in the late spring and summer. Bottlenose dolphins (*Tursiops truncatus*) include a coastal population that is generally found within one km of the shore as well as an offshore population. Only the coastal form is found in the three marine sanctuaries. Harbor porpoises (*Phocoena phocoena*) are found in coastal waters in depths generally less than 100 m. The vast majority of the central California population is concentrated in the Gulf of the Farallones. Dall's porpoise (*Phocoenoides dalli*) occurs in both offshore neritic and pelagic waters. Similarly, orca (*Orcinus orca*) occur in both neritic and pelagic waters from California to Alaska. Orcas eat a variety of different types of prey, including fish, squid, seals, sea lions, seabirds, dolphins, porpoises, and occasionally large whales.

Sperm whales (*Physeter macrocephalus*) frequent waters of the continental slope and in the vicinity of seamounts where subsurface topography is steep. They subsist on fish and squid, are found year-round off California, but are most abundant in the spring and fall. Although the northeastern Pacific population of sperm whales is increasing under international and federal protection, this species continues to be listed as federally endangered.

Large baleen whales, including blue, gray, humpback, and fin whales, either migrate through the waters of coastal California, or move into the area to feed during the summer and fall. Baleen whales depend on concentrations of euphausiids for food. Large numbers of blue and humpback whales feed on euphausiids, anchovies, and sardines in the vicinity of Cordell Bank, the Farallon Islands, and Monterey and Bodega Canyons. Blue and humpback whales migrate south to mate and give birth in protected warm waters off

Mexico and Central America during the winter and spring. Gray whales (*Eschrichtius robustus*), the most commonly observed cetacean off central California during the winter and early spring, migrate annually from their feeding grounds in the Arctic Ocean and Bering Sea to their calving grounds in Baja California. Fin whales (*Balaenoptera physalus*) feed on euphausiids and schooling fish off southern and central California throughout the year.

Ecological linkages between neritic and epipelagic communities and other marine ecosystems

Phytoplankton, which is commonly found in neritic and epipelagic waters, is the primary source of production in the oceans. Although phytoplankton grows in surface waters, they are transported to other habitats by ocean currents, other organisms, and gravity.

Zooplankton and small, schooling fishes comprise the principal trophic linkage between primary and higher-level production. Euphausiids, especially *Euphausia pacifica* and *Thysanoessa spinifera,* directly support a variety of neritic and pelagic predators, including various fishes (anchovy, squid, salmon, hake, blue sharks), seabirds (sooty shearwaters, Cassin's auklets, common murres), and baleen whales (blue, humpback, gray, and fin whales). Euphausiids are a common source of food that may be the primary reason for aggregation of midwater species embedded in the food web, such as the market squid, Pacific hake, plainfin midshipman*,* Pacific herring*,* juvenile rockfishes, Pacific butterfish, and speckled and Pacific sanddabs.

Sinking detritus, which includes dead plankton, fecal material, discarded mucous webs of gelatinous zooplankton, bacteria, and dissolved organic particles, is a primary source of food for organisms in the deep ocean (*see continental slope and deep sea*). Organisms in mesopelagic and abyssal zones consume most of the nutrients in the sinking detritus. Some detritus, about 5-15% of the production in surface waters, reaches the sea floor where it provides food for organisms on the continental shelf and slope, in submarine canyons, and in the deep ocean.

Many organisms that live as adults in intertidal habitats, kelp forests, on the continental slope and shelf, and in submarine canyons, spend a portion of their life in pelagic habitats. Mussels, barnacles, sea urchins, and abalone have pelagic larvae that settle in rocky intertidal habitats after a period of larval development. Many common demersal fishes of the continental shelf and slope, including rockfish, hake, sablefish, thornyhead, and sole, produce young that lead a pelagic existence for the first few months of their life. Similarly, some other species are pelagic as adults and rely on other habitats to complete their life cycles. For example, juvenile Pacific mackerel are commonly found near sandy beaches, around kelp beds, and in open bays.

Relative status of neritic and epipelagic communities

Phytoplankton blooms, including toxic blooms, have increased in frequency and distribution worldwide since 1980. Frequency of blooms may be increasing with nutrient enrichment from agricultural and urban storm runoff, and sewage effluent. Several phytoplankton species produce toxins that may impact other organisms. Toxic phytoplankton become dominant when warm waters are carried closer to shore during relaxation events. Toxic algal blooms are common in the Gulf of the Farallones between August and October. Toxins produced by the dinoflagellate *Alexandrianum catenella* are primarily responsible for paralytic shellfish poisoning in California. The diatom *Pseudonitzschia australis* produces the neurotoxin domoic acid, which has contributed to deaths of seabirds and marine mammals that consumed tainted fish.

The biomass of macrozooplankton in waters off southern California appears to have decreased by 80 percent between 1951 and 1995. The lowest macrozooplankton biomass of central California was recorded in 1998. Since 1999, macrozooplankton abundance has rebounded to values near the long-term mean.

Numerous species that depend on zooplankton as a primary food source may be affected by the persistent low zooplankton biomass since the mid-1970s. Sooty Shearwaters, which consume euphausiids in the North Pacific during their non-breeding season, have exhibited a dramatic decline in abundance in the waters of the California Current. Changes in the abundance of euphausiids also may have contributed to the decline of planktivorous Cassin’s Auklets.

The decline in productivity of the California Current System may be associated with long-term variation in climate. Populations of some species, including Pacific sardine and northern anchovy, vary widely with climate fluctuations. Data on fish scales in sediment layers, collected in the Santa Barbara Basin from a period of over 1,500 years, indicate that sardine populations typically fluctuate between abundant and scarce over periods of 60 years, and somewhat in accordance with the Pacific Decadal Oscillation. The sardine fishery off central California collapsed in the 1950s after heavy fishing and environmental changes. Northern anchovy populations increased dramatically during the collapse of the sardine populations, suggesting that these species occupy similar ecological niches. Large populations of sardines reappeared in the Gulf of California in the early 1970s. The sardine population increased off southern and central California in the late 1980s and, by the early 1990s, sardines appeared in small numbers off British Columbia. As the sardine population increased, the northern anchovy population has declined steadily.

Fisheries may substantially affect the stocks of their target species. Commercial fishing contributed to the dramatic decline of the sardine fishery in the 1950s. After the collapse of the sardine fishery, strict fishing regulations were instituted and, after 50 years of protection, sardine populations have grown significantly. Other factors also contribute to fishery declines. Many marine species respond dramatically to climatic shifts such as El Niño or phases of the PDO. In addition, the disturbance and destruction of upland salmon breeding habitat has resulted in declines of all populations of salmon. Several runs of Chinook salmon, coho salmon, and steelhead trout in central California are extinct and the remainder have been listed as federally endangered and threatened. Almost all the salmon remaining in California waters are raised in hatcheries. Salmon habitat restoration projects, particularly for the coastal coho salmon, have helped to restore a few of these populations.

Human activities, including fishing, boating, and coastal development, may affect non-targeted species, including turtles, seabirds, and marine mammals. Since 1980, the population of leatherback sea turtles in the Pacific Ocean has declined by 95% from more than 80,000 nesting females to less than 3,000. Leatherback sea turtles are killed accidentally during gillnet and longline fishing activities. In addition, turtles may be killed when they ingest marine debris. Seabirds, particularly albatross, are frequently caught on hooks set out on long-lines. In trawl fisheries, seabirds may be attracted to the catch and become tangled in nets as they are gathered. Unusually high mortality of common murres from November 1997 to March 1998 was associated with spilled oil from submerged vessels, changes in food availability during El Niño, and an increase in set gillnet fishing in southern Monterey Bay. Marine mammals, including common and Pacific white-sided dolphins, and harbor porpoise, can become tangled, injured, or killed in gear from set and drift gillnet, and purse-seine fisheries. Restrictions on these fisheries have reduced the rate of entanglement, but some animals are injured or killed each year during routine fishing operations. Marine mammals also may be injured or killed by collision with ships.

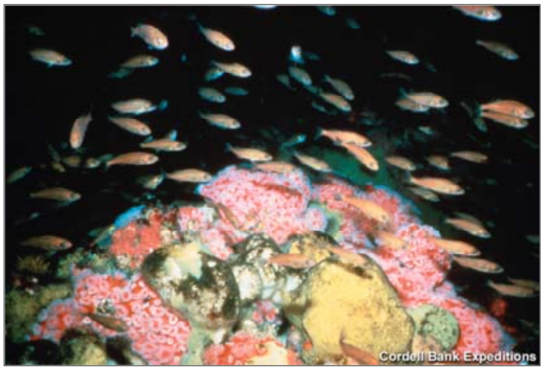
Hunting of large whales during the last two centuries contributed to dramatic declines of all whale species. Some species are recovering under international protection. Gray whales, which recovered completely from very low populations, were removed from the Endangered Species List in 1994. Since protection, blue whales in the eastern North Pacific have increased from a very small population, which was nearly entirely depleted off California, to approximately 2,000 individuals. The population of humpback whales has increased to over 6,000 individuals from a low of 1,200 in 1966. Fin whales were hunted to near extinction during the last century but under protection, the fin whale population has increased to approximately 1,850 individuals. All three species are currently listed as endangered.

Hunting of pinnipeds for meat and fur contributed to declines of many species. The population of northern elephant seals was reduced to less than 100 individuals on Isla de Guadalupe off the coast of Mexico. Since protection, the world population of northern elephant seals has increased to over 84,000 individuals and likely has reached its pre-exploitation biomass. Elephant seals are, by far, the most abundant breeding pinniped species in the marine sanctuaries. Harbor seals were greatly reduced to a few hundred individuals by commercial hunting. Under state and federal protection, the harbor seal population has increased to approximately 28,000 individuals in California, a large portion of which occur in the marine sanctuaries. California sea lions were reduced to low populations by hunting, but have increased at a rate of about 5% per year to over 200,000 individuals. This species, too, is likely near to pre-exploitation biomass. In contrast, the Steller sea lion population has declined over the last 30 years due to reduction in sardine populations, entanglement in fishing gear, deliberate shooting to protect salmon and herring fisheries, and perhaps interference of reproductive capabilities owing to chemical pollution. The Steller sea lion is listed as a state and federally threatened species.

Gaps in ecological knowledge about neritic and epipelagic communities

Neritic and epipelagic communities occupy a variety of habitats (e.g., epi-, meso-, and bathypelagic zones) under different physical conditions. Consequently, some aspects of neritic and epipelagic communities are well understood whereas others remain virtually unknown. Although the natural histories of many pelagic species have been described, some critical aspects, such as the dispersal paths of invertebrate and fish larvae, are not known. Human activities may disrupt the ecology of neritic and epipelagic communities, making it more difficult to understand the natural variability in the oceans. Point source and non-point source pollution enters the marine environment and disperses, often beyond our ability to trace its path. However, the effects of pollution on neritic and epipelagic communities may be significant. In addition to chemical pollutants, the oceans are subjected increasingly to noise pollution. Preliminary studies suggest that hearing loss and organ damage has occurred in marine organisms subjected to elevated levels of noise. As the number of observations suggesting negative impacts of noise pollution increases, questions remain about the linkages between noise pollution and injury, or death, of marine organisms.

F. Benthic Communities on the Continental Shelf



The continental shelf descends gradually from the coast to the shelf break at a depth of approximately 200 m (*Figure 1: Study Area*). Various habitats are found on the continental shelf, including subtidal rocky reefs, kelp forests, and soft bottom habitats. A layer of deep mud covers a portion of the continental shelf off central California. Outcropping bedrock and sand cover the continental shelf at depths greater than 90 m. The different sediments and the range of depths on the continental shelf provide diverse habitats for a variety of marine organisms.

<u>Ecological linkages among benthic species on the continental shelf</u>

Light penetrates the surface waters, supporting a highly productive nearshore community to depths of approximately 30 m. Shallow rocky reefs often support kelp forests that provide physical structure and an abundant source of food for subtidal organisms (*see kelp forest communities*). A portion of the production that is generated in shallow waters eventually sinks to the continental shelf and deep sea, providing nutrients for organisms that live there.

Soft bottom habitats lack the physical structure and high production associated with kelp forests and rocky reefs. Species that live on the continental shelf are subjected to shifting sediments due to wave action. Some species find shelter from the shifting sands by living in tubes and burrows. Clams are permanently buried in the sand with their siphons extended to the surface. Some crustaceans and mollusks live beneath the sand, emerging at night to forage. Crustaceans are common from the surf zone to 15 m depth, whereas polychaete worms are common in deeper water. Dungeness crabs (*Cancer magister*) are concentrated on sandy to sandy-mud bottoms from the intertidal to approximately 100 m. Brown and red rock crabs (*C. antennarius* and *C. productus*, respectively) are common on rocky substrate, whereas yellow rock crabs (*C. 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. Sea pens, notaspidean opisthobranchs, the octopus *Octopus rubescens,* the benthic squid *Rossia,* and the sea star *Luidia,* are common large epifaunal invertebrates at depths of 60-100 m in Monterey Bay.

Flatfish (Pleuronectiformes), including various sole, halibut, flounder, turbot, and sanddab, are camouflaged on the sandy surface of the sea floor. Some species, such as yellowfin sole (*Limanda aspera*) and spotted turbot (*Pleuronichthys ritteri*), are found only on the continental shelf. Others, such as English sole (*Parophrys vetulus*), Dover sole (*Microstomus pacificus*), and Pacific halibut (*Hippoglossus stenolepis*), are found at depths of 500 to 1000 m on the continental shelf and slope. Starry flounder (*Platichthys* *stellatus*) are common nearshore and in estuaries during the summer where they move up rivers as much as 120 km to feed on crustaceans, worms, small mollusks, and small fishes.

Rockfish (Scorpaenidae) are among the most diverse groups of fish that live on or near the continental shelf off central and northern California. Over 80 rockfish species, including widow, yellowtail, canary, shortbelly, and vermilion rockfish, bocaccio, chilipepper, cowcod, yelloweye, thornyheads, and Pacific Ocean perch, are found in the northeastern Pacific Ocean. Rockfish are associated with rocky features on the continental shelf and slope and in submarine canyons. Shortbelly rockfish (*Sebastes jordani*) are the most abundant rockfish species on the continental shelf and upper slope off California. Various seabirds (including common murre and Brandt's cormorant) rely on shortbelly rockfish for food (*see offshore islands*). Cowcod (*S. levis*), an important commercial species, are found in rocky habitats at depths of 100-560 m, generally near offshore banks and islands.

Greenling and lingcod (Hexigrammidae) generally occur in nearshore waters of the North Pacific. Kelp greenling (*Hexagrammos decagrammus*) are found in kelp beds and on sandy bottoms to depths of 50 m where they feed on polychaete worms, brittle stars, mollusks, and small fishes. Lingcod (*Ophiodon elongatus*), an important commercial and sport species, aggregate near rocks, nearshore and to depths of over 400 m on the continental shelf and slope.

Sculpin (Cottidae) are cold-water bottom fishes that occur in shallow water and tidepools, as well as in deeper water on the continental shelf. Cabezon (*Scorpaenichthys marmoratus*), the only sculpin species targeted by commercial anglers, are common in subtidal habitats in and around rocky reefs, kelp forests, and sandy and muddy bottoms to depths of 80 m on the continental shelf.

Some sharks and skates live on or just above the surface of the continental shelf. Several species, including spiny dogfish (*Squalus acanthias*), leopard shark (*Triakis semifasciata*), and California skate (*Raja inornata*), are common in shallow bays where they eat invertebrates and fishes. Leopard sharks are particularly common in bays of northern California. Some skates, such as big skate (*Raja binoculata*), are found in subtidal habitats over the continental shelf, whereas others, such as the longnose skate (*Raja rhina*) are found on both the continental shelf and slope. Spotted ratfish (*Hydrolagus colliei*), also cartilaginous, are found near the bottom to depths of over 900 m on the continental shelf and slope.

Ecological linkages between benthic species on the continental shelf and other marine ecosystems

Numerous species that live on the continental shelf as adults require different habitats during other stages of their life cycles. Dungeness crab larvae are pelagic, and juveniles settle in nearshore waters and estuaries, such as Humboldt Bay and San Francisco Bay. Juvenile spot prawns are pelagic; they settle on the bottom at depths as shallow as 60 m, moving down the continental shelf as they grow. Juvenile English sole are found in shallow bays and estuaries. The population density of juvenile English sole is several times higher in estuaries than along the open coast, whereas adult sole are seldom found in estuaries. Pelagic larvae of bocaccio are common within 30 m of the surface where they feed on plankton. By late May, juvenile bocaccio settle on the bottom, often in kelp beds. Cowcod larvae spend about 100 days in the plankton, settling during the spring and summer months in fine sand and clay sediments at depths of 45-110 m. Larval cabezon are pelagic for 100-120 days, feeding on tiny crustaceans and other zooplankton in the open ocean. Juvenile cabezon leave the open waters and settle in kelp beds, tide pools, and other shallow rocky habitats. Lingcod larvae are pelagic and juveniles settle in intertidal areas of bays, near algae and seagrass beds. Without access to a variety of pelagic and coastal habitats, many species of the continental shelf could not complete their life cycles.

Relative status of benthic communities on the continental shelf

Continental shelf communities are vulnerable to numerous threats from human activities. Development along rivers has altered both the sediment load and the amount of fresh water that is deposited in the ocean and distributed over the continental shelf. Sewage pipes on the sea floor modify benthic communities nearby, providing hard substrate for reef organisms and additional nutrient input. Catastrophic spills of untreated sewage have significant and localized effects but few long-term consequences. Certain commercial fishing activities, such as bottom trawling, affect continental shelf communities by periodically disturbing soft-bottom habitats and removing a portion of the organisms that live there. Non-consumptive activities, such as SCUBA diving, may cause damage to reefs and kelp forests through careless contact by divers.

Many species that live on the continental shelf are susceptible to fishing pressure, because they grow slowly and some, such as lingcod, are relatively sedentary as adults. Rockfishes are particularly vulnerable to fishing, because they are long-lived (approximately 13-100 years) and have relatively slow growth, late maturity (4-12 years), and unpredictable recruitment from year to year. Several rockfishes, including bocaccio, cowcod, canary rockfish, and Pacific Ocean perch, are considered overfished by the Pacific Fishery Management Council. Bocaccio abundance recently dropped to less than 2% of historical levels. Cowcod biomass began to decline in the 1950s under intense fishing pressure and by 1998 the population was less than 7% of its historical size.

In response to these declines, state and federal management agencies have established closures and strict fishing regulations. In December 2000, a vast area covering more than 13,500 km^2 in southern California was protected below 36 m to help restore cowcod. In June 2002, the Pacific Fishery Management Council closed a large area of the continental shelf, at depths of 36-274 m from the U. S. - Mexico border to Cape Mendocino and at depths of 183-457 m from Cape Mendocino to the U. S. - Canada border, to all bottom fishing for groundfish (including rockfish, flatfish, roundfish, sharks and skates, and ratfish). These emergency closures are intended to protect and restore groundfish populations. However, once overfished, some species require long periods of time to recover. For cowcod, the estimated time to recovery is over 90 years if cowcod fishing is prohibited.

Gaps in ecological knowledge about benthic communities on the continental shelf

The continental shelf is the geological extension of the continent, and as such, is strongly influenced by human and natural activities that occur on land and along the coast. As mentioned in the preceding section, development of watersheds and coasts strongly influences the sedimentary, biological, and chemical input to nearshore systems. Changes in watersheds due to development during the last century have caused dramatic decreases in the sediment load and freshwater input to marine systems, but the potential effects of these decreases on continental shelf communities are poorly understood.

There are significant gaps in our understanding of the effects of natural processes, such as storm cycles, currents, and waves, on continental shelf communities. Waves and currents scour the sea floor, contributing to changes in the distributions of benthic organisms. Extreme storms may generate waves that alter the benthic landscape, causing changes in the abundance and distribution of benthic organisms. Changes in community structure caused by natural processes certainly affect the productivity of continental shelf communities, but the changes in productivity are difficult to predict given our limited knowledge of the long-term patterns of shelf community dynamics.

Knowledge of continental shelf communities is incomplete, in part because most of the shelf exceeds the deepest diving depths possible with SCUBA equipment. Portions of the continental shelf are accessible only by fishing gear, remote cameras, remotely operated vehicles, and submersibles. The high cost and skill required to deploy this equipment limits our ability to collect data about communities on the deep continental shelf. In addition, the experimental studies that have generated much of our understanding of species interactions in intertidal or shallow subtidal habitats are logistically impossible at these deeper depths. Relatively little is known about the long-term physical and biological impacts of trawling on the sea floor. However, recent declines of benthic fishes targeted by trawl gear indicate that fishing can have significant impacts on continental shelf communities. Additional information about shelf community structure and dynamics is necessary for effective management of these vulnerable species.

G. Continental Slope (200-3000 m)

The continental slope drops steeply from the edge of the continental shelf to depths of approximately 3000-4000 m where it reaches the abyssal plain. The waters of the continental slope are dark, cold, and under very high pressure. Below 1000 m, it is completely dark, because sunlight cannot penetrate the water at this depth. Water pressure is more than ten times higher at the top of the continental slope than at the surface, and may exceed 300 times the surface pressure at the abyssal plain.

Species that live on the continental slope depend on production from surface waters. A portion of the primary production from surface waters sinks (*see neritic and epipelagic communities*) to the sea floor where it is either consumed by organisms, decomposed, or buried in sediments. As the decomposing detritus sinks through the water column, it creates an "oxygen minimum zone" at about 800 m depth. The oxygen minimum zone is characterized by relatively low dissolved oxygen content and secondary production. Below the oxygen minimum zone, the dissolved oxygen and nutrient content of the water is higher.

Ecological linkages on the continental slope

Organisms that live on the continental slope and in the deep sea exhibit an array of specialized adaptations for life in the dark and under pressure. Many slope organisms produce their own light through bioluminescence, which is used to find or attract potential food or mates. Shrimps and several fishes, including flashlight and headlight fish, have light producing organs. To compensate for the high pressure at depth, body tissues and bones of these organisms are high in water content.

The dominant invertebrates of the continental slope vary with depth. An abundant and diverse community of benthic invertebrates is found at the continental shelf break. A community of ampeliscid amphipods occurs on the continental slope at a depth of approximately 700 m in the oxygen minimum zone. Ampeliscid amphipods are a likely and underutilized food source for organisms that occur in the oxygen minimum zone. Polychaete worms are relatively common at approximately 1000 m depth, at the bottom of the oxygen minimum zone. The increase in biomass of polychaete worms likely is associated with relatively high inputs of food to the sea floor in this zone.

Similar to the changes in invertebrate communities, the dominant fishes of the continental slope also vary with depth. Rockfishes (*Sebastes* spp.), flatfishes (Pleuronectiformes), and eelpouts (Zoarcidae), are the most common deep-sea benthic fishes at the continental shelf break in Monterey Bay. Rockfishes tend to associate with high relief rocky outcrops on the continental shelf and slope.

Thornyheads (*Sebastolobus* spp.), flatfishes (Pleuronectiformes), hagfishes (*Eptatretus* spp.), rockfishes (*Sebastes* spp.), and eelpouts (Zoarcidae), are common at depths of 400 m on the continental slope. Many of these species occupy similar habitats and generally are caught together. Shortspine thornyhead (*Sebastolobus alascanus*) are found on the continental shelf and slope at depths of about 30-1800 m, whereas longspine thornyhead (*S. altivelis*) are restricted to deeper waters, from 300-1800 m. Shortspine thornyheads prey on crustaceans, crabs, worms, clams, octopus, sea cucumbers, and fish. Longspine thornyheads consume primarily polychaetes and small crustaceans. Off California, the population of sablefish (*Anoplopoma fimbria*) is concentrated on the continental slope from 400-600 m, although this species can live at depths of up to 1,600 m. Juvenile sablefish consume copepods, amphipods, euphausiids, fish eggs, and fish larvae, whereas adult sablefish primarily eat euphausiids, tunicates, and fish.

Thornyheads, Dover sole (*Microstomus pacificus*), cat sharks (Scyliorhinidae), and snailfishes (Liparidadae), are common benthic fishes at 600 m (*see sections on neritic and epipelagic, continental shelf, and submarine canyon communities*). Off California, Dover sole are found primarily on mud bottoms at depths of 700-1100 m, although this species may occur in shallower or deeper waters. Petrale sole (*Eopsetta jordani*) aggregate in deep water during the winter, and disperse inshore and north during spring and summer months. Although flatfishes can migrate long distances, most individuals are recaptured within short distances of the release point. Spawning aggregations of petrale sole occur at depths of 300-400 m off Cape Mendocino, Point Delgado, Point Montara, and Point Sal.

Ecological linkages between the continental slope and other marine ecosystems

Primary production in surface waters supports the community of organisms on the continental slope (*see neritic and epipelagic communities*). Variation in primary production in surface waters can affect the rates of growth and reproduction of species that live on the continental slope. For example, high primary production during the spring and summer may be associated with increased growth and reproduction of organisms on the sea floor. However, the relatively low nutrient content of deep oceans, combined with low light, cold water, and intense pressure, make the deep sea an unfavorable environment for growth of larvae and juveniles.

Many fishes that live on the continental slope, including rockfish, Dover sole, and sablefish, produce pelagic young that spend the first few months to years swimming in warm and productive surface waters (*see sections on continental shelf and submarine canyons*). Pelagic larvae of many continental slope species settle out in relatively shallow water and migrate down slope as they grow. Larval and juvenile thornyhead are pelagic for more than a year before they settle on the bottom. Juvenile shortspine thornyhead settle on the upper continental slope and move into deeper water as they grow, whereas juvenile longspine thornyhead settle into deeper water occupied by adults. Larval sablefish live in surface waters offshore; they move into nearshore nursery areas as they grow. Juvenile sablefish are found in waters of the continental slope and the abyss. Dover sole larvae are pelagic for at least one year before settling to the bottom.

Relative status of the continental slope

Like those on the deep continental shelf, species that live on the continental slope are vulnerable to the effects of fishing, because they tend to grow slowly and reproduce less frequently than species that live inshore of the continental shelf break. Fisheries that target the continental slope expanded rapidly in the early 1970s with the development of fishing gear that was effective in deep water. Beginning in the 1970s, a fishery for blackgill rockfishes developed off central and southern California. Statewide landings increased dramatically until a peak in 1983 and subsequently declined to very low levels in the late 1990s. Thornyheads support commercially important fisheries off California, Oregon, Washington, Canada, and Alaska. The thornyhead stock has declined to 32 percent of the unfished stock size during the last ten years. The commercial fishery for sablefish expanded rapidly in the early 1970s, reaching a peak in 1979. The market collapsed in subsequent years, and drove the total annual landings lower during the last 20 years. The commercial fishery for sablefish expanded rapidly in the early 1970s, reaching a peak in 1979, and collapsing in subsequent years. However, sablefish has become more valuable as other groundfish species declined. Resource managers have been under increasing pressure to reduce fishing effort before species of the continental slope become severely overfished. The extensive shelf closures established by the Pacific Fishery Management Council in July 2002 are intended to slow or reverse these declines (*see continental shelf community*). Other human activities, such as laying cables on the sea floor, or the introduction of chemical pollutants and contaminants may negatively impact the benthic invertebrate and fish communities associated with the deep continental shelf and slope. One specific example of this is the 30-plus year old radioactive waste dumping area adjacent to the Farallon Islands.

Gaps in ecological knowledge about continental slope communities

Relatively little is known about the ecology of continental slope communities. Like the deep continental shelf, the slope is accessible only by fishing gear, remote cameras, remotely operated vehicles, and submersibles, making it difficult to observe, sample, and experimentally manipulate. However, information about the ecology of the continental slope is essential for effective management of fisheries that increasingly concentrate on the deep waters of the continental shelf and slope. One method of obtaining information about the dynamics of continental slope communities is through the study of organic deposits and fossils in sea floor sediments. These paleo-oceanographic data can provide context for present day variability.

H. Deep Sea (>3000 m) & Seamount Communities

Deep-sea communities are found seaward of the continental margin and in submarine canyons (e.g. Monterey Submarine Canyon) that dissect the continental shelf (*Figure 1: Study Region*). During the last two decades, technological innovations, such as submersibles and remotely operated vehicles, have allowed biologists to examine the ecology of deep-sea communities.

The deep sea floor is a relatively flat and featureless environment. In a few places, extinct undersea volcanoes, or seamounts, disrupt the monotony of the sea floor. Off central California, several seamounts are located near the bottom of the continental slope (*Figures 2 & 3: Northern and Central Region*). Gumdrop, Pioneer, and Guide Seamounts are located about 120 km off the California coast, southwest of the Farallon Islands. The summit of Pioneer Seamount rises about 1,950 m and Gumdrop Seamount rises 800 m above the sea floor. Davidson Seamount, rising 2,300 m above the sea floor, is located 120 km to the southwest of Monterey. These features support a diverse assemblage of deep-sea invertebrates and fishes. The relatively high biomass near seamounts attracts various predators, including fishes and marine mammals.

Ecological linkages in the deep sea

Like the continental slope, the deep sea is characterized by conditions of low light, cold temperature, and high pressure. Like other organisms in habitats that do not receive high light or nutrient input (such as the continental slope and submarine canyons), those in the deep sea depend on production in surface waters. Because of these extreme conditions, species that live in the deep sea eat less frequently and grow more slowly than species in surface waters. Species in the deep sea also tend to live longer than those in surface waters, in part because sexual maturity and reproduction are delayed. In spite of the extreme conditions, the deep sea supports a remarkable diversity of organisms.

Deep-sea invertebrates have been surveyed at several sites throughout the study area, including Monterey Canyon, Pioneer Canyon, and the Navy Ocean Disposal Site (located approximately 12 km west of the Farallon Islands and 70 km west of the Golden Gate Bridge). The most abundant large invertebrates at these sites were holothurians, or sea cucumbers. Holothurians are deposit feeders that live in areas where current speeds are low. Three holothurian species, *Echinocucumis hispida, Ypsilothuria bitentaculata*, and *Molpadia* sp., were particularly common.

Ophiuroids or brittlestars are the dominant megafauna in many areas of the deep sea. Three ophiuroid species, *Ophiomusium glabrum*, *Amphiura carchara,* and *Amphilepis platytata,* are abundant in the deep sea off central California. *Ophiura leptoctenia* and *Ophiacantha normani* are most abundant between 1,000 and 2,000 m. Ophiuroids are found in areas of high water movement and food availability, often associated with sea pen (Pennatulacea) beds. Because of their abundance, feeding behavior, and high activity levels, ophiuroids likely alter the ecology of benthic soft-bottom communities.

Sea pens form thick beds on soft sediments in sheltered low energy sites. Sea pens are soft coral-like animals with stinging organelles, which are contained in polyps along the branches off the long axial polyp (the pen or oozoid). Sessile sea pens capture small organisms that are carried in the water column on gentle currents. The sea pen *Kophoblemnon* sp. is abundant near the Farallon Islands, but uncommon at Pioneer or Monterey Canyons.

Other common deep-sea invertebrates off central California include the burrowing sea star, *Eremecaster* sp., the corallomorpharian anemone, *Corallimorphus rigidus,* the lithode crab, *Paralomis verrilli,* and the deep-sea shrimp, *Crangon abyssorum*.

The invertebrate species composition on seamounts is quite different from the composition of deep-sea communities on the soft sea floor, in part because seamounts provide complex and rocky structure. Dense patches of sponges and coral forests cover the rocky surface of Davidson Seamount. Many different species of sea stars, crinoids, and sea cucumbers have been identified on the Davidson Seamount using remotely operated vehicles.

Most deep-sea fishes off central California belong to one of four families: grenadiers (Macrouridae), eelpouts (Zoarcidae), moras (Moridae), and skates (Rajidae). Grenadiers and eelpouts are common but not specifically associated with particular habitat types. Grenadiers (*Coryphaenoides* spp.) are found in areas of high bioturbation, characterized by mounds, pits, and extruded sediment piles. Grenadiers, eelpouts (*Lycenchelys* spp.), and the rare synodontid, *Bathysaurus mollis,* may be associated with sea pens, sea stars, brittlestars, or holothurians. The snailfish (*Paraliparis rosaceus,* Liparididae) and the finescale codling (*Antimora microlepis*) are associated with featureless areas characterized by soft sediments. Eighteen species of deep-sea fishes are associated with the rocky structure of the Davidson Seamount. Although some species appear to be associated with particular features, most deep-sea fishes are not abundant enough to identify habitat associations.

Ecological linkages between the deep sea and other marine ecosystems

Deep-sea communities depend almost entirely on primary production in surface waters. Sinking detritus is a primary source of nutrients for bathypelagic and deep-sea communities (*see neritic and epipelagic community*). Most nutrients in surface waters are absorbed or consumed by organisms, or decomposed in the epi- and mesopelagic zones. On average, less than 3% of primary production sinks through the water column to the deep sea. However, off central California where production is particularly high, as much as 5-15% of the primary production may reach the sea floor. Once the organic matter reaches the sea floor it is consumed almost entirely by benthic organisms. A very small portion may dissolve or become buried in sediments.

Organisms in the deep sea use a variety of foraging strategies to take advantage of the unpredictable and patchy supply of food. Many deep-sea animals, including sponges, sea anemones, tube worms, barnacles, and some seastars, are “sit-and-wait” predators. Bottom-dwelling skates, rays, and sharks often rest on the bottom and wait for prey. Some deep-sea animals, including amphipods and deep-sea shrimps, are active scavengers. These active scavengers break down carcasses and scatter pieces of the carcasses on the sea floor, attracting slower-moving animals, such as mollusks, sea stars, brittlestars, and sea cucumbers. Grenadiers are opportunistic feeders that swim slowly above the sea floor, searching for prey, such as crustaceans, mollusks, worms, and other fishes. A few large deep-sea squid (e.g., *Architeuthis dux*) may be active predators. Common dolphins (*Delphinus* spp.) occasionally concentrate near seamounts and along escarpments in the deep sea, possibly because dolphins are attracted to the concentration of invertebrates and fishes around the seamount, or dolphins may use these submerged features as landmarks during migration.

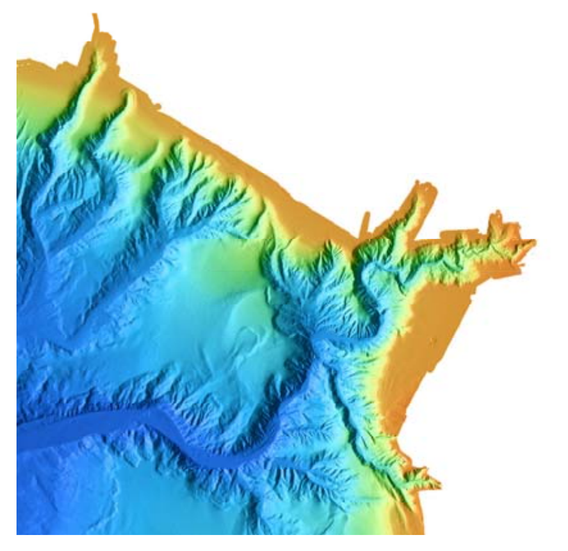
Relative status of the deep sea

A decline in surface production between 1989 and 1996 contributed to a decline in the supply of food to the deep sea off central California. The decrease in the food supply may be associated with the decline in zooplankton abundance throughout the North Pacific Ocean (*see natural disturbances*). The decline in the food supply to the deep sea did not correspond to a decline in the demand for food in deep-sea communities. Consequently, the food shortage is likely to reduce the abundance and reproductive potential of organisms in the deep sea.

Gaps in ecological knowledge of the deep sea

The deep sea is among the last frontiers on Earth. Relatively little is known about the ecology of the deep sea. The deep sea is difficult to study because it is accessible only by remote cameras, remotely operated vehicles, and submersibles. To date, studies of the deep sea include only observation, identification of species, and estimation of relative abundance. Often, studies of the deep sea identify species previously unknown to science. Observations suggest that deep-sea communities are patchy and dynamic. However, additional information is needed to determine interspecific interactions in deep-sea communities.

I. Submarine Canyon Communities



The continental shelf off central California is highly dissected by numerous submarine canyons. Submarine canyons are submerged v-shaped valleys that begin on the continental shelf, extend down the slope, and end on the abyssal plain. A variety of habitats are found in submarine canyons, including vertical cliffs, ledges, talus slopes, cobble and boulder fields, and soft mud. Canyon walls are often steep and rocky whereas canyon bottoms tend to slope gently and accumulate finer sediments, such as silt and mud. Submarine canyons form during erosion of rapidly flowing currents that carry heavy sediment loads, known as turbidity currents. When turbidity currents reach the base of the continental slope, they slow and deposit their sediment loads in broad submarine fans.

Unique submarine canyons

Pioneer Canyon bisects the continental slope just south of the Farallon Islands. Pioneer Canyon consists of two smaller canyons that merge near the shelf break to form the main valley of the canyon.

The Ascension Canyon system, west of Point Año Nuevo, includes three major canyons: Ascension, Año Nuevo, and Cabrillo. Near their heads, the canyon walls are steep and v-shaped. The main channel of Ascension Canyon is relatively straight and narrow (<0.5 km). Sediment slides influence the shapes of the head and the northwestern wall of Ascension Canyon.

The Monterey Canyon system, located within Monterey Bay and offshore, includes three major canyons: Soquel, Monterey, and Carmel. In addition to these canyons, the Monterey Canyon system includes several prominent meanders: Gooseneck, Monterey, and San Gregorio.

Soquel Canyon is located on the continental shelf just south of Santa Cruz. The canyon extends about 10 km southwest where it intersects the larger Monterey Canyon at a depth of about 1,000 m.

The head of Monterey Canyon is located near Moss Landing. The upper part of the canyon is relatively narrow (~250 m wide) and the canyon walls are quite steep (10-35°). Although sediment slides occur on both walls of the canyon, slumping and sliding are more prevalent on the north wall. The Monterey Canyon cuts steeply into the continental shelf, reaching depths of 1,300 m in the outer bay. The canyon floor continues to widen as it meanders across the continental shelf, reaching a width of over 3.5 km in some places. From the edge of the continental shelf, the Monterey Canyon slopes down to the abyssal plain to a depth of 3,200 m. On the deep sea floor, the canyon expands out across a broad submarine fan, extending over 160 km wide.

Carmel Canyon is formed by the confluence of three canyon heads, two in Carmel Bay and one along an active fault zone southwest of Carmel Bay. The canyon intersects Monterey Canyon approximately 30 km from its head at a depth of about 1,970 m.

Sur Canyon is located approximately 60 km south of Monterey Canyon. Several heads of Sur Canyon originate on the Sur Platform. The canyon extends to the west for more than 50 km where it reaches the abyssal plain just northeast of the Davidson Seamount. The steep north side of the Sur Canyon is particularly susceptible to slumping and sediment flows.

Lucia Canyon slopes to the west across the narrow continental shelf just south of Sur Canyon. The incline of the canyon is relatively gentle on the upper continental slope, but becomes steeper toward the bottom. The steep canyon walls are heavily scarred with landslides along the lower continental slope.

Ecological linkages within submarine canyons

Large submarine canyons, such as Monterey Canyon, extend from shallow waters near their heads to the deep sea. Little light penetrates the canyons to depths of more than 500 m. At these depths, water temperature is cold (5-12^{o}C) and the overlying water exerts tremendous pressure (up to 318 atm). Organisms that live in submarine canyons must be able to withstand these extreme conditions.

Macroalgae, and other organic matter produced in shallow or surface waters, may settle at the mouth and along the edges of submarine canyons. Lysianassid amphipods and *Capitella* worms are found in this plant debris. The persimmon eelpout (*Maynea californica*) is commonly associated with macroalgae that drift on the bottom of Monterey Canyon to depths of 70-550 m.

Prickly sharks (*Echinorhinus cookei*), which are rare throughout the Pacific, aggregate at the mouth of the Monterey Canyon. Prickly sharks eat small sharks, shark egg cases, octopus, squid, and some bony fishes.

Clams and worms burrow into the hard mud outcrops on more stable canyon walls. Articulated brachypods (*Laqueus californianus* var. *vancouveriensis*) are found on canyon walls at depths of 500-700 m. Suspension-feeding 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.

The soft sediments commonly found at the base of submarine canyons, and occasionally on the walls, also support a diverse invertebrate community. Droopy sea pens (*Umbellula lindahli*) are found in soft sediments at depths below 500 m throughout the Monterey Canyon. The most abundant invertebrates in Pioneer Canyon are holothurians, *Echinocucumis hispida* and *Ypsilothuria bitentaculata*. Several brittle stars, including *Ophiomusium glabrum, Amphiura carchara* and *Amphilepis platytata* were found in large numbers on the deep sea floor. One species of brittlestar (*Ophiocantha pacifica*) and one species of asteroid (*Eremicaster gracilis*) were found in both Monterey and Pioneer Canyons.

Rattails and whiptails (Macrouridae) are common fishes at depths of 200-6000 m, where they swim just above the sea floor. 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 of the continental shelf, slope and in submarine canyons (*see continental shelf and slope communities*). Although these fishes may occur in relatively shallow waters (<60 m), many species are more common in deeper waters. Flatfishes feed on a variety of invertebrates, including worms, small crustaceans, and clams. Some flatfishes (e.g., petrale and English sole) also consume small fishes.

The rocky cliffs, ledges, talus slopes, and cobble and boulder fields of submarine canyons provide cover for numerous fish species. Adult rockfishes (*Sebastes* spp.) are commonly associated with some structure. Thornyheads (genus *Sebastolobus*), which are in the same family as rockfishes, also occur in submarine canyons and on the continental slope at depths of about 1200 m. Spawning populations of Pacific hake (*Merluccius productus*) are found at depths of 130-500 m, and sablefish (*Anoplopoma fimbria*) are concentrated from 400-600 m over the continental slope and in submarine canyons. These deep-sea fishes primarily consume euphausiids and other invertebrates. A few species, such as shortspine thornyhead and sablefish, also eat small fishes.

Ecological linkages between submarine canyons and other marine ecosystems

Although upwelling does not occur in the Monterey Canyon, there are areas of high productivity near the canyon. Cool, nutrient-rich waters accumulate at upwelling regions near Point Año Nuevo and Point Sur. These waters and associated nutrients can then be transported to Monterey Bay via surface currents.

The south side of the Monterey Canyon is particularly productive due to the combination of currents moving southward and the canyon structure. As organisms (such as euphausiids) migrate up the water column to feed, they may be transported southward on the California Current and trapped in relatively shallow waters over the continental shelf just south of deep canyons. These concentrations of organisms attract a variety of predators, including fishes, birds, and marine mammals. Blue and fin whales occasionally feed on dense swarms of euphausiids near the Monterey Canyon.

Some of the production in submarine canyons is introduced from adjacent nearshore habitats. Drifting macroalgae may accumulate around the heads and along the slopes of submarine canyons. The detritus may be washed down the canyon during storms, contributing to productivity in the deep sea.

Many species that occur in submarine canyons may require other habitats to complete their life cycles. Common fishes of the continental slope and submarine canyons (e.g., sole, sablefish, hake, and rockfish) produce pelagic young that spend the first few months to years in the upper water column. These pelagic larvae settle into the relatively shallow water of estuaries, bays, kelp forests, rock outcrops, and cobble fields. As they grow, the young move into deeper waters.

Relative status of species in submarine canyons

Submarine canyons are vulnerable to a variety of human activities because they extend across a range of depths, from shallow canyon heads that may be heavily influenced by coastal development, to deep sea that may be affected by deposition of sediments and pollutants. Elevated concentrations of persistent organic pollutants (e.g., petroleum hydrocarbons, chlorinated pesticides, polychlorinated biphenyls) have been found in fish from the Monterey and other submarine canyons. The risk of bioaccumulation of pollutants is higher in submarine canyons than in surrounding waters because gravity and turbidity currents tend to concentrate the flow of sediments and pollutants into the canyon.

The complex structure of submarine canyons may help to protect species associated with these habitats from overfishing. Species associated with structure in submarine canyons tend to be difficult to locate and target. However, fishes of the continental slope and submarine canyons are increasingly harvested as fishing technology improves.

In recent years, Dover sole, thornyheads, sablefish, Pacific hake, and rockfishes dominated the California commercial groundfish landings. These fishes are particularly vulnerable to overfishing because they are slow growing, slow to reproduce, and long-lived. Some rockfishes have declined dramatically, and a few species, including bocaccio, cowcod, canary rockfish, and Pacific Ocean perch are officially recognized as overfished by the Pacific Fishery Management Council. Sablefish landings have declined significantly over the last two decades, probably due to a combination of reduced spawning stock, changes in the market, and stricter regulations. Thornyhead also declined, reaching a low of about one-third the unfished stock size by 1999. In order to slow or reverse these declines, the Pacific Fishery Management Council established extensive closures of the continental shelf and slope in July 2002.

Gaps in ecological knowledge about submarine canyons

Monterey Submarine Canyon is among the most intensively studied submarine canyons in the world. Details of the bathymetry of Monterey and the associated submarine canyons are well known. Physical processes that shape the canyon have been described.

The ecology of the Monterey Submarine Canyon has been characterized in numerous academic reports and popular books. Marine plants, fishes, and invertebrates found in and around the Monterey Submarine Canyon are studied and displayed at the Monterey Bay Aquarium and Research Institute. However, dynamic processes that maintain the physical structure and ecology of Monterey Submarine Canyon are not fully understood, in part because the canyon reaches a depth of 3,656 m, far below the maximum depths accessible using SCUBA gear. Most of the canyon is impossible to access without the assistance of remote cameras, remotely operated vehicles, and submersibles. Logistical considerations also have limited study of other submarine canyons (such as Pioneer, Lucia and Sur Canyons) primarily to bathymetric characterizations and general descriptions of canyon communities. Additional information is needed to fully characterize the ecological processes that occur within submarine canyon communities.

J. Cold Seep Communities

Cold seeps are regions on the seafloor that release sulfide- and methane-rich fluids. Cold seeps are common along the translational margin off central California and other places throughout the world where the seafloor is compressed under high pressure (*Figure 3: Central Region*). Cold seeps form where fluids and gases are forced through weak regions of the sea floor, such as permeable and organic-rich substrates (Clamfield, Mount Crushmore), fault zones (San Gregorio, Monterey Bay, Ascension), and anticlinal folds (Pick-up Sticks). Submarine canyons create depressions on the seafloor that concentrate the flow of gases and fluids to the surface. Increased pressure on faults along the walls of Monterey Submarine Canyon squeezes fluids and gases from the sandstones of the Purisima Formation (Mt. Crushmore) and the hydrocarbon-rich Monterey Formation. Some cold seeps are caused by geomorphic focusing (Horseshoe Head Scarps, Chimney Field, Tubeworm City) and mud volcanoes (Camp Cup, Clam Flats).

Ecological linkages within cold seeps

The faunal composition of cold seeps is affected strongly by chemistry and depth. Most cold seeps are found in the deep sea (600-3000 m) under conditions of low light, temperature, and oxygen, and high pressure. In spite of these difficult conditions, numerous organisms are adapted to life around cold seeps.

Vesicomyid clams (*Calyptogena* spp.) are the dominant species at cold seeps off central and northern California. The distributions of individual species correspond closely to patterns of sulfide and methane concentrations. The vesicomyid clam *Calyptogena kilmeri* is most common at seeps with high sulfide concentrations. In contrast, *C. pacifica* is less abundant and usually located at the edge of seeps where sulfide levels are lower.

Vesicomyid clams support chemoautotrophic bacteria (*Beggiatoa* spp.) in a symbiotic relationship, using organic compounds produced by the bacteria. The bacteria derive energy from the inorganic chemical compounds released by the cold seeps. The clams congregate near seeps, where they find the appropriate concentrations of hydrogen sulfide to support bacterial production of organic compounds. If the gas concentration changes or ceases the clams move to more productive sites.

Various species are attracted to the biological activity around cold seeps. Lithodid and brachyuran crabs have been observed to prey on vesicomyid clams. Tanner crabs (*Chionoecetes bairdi*) prey on vesicomyid clams in the laboratory and are likely to consume wild clams as well. Buccinid snails (*Neptunea amianta*) are abundant throughout the continental slope and scavenge dead vesicomyid clams at cold seeps in Monterey Bay. Holes in vesicomyid shells provide further evidence of predation by snails. Large octopi (*Octopus dolfleini*) occur near cold seeps, but have not been observed to prey on seep fauna. Columbellid gastropods are common at cold seeps, but appear to have little influence on their clam hosts. In fact, columbellid gastropods may benefit vesicomyid clams by removing bacterial films from the clams' shells. Several benthic fishes occur at seeps in Monterey Bay, however fishes do not appear to prey upon clams or bacterial mats.

Ecological linkages between cold seeps and other marine ecosystems

Over time, pressure beneath the sea floor is reduced through release of gases and fluids from cold seeps. Eventually, the flow of gases and fluids may cease and seep-associated species may be forced to move. Although they are highly specialized, seep-associated species are capable of exploiting other sources of nutrients as they move between seeps. For example, whale carcasses on the deep sea floor may be covered with thick bacterial mats similar to those at cold seeps. Anaerobic bacteria that decompose the lipid-rich whale bones release hydrogen sulfide, which supports bacteria traditionally associated with cold seeps. Many of the seep-associated invertebrates, including clams, aggregate on whale carcasses. Seep-associated organisms may use whale and other carcasses as sources of food during dispersal between cold seeps.

Relative status of cold seeps

With few exceptions, cold seep communities are restricted to extremely specialized habitats where sulfide- and methane-rich fluids are released from the seafloor. Over time, as physical forces shift, the concentration of sulfide and methane in fluids released from cold seeps may decline, and eventually the seepage may cease altogether. Changes in the chemical composition of fluids influences abundance and diversity of species associated with the seeps.

Gaps in ecological knowledge about cold seeps

Although numerous cold seeps have been located off central California, ecological interactions among seep-associated species are poorly known. Scientific study of cold seeps is difficult because seeps are located in the deep sea, under conditions of reduced light, temperature and oxygen, and intense pressure. These conditions also make it difficult to exploit the organisms associated with cold seeps. Thus, cold seep communities are not targeted for fishing or other extractive activities. Additional research is needed to characterize ecological interactions among the chemoautotrophic bacteria, their vesicomyid clam hosts, and the myriad of species attracted to this remarkable production in the deep sea. Predation, competition, and disturbance likely influence the demographic rates of populations associated with cold seeps. The presence of at least four geologically distinct seep sites in Monterey Bay provides a unique opportunity to investigate the ecology of cold seep communities.

K. Offshore Island Communities


Jan Roletto

The islands off of California's coast are unique habitats that provide breeding and resting sites for migrating seabirds and marine mammals. Together, the Farallon Islands, Año Nuevo Island, and the rocks off Point Reyes, support interconnected populations of breeding seabirds and pinnipeds. In addition, California's islands support numerous rare, endemic species that survived isolation and evolved as a consequence of their isolation under the effects of selection on islands. Historically, islands have been strongly influenced by hunting for animals and their eggs, which resulted in the near extinction of northern elephant seals, northern fur seals, common murres, Cassin's auklets, and tufted puffins from the California coast. Today, the Farallon Islands are protected by the Farallon National Wildlife Refuge, and Año Nuevo Island is a state reserve.

The Farallon Islands, located approximately 50 km west of San Francisco, are the only major offshore islands in central and northern California (*Figure 2: Northern Region*). The five Farallon Islands are part of a granite ridge that rises from the seafloor. Southeast Farallon and West End islands together cover just over 35 hectares. Southeast Farallon Island is the largest and the only one of the Farallon Islands to have been occupied by humans. Middle Farallon Island is about 4 km to the northwest, and the North Farallon Islands are a group of three rocks located 8 km farther to the northwest. The Farallon Islands are located at the edge of the continental shelf and south of the largest upwelling center along the California coast. The high marine productivity of this region attract a diverse assemblage of invertebrates, fishes, seabirds, and marine mammals.

A number of coastal rocks also occur within the marine sanctuaries. The largest, Año Nuevo Island, is located offshore of Point Año Nuevo and south of Half Moon Bay and Pigeon Point (*Figure 2: Central Region*). This small, rocky islet is approximately 400 m long and 260 m wide. Higher parts of the island are covered with sand and vegetation. Año Nuevo Island was likely a part of the mainland just a few hundred years ago.

Other important coastal rocks in the study area include Bird Rock near Tomales Point, Double Point and Point Resistance rocks just south of Point Reyes, Devil's Slide rock near Pacifica, a rock off Point Lobos, and Hurricane rocks off Big Sur. Morro Rock is substantial, but since it is connected to the mainland at low tide, it is not an important marine bird roosting or breeding site.

Ecological linkages on offshore islands

The Farallon Islands are the most important area for nesting seabirds off the California coast. Seabirds also nest on coastal rocks and islands, but no other site is used by all 12 of the bird species that breed on the Farallon Islands. Over 300,000 adult birds nest on the islands in May during the height of the breeding season. Twelve species of seabirds, including common murre, Cassin's and rhinoceros auklets, pigeon guillemot, tufted puffin, western gull, double-crested, Brandt's and pelagic cormorants, ashy and Leach's storm-petrels, and black oystercatcher, breed on the Farallon Islands. Smaller colonies of most of these species also breed at Point Reyes and Año Nuevo Island. Other than these locations, breeding sites for the majority of these species are few along the coast of California south of Humboldt County.

Murres and auklets are the most abundant and diverse of the breeding seabirds on the Farallon Islands. Common murres (*Uria aalge*) form dense breeding colonies (>100,000 individuals) on cliffs. Murres also breed along the Marin County coast in Point Reyes National Seashore at sites including Devil's Slide Rock, Castle Rock, Hurricane Point, Point Reyes, Double Point, and Point Resistance. Cassin's auklets (*Ptychoramphus aleuticus*), the second most abundant species on the Farallon Islands, nest in burrows on marine terraces and talus slopes on the Farallon Islands and very sparsely on Año Nuevo Island. Several thousand pigeon guillemots (*Cepphus columba*) breed at the Farallon Islands. Smaller populations are found at other locations along the California coast (Año Nuevo Island, Partington Ridge, Grayhound Rock, Point Reyes National Seashore, and cliffs along San Mateo and San Francisco counties). Only about 50 tufted puffins (*Fratercula cirrhata*) breed on the Farallon Islands each year. A few pairs have attempted to breed at Point Reyes. After the breeding season, auklets and murres leave breeding sites and follow their food resources north and south along the coast.

Although several gull species may be observed around the Farallon Islands, only one species breeds on the islands. Western gulls (*Larus occidentalis*) nest on the lower slopes and flat areas of Southeast Farallon Island, Año Nuevo Island, and other locations along the central California coast, including Cape San Martin, Elkhorn Slough, and Morro Rock.

Three cormorant species breed on the Farallon Islands. Brandt's cormorants (*Phalacrocorax penicillatus*) nest in scattered colonies on coastal rocks and in coastal wetlands, as well as at Año Nuevo Island, and Point Reyes. Pelagic cormorants (*Phalacrocorax pelagicus*) nest on narrow cliff edges of the Farallon Islands, Point Reyes, and other locations along the California coast, including Bodega Head, Devil's Slide Rock (south of San Francisco), and Año Nuevo Island. Double-crested cormorants (*Phalacrocorax auritus*) breed on the Farallon Islands and throughout the San Francisco Bay region, especially on the larger bridges over the inner bay. Unlike most other species that breed on the Farallon Islands, double-crested cormorants forage primarily in estuaries, lagoons, and bays, and pelagic cormorants forage primarily in intertidal areas.

The Farallon Islands support breeding populations of two storm-petrel species. Ashy storm-petrel (*Oceanodroma homochroa*) and Leach's storm-petrel (*Oceanodroma leucorhoa*) nest in burrows and crevices, deep beneath the surface of talus slopes, under boulders and in rock walls on Southeast Farallon Island. Most of the remainder of the California populations of these species nest on the Channel Islands, although small numbers breed on a few coastal rocks. Storm-petrels feed on epipelagic invertebrates and fish, with the ashy storm-petrel frequenting waters of the continental slope and the Leach's storm-petrel those waters farther to the west.

Large breeding populations of pinnipeds are found on offshore islands of central and northern California (*also see neritic and epipelagic communities*). Pinnipeds haul out on shore to rest or breed. Northern elephant seals (*Mirounga angustirostris*) breed at Point Año Nuevo Island and the adjacent mainland, Point Piedras Blancas, Big Sur Beach, Point Reyes, and the Farallon Islands. A small breeding population of northern fur seals (*Callorhinus ursinus*) is found on the Farallon Islands. Although the California sea lion (*Zalophus californianus californianus*) is the most widely distributed pinniped off central and northern California, this species breeds mainly on offshore islands in Mexico and southern California. A few California sea lion pups have been born on Año Nuevo and the Farallon Islands. Steller sea lions (*Eumetopias jubatus*) once bred in great numbers on the Farallon Islands, Año Nuevo Island, and the Channel Islands, but breeding populations have declined steeply and the southernmost breeding site is now Año Nuevo Island.

The waters around the Farallon Islands are important to pinnipeds during the non-breeding season. During the winter, the Steller sea lions haul-out at Point Reyes and on the rocky islands off the Sonoma coast. Cordell Bank is a primary feeding area for this species, possibly because of the abundance of rockfish and sardines around the bank. The Gulf of the Farallones contains approximately one-fifth of the California population (about 5,000) of harbor seals.

Ecological linkages between offshore islands and other marine ecosystems

The Farallon and Año Nuevo islands, Point Reyes, and the rocks and coasts near Point Reyes comprise a demographic unit characterized by extensive interchange of individuals among the resident species. Among banded or marked individuals that have been seen at all or two of the three locations are: white sharks, Brandt's cormorants, black oystercatchers, western gulls, rhinoceros auklets, steller sea lions, and northern elephant seals. Aside from this triangle of breeding sites, there is no other major breeding site for marine birds or mammals along the coast to the north until Cape Mendocino, and few to the south until the Channel Islands. Other seabirds that nest within or adjacent to the marine sanctuaries are Caspian and Forster's terns and marbled murrelet. The waters from Point San Pedro to northern Monterey Bay are particularly important to marbled murrelet, which is listed as threatened. Small numbers of 5 marine bird species breed on the rocks off Big Sur. A small rock off Pacifica, just south of San Francisco, supports small numbers of murres and cormorants.

Seabirds provide organic material and nutrients to habitats they use for breeding and feeding. Seabirds deposit excreta, feathers, eggshells, and carcasses in habitats they use. This nutrient input may increase plant productivity in areas around seabird colonies.

Seabirds are important predators in neritic and epipelagic habitats throughout the world's oceans. Sanctuary waters provide important, if not exclusive, foraging habitat for some species. During their breeding season, hundreds of thousands of Common Murres, and many other seabirds feed on shortbelly rockfish, anchovy, sardine, and euphausiids around the Farallon Islands (*see neritic and epipelagic communities*). Some species travel far from their nesting sites to forage in highly productive waters. For example, Ashy Storm-petrels frequent waters overlying the continental slope west of the Farallon Islands to feed on pelagic invertebrates and fish. Some species, such as the Black-footed Albatross, travel long distances to waters near the Farallon Islands to forage while they are breeding on islands in the central Pacific Ocean, primarily the Midway and Hawaiian Islands. During their non-breeding season, millions of Sooty Shearwaters migrate to the northern hemisphere to forage on fish, squid, and euphausiids in the North Pacific and North Atlantic (*see neritic and epipelagic communities*).

Although pinnipeds use sandy beaches, mudflats, and rocky shores for resting and breeding, they depend on the food supply in pelagic habitats. California and Steller sea lions forage on a variety of invertebrates and pelagic fishes over the entire continental shelf. Northern elephant seals feed in open waters over the continental shelf and offshore where they hunt for deep-water fishes and invertebrates, including squid, octopus, hagfish, ratfish, hake, and rockfish. Female and juvenile elephant seals remain off California and Oregon, whereas males travel as far northwest as the Aleutian Islands and the Gulf of Alaska. During migration, northern fur seals are the most abundant pinnipeds seaward of the continental shelf off California, where they hunt sablefish, rockfish, and anchovy, squid, crabs, and various other prey. Harbor seals, which are found primarily in coastal habitats, generally do not make extensive pelagic migrations, but occasionally travel 300-500 km to find food.

Relative status of offshore islands

Many bird species on offshore islands in California have declined during the last 150 years due to a variety of factors, including exposure to toxic materials, egg collecting, disturbance, habitat destruction, effects of fishing gear, environmental changes, and increased predation. Some of these impacts were reduced when Southeast Farallon Island became a National Wildlife Refuge in 1969, and when the Gulf of the Farallones National Marine Sanctuary was established in 1981. Under protection, many seabird populations have increased or recovered.

Physical and chemical pollution have increased mortality and reduced breeding success of numerous seabirds. Concentrations of organochlorine pollutants (including DDT and PCBs) contributed to eggshell thinning in the 1970s. Levels of DDT and PCBs have decreased substantially since the 1970s.

Since 1970, oiled birds have been observed regularly on the coast of central and northern California. Oil destroys the feathers' ability to insulate the bird and a small amount of oil can result in death by hypothermia. Common murres are the most frequently encountered oiled birds (0.5 birds/km) on beaches between Bodega Head and northern Santa Cruz County. Since October 1993, over 6,000 oiled birds, mostly common murres, and scattered tarballs have been collected systematically on sandy beaches from Bodega to Monterey Bay. Much of the oil may come from cleaning tanks of vessels or discharging bilge water prior to entering the San Francisco Bay. In addition, two moderate oil spills were associated with the *Command* and *Cape Mohican* during this period of time, and the sunken vessel, the *Jacob Luckenbach,* was confirmed to be the source of several spills.

Many seabirds directly suffer from the harmful effects of fishing gear, such as gillnetting and long-line fishing. Gillnet fishing in the north Pacific Ocean contributes to the mortality of various species, including common murre, sooty shearwater, and storm-petrels. Unusually high mortality of common murres from November 1997 through March 1998 may have been associated with a simultaneous increase in set gillnet fishing in southern Monterey Bay, as well as other factors. About 235,000 sooty shearwaters were killed by the north Pacific squid fishery in 1990.

During the last 150 years, many pinnipeds were hunted to near extinction, but effective protection has helped to restore some of these species. The population of northern elephant seals increased dramatically from less than 100 individuals to approximately 150,000 individuals today. The harbor seal population increased at a rate of 3.5% per year between 1982 and 1995, and by 2000 had grown to at least 28,000 individuals. In addition, the California sea lion population, increasing between 5% and 6.2% per year, grew to approximately 210,000 individuals by the year 2000. However, steller sea lions have not recovered; over the last 30 years the population has declined by 80% and currently numbers approximately 500 individuals in California. The northern fur seal population also has not fully recovered from the effects of hunting during the last century. However, the population is increasing and in 1997 a small colony resumed breeding on the South Farallon Islands during the summer.

Numerous factors, including hunting, exposure to pollutants, toxins, fishing gear, collision with boats, decline of prey, and disease, contributed to historical declines of pinnipeds, and some of these factors continue to affect pinniped populations. Marine mammals were fully protected from hunting in 1972, with the passage of the Marine Mammal Protection Act. However, some pinnipeds are killed incidentally by entanglement in fishing gear, particularly set and drift gillnets. Pinnipeds may be deliberately shot to protect some fisheries, or for use as crab bait. Occasionally pinnipeds (particularly harbor seals and northern elephant seals) may be injured or killed by collisions with boats or cars. Northern elephant seals, particularly those that haul out at Point Piedras Blancas, occasionally move onto the coastal highway where they may be injured by cars. In order to reduce the numbers of pinniped injuries and deaths, fences have been erected around many of the beaches where pinnipeds haul out to rest, molt, mate, and have their young.

Pinnipeds and seabirds are vulnerable to accumulation of toxins, such as organochlorines and domoic acid, which is produced during harmful algal blooms. Organochlorines, domoic acid, and other toxins are filtered from the water by plankton and various filter-feeding invertebrates, such as mussels and clams, and subsequently ingested by other invertebrates, and fishes. The toxins become concentrated in organisms, such as marine mammals and seabirds, that consume large quantities of plankton, invertebrates, and fishes that carry the toxins. Organochlorines, such as PCBs and DDT, are highly lipophilic and persistent, and thus have accumulated in the marine food chain for several decades since their development and application. Levels of domoic acid increase with blooms of diatoms, such as *Pseudo-nizschia* spp., that produce domoic acid. These harmful algal blooms are associated with increased nutrient-rich freshwater input. Accumulation of low levels of these toxins may cause disorientation and neurological disorders among marine mammals and seabirds, whereas accumulation of high levels of these toxins is lethal.

Viral and bacterial diseases may contribute to pinniped mortality, particularly when pinnipeds are physiologically stressed. All marine mammals are vulnerable to bacterial pneumonia and salmonella. Salmonella is an opportunistic pathogen that may be normally found in healthy animals but may cause disease in stressed animals. *Leptospirosis* occurs mainly in California sea lions, but has been found in other pinnipeds. *Leptospirosis* can damage kidneys and eventually cause kidney failure. The disease is likely transmitted to sea lions through agricultural and sewage runoff. Vulnerability of pinnipeds to viral and bacterial diseases depends, in part, on the pinniped density and food availability. Large populations of pinnipeds struggling to survive during periods of food scarcity are likely to contract viral and bacterial diseases.

Decline of primary prey may contribute to mortality or reduced breeding success of pinnipeds. California sea lions suffer increased mortality during El Niño events due to reduced food supply. The Steller sea lion decline followed a major decline in their primary prey (sardine) in the 1950s. Food shortages mainly affect the reproductive potential of young females and the survivorship of juveniles.

Some gaps in ecological knowledge about offshore islands

The ecology of offshore islands is fairly well known because islands are accessible and have been inhabited by humans and studied for many years. Scientists have identified a variety of physical and biological factors that influence the structure of communities on offshore islands. Our current understanding provides the foundation for further investigation of these complex and isolated communities. For example, although population sizes and trends may be known, the factors that limit population size on islands are not fully understood. Food availability may limit island populations; however, around the Farallon Islands, where food is abundant, space for foraging may limit population sizes. Human activities and natural processes have caused declines and increases in various invertebrate and fish populations. Because seabirds and marine mammals depend on invertebrates and fish for food, changes in the population sizes of prey species are likely to have indirect effects on predators. Populations of some seabirds have declined steadily during the past century. For some species, such as sooty shearwaters, the local decline may be attributable to changes in spatial distribution or may reflect significant changes in demographic rates.

X. Biogeographic Distributions

Because oceans are interconnected, many marine species have continuous and broad distributions. Climatic barriers, biotic factors, the absence of a required habitat, and barriers to dispersal, operate to influence the boundaries of these distributions. Differences in physiological tolerances and ecological relationships result in unique distributions for many species. In other cases, a large number of species share similar patterns of distribution. These shared borders, known as biogeographic boundaries, mark the transition between areas dominated by distinctly different suites of species. On a large scale, the distributions of many species found in the north Pacific extend as far south as Point Conception or even Baja California, whereas the distributions of many species found off southern California extend as far north as Vancouver Island or the Gulf of Alaska.

Biogeographic transitions often correspond to major coastal or oceanographic features. The biogeographic boundary at the Gulf of Alaska occurs at the abrupt transition between sea and land along the south coast of Alaska. The Aleutian Islands mark the transition between the Alaskan Current in the Gulf of Alaska and the Alaskan Coastal Current and Alaskan Stream in the Bering Sea. Although this oceanographic shift is the northern boundary of many taxa, the distributions of some species, particularly marine birds and mammals, extend north from the Gulf of Alaska, around the Aleutian Islands, and into the Bering Sea. Another biogeographic transition, near Vancouver Island, corresponds to the eastern portion of the North Pacific Drift, which is diverted north into the Gulf of Alaska as the Alaskan Current and south along the western coast of North America as the California Current. The California Current is the dominant eastern boundary current from Vancouver Island to Mexico. At Point Conception in southern California, the cool water of the California Current intersects the relatively warm water of the California Countercurrent, which flows north along the coast of southern California. The intersection of these currents corresponds to a significant biogeographic boundary. South of Point Conception the intensity of coastal upwelling decreases, resulting in warmer and less nutrient-rich surface waters.

Substrate type and depth strongly influence species composition in a particular area. For example, kelp forest communities are associated primarily with shallow rocky substrate, which provides surface to which kelp can attach. Shallow subtidal invertebrates, such as clams, are associated with soft sediments where they burrow into the substrate for protection from predators or from the constant agitation caused by waves.

Major gaps between patches of a particular substrate may affect the potential for interactions among individuals of one or several different species associated with that substrate. For example, the extensive sandy seafloor of Monterey Bay could inhibit the dispersal of species associated with rocky reefs that cannot move long distances as either adults or pelagic larvae. South of Monterey Bay, the dominant alga in shallow water is giant kelp, whereas north of the bay the kelp forests are more commonly dominated by bull kelp. In addition to marking the transition in the dominant kelp species, Monterey Bay forms the northern boundary of about 50 species of benthic marine algae and the southern boundary of about the same number of species. The bay is also a substantial barrier for about 100 species of marine benthic invertebrates. Additional research is necessary to identify the causes of these biogeographic patterns.

Various physical factors influence species composition along a gradient of depth from the intertidal to the deep sea. In the intertidal zone of both rocky habitats and sandy beaches, exposure and inundation constrain the upper and lower limits of species' ranges. Few marine algae, gastropods, and fishes persist in the high intertidal zone, where nutrient input is relatively low and organisms are exposed for prolonged periods of time. Complex intertidal communities inhabit the middle and low intertidal zones where production is higher and exposure to the drying effects of the sun is reduced. High density and species diversity contribute to intense interspecific interactions (e.g., predation, competition) in the low intertidal zone. High intertidal communities tend to be structured primarily by interactions between an organism and its physical environment, whereas interspecific interactions strongly influence the structure of communities in low intertidal habitats.

Levels of light, temperature, and pressure, among other factors, influence the structure of marine subtidal communities. High levels of light penetrate the shallow subtidal zone, warming surface waters and stimulating growth of photosynthetic organisms. The zone of maximum algal production occurs between the intertidal and 30 m depth. High production in this zone concentrates invertebrates, fishes, marine mammals, and seabirds that use the algae for food and shelter. Production decreases with depth as light levels diminish. Conditions of darkness, intense pressure, and near freezing temperatures in the deep sea limit the numbers of species that live there, the density of organisms, and their rates of growth and reproduction. Many species that live in the deep sea as adults produce larvae that drift in surface waters where temperatures are higher, pressure is lower, food is abundant, and the conditions, in general, support more rapid growth.

Biogeographic Distributions of Benthic Marine Algae

The most comprehensive historical study of California marine algae identified two primary biogeographic barriers along the California coast: Point Conception and Monterey Bay. In California, the largest percentage of algal range endpoints occurred near Point Conception and the Southern California Islands (33-35°N). Approximately 20% of the algal range endpoints in California occurred in the vicinity of Monterey Bay (36-37°N).

More recent and comprehensive analysis of marine algae along the west coast of North America (D. Sax, unpublished data) indicates that there are several important biogeographic transitions (*Figure 9: Algae Range Endpoints*), including Prince William Sound (60.5°N), the Strait of Juan de Fuca (48.5°N), Monterey Bay (36.5°N), the Channel Islands, and Point Conception (33-34°N). The database includes 749 species of algae. Information about each species was gathered from primary literature and includes the northern and southern range endpoints to the nearest 0.5° latitude. The most important range endpoint for marine algae is Prince William Sound, which is a northern barrier to 164 species. Another major transition occurs at the California Channel Islands and Point Conception (33-34°N), which are the northern range endpoints for 143 species and the southern range endpoints for 92 species. Vancouver Island (48-49°N) is a transition for 77 species that occur north and 63 species that occur south of this island. Monterey Bay is another important transition for 49 species that occur north and 48 species that occur south of the area.

Recently, the relationship between depth distribution and latitudinal gradient for 460 species of marine algae off the western coast of the United States and Canada was investigated. The changes in algal species composition and abundance are associated with physiological tolerances for temperature, exposure, and nutrient input. At all latitudes, the average number of species increased with depth from high to low intertidal and subtidal zones. In addition, species that occur across several depth zones are likely to have broader latitudinal distributions than species that occupy a single depth zone. Species that occur across a wide range of depths are likely to possess a broad range of physiological tolerance and thus may be distributed widely along the coast.

Biogeographic Distributions of Marine Invertebrates


Cordell Bank Expeditions

Historical studies indicate that biogeographic distributions of marine benthic invertebrates are characterized by relatively distinct boundaries at oceanographic barriers. Within California, Point Conception and Monterey Bay are recognized as biogeographical boundaries for shallow-water benthic molluscs, ascidians, crabs, and molluscs. A closer look at the Point Conception breaks shows concurrent range endpoints at both San Clemente Island (33°N) and the northern Channel Islands (34°N) for marine molluscs. Major biogeographic barriers for eastern Pacific molluscs from Alaska to Baja California occur at Vancouver Island (48-49°N), the northern Channel Islands (34.4°N), and Punta Eugenia (28.2°N).

More recent analysis of marine benthic invertebrates along the coast of California (G. Eckert, unpublished data) suggests similar biogeographic patterns (*Figure 10: Invertebrate Range Endpoints*), with significant transitions at San Diego (32.5°N), the Channel Islands/Pt. Conception (33-34.5°N), and Monterey Bay (36.5°N). Additional biogeographic transitions occur at Vancouver Island (49.5°N) and the Aleutian Islands (53°N). The database used in this analysis includes 539 species of marine benthic invertebrates from the coast of California. Information about each species was gathered from the primary literature and includes the northern and southern range endpoints to the nearest 0.5° latitude. The most significant range endpoints for marine benthic invertebrates are San Diego (32.5°N), which is the southern range endpoint for 109 species, and Monterey Bay (36. 5°N), which is the northern range endpoint for 64 species and the southern range endpoint for 40 species. Another important biogeographic transition occurs in the vicinity of the Channel Islands/Pt. Conception (33-34.5°N), which forms the northern biogeographic boundary for 85 species and the southern biogeographic boundary for 72 species. Vancouver Island is the northern range endpoint for 55 species of marine benthic invertebrates and Sitka is the northern range endpoint for about 50 more. Additional data (K. Roy, unpublished data) emphasizes the biogeographic transitions occurring at Point Conception and Monterey Bay. These data includes absolute ranges of both gastropods (prosobranchs only) and bivalves and spans the area from the Mexican to Canadian borders.

In addition to changes in latitudinal distributions, the community composition of marine gastropods changes with increasing depth. Marine gastropods can be separated into three main groups that are characteristic of the euphotic zone (0-40 m), continental shelf (40-200 m), and continental slope (>200 m). An investigation of depth distribution and latitudinal gradient for 163 gastropod species revealed greater species numbers in the euphotic zone and continental shelf than the continental slope across all latitudes. Like marine benthic algae, gastropod species that occur across several depth zones are likely to have broader latitudinal distributions than species that occupy a single depth zone.

Biogeographic Distributions of Pacific Coast Fishes


Cordell Bank Expeditions

A sample of 294 Pacific coast fishes exhibits three major biogeographic transitions along the coast of California at San Diego (32.5°N), the Channel Islands/Pt. Conception (33.5-34°N), and Monterey Bay (36.5°N; *Figure 11: Fish Range Endpoints*). San Diego is the northern range endpoint for 20 species of Pacific coast fish and the southern range endpoint for 36 species. The Channel Islands/Pt Conception region is the northern range endpoint for 67 species of Pacific coast fishes and the southern range endpoint for 32 species. Another important biogeographic transition occurs at Monterey Bay, which is the northern range endpoint for 31 species of Pacific coast fishes and the southern range endpoint for 13 species. A few minor shifts in species composition occur at the Aleutian Islands (54°N), Kodiak Island (57.5°N) and Prince William Sound (60.5°N).

Two orders dominate the sample of fishes of the eastern Pacific coast: perch (Perciformes, N=122) and rockfish (Scorpaeniformes, N=78). Each of these orders exhibits different biogeographic patterns. Perch are generally distributed south of Point Reyes, which is the most distinct biogeographic transition among members of this taxon. In contrast, Scorpaeniform fishes are distributed widely along the western coast of North America, from Baja California to the Bering Sea.

In addition to the changes in latitudinal distributions, the composition and abundance of fish species changes with increasing depth. In contrast to the patterns observed for marine algae and gastropods, an investigation across 234 fish species along the west coast revealed species numbers declining with latitude and depth. The greatest numbers of species occurred south of 50°N latitude and shallower than 200 m.

Biogeographic Distributions of Seabirds and Shorebirds


Gulf of the Farallones National Marine Sanctuary

The distributions of most seabird and shorebird species found in central California extend from the Gulf of Alaska to Mexico (*Figure 12: Seabirds and Shorebirds Range Endpoints*). The database used for this analysis includes 132 shorebirds and seabirds. Information about each species was gathered from field guides and includes the northern and southern range endpoints to varying intervals of latitude. Unlike the datasets above for seaweeds, invertebrates, and fish, range descriptions for many bird species often list boundaries that are broad regions rather than specific locations (e.g., Bering Sea or Mexico). As a result, plotting range boundaries within 0.5° latitudinal bins would not be justified. Therefore, for birds we used a more conservative approach and plotted boundaries within broader 2° bins. Most of the northern range limits occurred in the Gulf of Alaska and Bering Sea, whereas most of the southern range limits occurred in Mexico. Although the central and northern coast of California does not present a significant biogeographic barrier for most seabirds and shorebirds, ranges of a few species end in this region. Central California is the northern endpoint of the distributions of four species (black-vented shearwater, least bittern, black storm-petrel, and clapper rail) and northern California is the northern endpoint of the distributions of the elegant tern and ashy storm-petrel. Although most seabird and shorebird species extend as far south as Baja California or Mexico, the southern endpoint of the distributions of few species occur in central California. San Francisco is the southern endpoint for one species, long-tailed duck, and Santa Cruz is the southern endpoint for five species, including Barrow's goldeneye, harlequin duck, and yellow-billed loon.

Biogeographic Distributions of Marine Mammals

Local oceanographic patterns and habitat features generally do not constrain the distributions of large marine mammals. Instead, annual cycles of productivity and physiological limitations of their young influence the distributions of marine mammals. The majority of marine mammals in the eastern Pacific Ocean are distributed widely along the western coast of North and South America (*Figure 13: Marine Mammals Range*

Endpoints). The database used for this analysis includes 49 marine mammal species. Information about each species was gathered from field guides. As with the bird data, several range boundaries were listed as moderately larger regions. Therefore, the boundaries are lumped into 2° bins. The distributions of the majority of eastern Pacific marine mammals (16 species) extend south from the Bering Sea or Gulf of Alaska. Many range as far south as the equator. A few delphinid species, including the melon-headed whale, pygmy killer whale, false killer whale, short-finned pilot whale, and striped dolphin, typically are found in waters south of Point Reyes. Two species, the pygmy sperm whale and rough-toothed dolphin, are found as far north as northern California. The distributions of two species, the dwarf sperm whale and northern right whale dolphin, extend as far north as British Columbia. Five species (northern right whale dolphin, Dall's porpoise, harbor porpoise, Hubb's beaked whale, and Stejneger's beaked whale) occur in the north Pacific, rarely traveling south of the Channel Islands.

Pinnipeds exhibit wide distributions from Alaska to central or southern California and Baja California. Harbor seals are widespread in coastal habitats of the Northern Hemisphere. California sea lions are found from Vancouver Island, British Columbia to the southern tip of Baja California in Mexico. Most of the population of steller sea lions is in the Gulf of Alaska and the Bering Sea, but small populations are found along the coast as far south as central California. Northern elephant seals are distributed from the Aleutian Islands to Baja California. Although most of the worldwide population of northern fur seals is found on the Pribilof Islands, a small number of northern fur seals is found on Bogoslof Island in the southern Bering Sea, San Miguel Island off southern California, and the Farallon Islands.

Summary of Biogeographic Distributions

Marine organisms of the northeastern Pacific Ocean, including plants, invertebrates, fishes, birds, and mammals, share important aspects of their geographical distributions. For many taxa, biogeographic boundaries coincide with major oceanographic shifts, such as the bifurcation of currents or the intersection of two bodies of water. The majority of species in the study area occur in suitable habitats along the coast from the Gulf of Alaska to Point Conception. The distributions of some species are confined to the waters south or north of Vancouver Island, where the North Pacific Drift flows toward the coast, and is bifurcated to become the southward-flowing California Current. Other minor biogeographic transitions occur near major bays and points along the coast, including San Francisco, Monterey, and Santa Monica bays, and Point Arena, Point Reyes, and Point Año Nuevo.

For some species, an individual range includes the entire geographical distribution of the species. These species use local resources during long-distance migration, but no individual site supports a resident population. Examples of these species include baleen whales that feed at highly productive sites along their migration route, and seabirds that use estuaries along the coast as resting and feeding sites during their annual migrations.
For other species, the entire geographical range far exceeds the range of an individual. Many intertidal invertebrates and fishes have dispersal and sedentary phases during their

life cycles. Examples of these species include barnacles that settle into intertidal habitats, and rockfish that settle into kelp forests or rocky reefs after a pelagic larval stage.

XI. Conclusions

Marine ecosystems off central and northern California are among the most productive in the world, supporting a great diversity of intertidal and subtidal communities. The structure of these communities depends on complex and dynamic interactions between physical and biological variables. Each community is unique despite the fact that similar oceanographic and ecological processes influence all communities off central and northern California. The California Current flows southward, gathering and distributing nutrient-rich waters from upwelling centers along the coast. Within the California Current System, various communities form according to physiological needs of individual species for light, substrate type, and nutrients. Species' distributions are limited by physiological tolerance along gradients of temperature and pressure, among other physical factors. Particularly diverse communities form in highly productive habitats, such as the low intertidal zone and kelp forest. Competition for resources and predation are primary ecological linkages within and between these communities. Some communities form under highly specialized conditions, e.g., low nutrient, low light, and high pressure. In such cases, physical factors are likely to influence community structure more than interspecific interactions. The structure of marine communities is complicated further by natural perturbations and human activities. The following section describes the basic ecological linkages within and between marine communities off central and northern California.

Ecological linkages within and between communities

The eastern Pacific Ocean is among the most productive of the world's oceans due to persistent upwelling of nutrient-rich water. Along the central coast of California, upwelling centers are located near Points Arena, Reyes, Año Nuevo, and Sur. Upwelling occurs when strong southerly or westerly winds force surface waters offshore. This process influences the distribution of larvae in surface waters as they are transported far offshore when these waters are displaced during upwelling. Relaxation of upwelling-favorable winds also influences the distribution of larvae; those entrained in waters offshore may be transported back to the coast where they are likely to settle. Pulses of recruitment, e.g., of sea urchin larvae, are closely associated with the patterns of upwelling and relaxation.

Nutrient-rich waters drawn to the surface through the process of upwelling, combined with sunlight in surface waters, support the basis of the marine food web: phytoplankton. Chlorophyll production, an indication of phytoplankton growth, is concentrated around upwelling centers and lags slightly behind the onset of upwelling. Maximum chlorophyll production tends to occur in July and August after several months of persistent upwelling. Phytoplankton blooms attract planktivorous species, including zooplankton, euphausiids, and some fish. In turn, these organisms attract a variety of predators, including larger invertebrates, fish, marine mammals and seabirds. Upwelling centers provide important feeding grounds for baleen whales during their migration. However, production varies from year to year, and whales, and other species, may concentrate their feeding efforts at the most productive locations. In some cases, during particularly productive years, whales may remain in the vicinity of an upwelling center, without completing the northward migration.

Physical features also affect the distributions of plankton, euphausiids, other invertebrates, and fish larvae. Some deep-sea species express diel vertical migration. As they rise from deeper waters of submarine canyons to surface waters where they feed, these organisms may be transported on currents and trapped in the shallow waters over the continental shelf in the vicinity of the canyons or above submerged banks. This concentration of food in the water column likely attracts predators, including baleen whales and seabirds.

Nutrients cycle through the marine food web, and eventually to the deep sea where they are consumed or buried in sediments on the sea floor. Communities that live on the continental slope and in the deep sea depend on the distribution and quantity of primary production and the rate of movement of organic material to the bottom. Temporal and spatial variations of deep-sea communities correspond to changes in surface production. The amount of organic material reaching the sea floor in the northeastern Pacific Ocean (5-15% of surface production) is greater than in other parts of the world’s oceans (3-5%) due to substantially higher production near coastal upwelling centers. The distribution of deep-sea organisms is patchy and centered around sources of nutrients and organic material.

Rivers carry fresh water, nutrients, and sediments from watersheds to coastal wetlands and, eventually, to the ocean. The structure of habitats near a river mouth depends, in part, on the type of sediment carried by the river and deposited in lagoons, estuaries and on beaches. Historically, rivers transported far more sediment than today. Dams, which have been built on nearly all major rivers in central and northern California, reduce the sediment load in rivers and inhibit the movement of freshwater and anadromous species. All salmon species in central California have declined substantially and some populations are extinct, in part as a consequence of habitat destruction and modification.

Freshwater plumes, which originate at river mouths, may extend far offshore into the marine environment. During months of heavy rainfall and snowmelt, a freshwater plume from the San Joaquin and Sacramento rivers frequently extends across the San Francisco Bay and into the Gulf of the Farallones. Signatures of this plume have been detected as far south as Point Conception. Fresh water alters the salinity, temperature, and nutrient content of seawater. During periods of intermittent upwelling, nutrient input from the San Francisco Bay Plume contributes substantially to production in the Gulf of the Farallones.

Life history characteristics affect the distribution of species, and thus, the structure of communities. Some species complete their life cycles within a single habitat. However, most marine species, including such diverse species as jellyfish, sea urchins, and rockfish, have both sedentary and dispersal phases during their lives. Dispersal of most marine species occurs during the larval stage, during which microscopic larvae may drift long distances from their natal sites. The larvae of many species settle and grow in habitats different from those they inhabit as adults. Estuaries are important nursery areas for larvae and juveniles of many marine fishes that eventually move into deeper waters. Larvae of sea urchins and mussels drift in surface waters for months before they settle in rocky intertidal habitats. Anadromous species, such as salmon, are the most extreme examples of separation of larval and adult habitat. Competition between adults and larvae for food and shelter are reduced by these differences in habitat requirements.

Some species, including a large number of marine birds and mammals, are migratory and thus, use a network of habitats as they travel between feeding and breeding grounds. Millions of migratory shorebirds rely on wetlands scattered along the coast from Alaska to South America. Migratory bird populations have declined with the loss of wetlands due to extensive coastal development. Baleen whales rely on scattered concentrations of krill and small fishes; the location of these concentrations may vary from year to year, but a subset of these is necessary to support the energetic needs of migrating whales.

Species that have similar requirements for food and shelter are likely to compete for these resources. Under natural selection, differences between species become magnified such that each species occupies a particular niche. Competition among marine organisms is evident in highly productive regions, such as estuaries, the low intertidal zone of sandy beaches and rocky coasts, and kelp forests. Interspecific competition occurs in these habitats, in part, because numerous species are attracted to the same abundant resources.

Predation may contribute to species diversity by controlling the abundance of superior competitors and allowing inferior competitors to exploit a shared resource. Some marine habitats are strongly influenced by apex predators. The quintessential example is the role of sea otters in structuring the kelp forest community. Sea otters consume invertebrate herbivores, including sea urchins and abalone, that consume kelp. By controlling the abundance of these herbivores, sea otters indirectly affect the abundance of kelp, which provides food and shelter for a complex community. In contrast, in southern California, where otters were exterminated in the mid-1800s, fishing controls the abundance of sea urchins and abalone.

The direct effect of predation itself structures some marine communities. In the rocky intertidal zone, predation by ochre stars controls the lower boundaries of mussel beds. Predation by sea otters likely contributes to local extirpation of some species, particularly those that already have been fished to low levels, such as abalone and Pismo clams. Otters are effective predators on clams and have caused the systematic decline of bivalve populations with their southward expansion. Human predation on marine organisms has contributed to systematic declines of many marine species; the most significant declines in central and northern California include salmon, sardine, rockfish, sea otter, pinnipeds, and whales.

Natural perturbations to marine and estuarine communities

The dynamic patterns of weather strongly influence the structure of marine communities. Large storms, which generally occur in the northeastern Pacific Ocean between November and March, can alter or completely transform marine communities. Powerful waves can displace marine organisms and tear marine plants from the substrate. Some of the organic material that accumulates on the surface of the ocean during large storms is transported to the shore and deposited in the intertidal zone. Plankton, detached marine algae, and carcasses of marine organisms wash ashore during large storms, providing additional nutrients to intertidal communities. However, in some cases, large storms may have the opposite effect on intertidal communities. Waves generated during large storms may remove sand or cobble from beaches, causing dramatic shifts in the distribution and composition of beach organisms. Sands are deposited on the beach during the summer when the wave action is reduced.

Every three to four years, a massive Kelvin wave, generated in the western Pacific Ocean, moves eastward, carrying warm surface waters and depressing the thermocline in the eastern Pacific. This event, driven by the El Niño-Southern Oscillation, has substantial effects on productivity and survivorship of marine organisms in the eastern Pacific Ocean. Although these effects are strongest off the coast of Peru and Equador, the impact of El Niño extends north along the coast central and northern California. Depleted surface waters inhibit phytoplankton growth, leading to an overall decrease in productivity. Survivorship and reproductive success of planktivorous invertebrates and fishes decrease with plankton abundance. Marine mammals and seabirds which depend on these organisms for food, suffer food shortages, leading to widespread starvation and decreased reproductive success. In addition to changes in demographic rates, the geographic distributions of species may shift during El Niño. For example, subtropical and warm temperate species, such as pelagic red crabs, may be carried on warm surface waters north to Monterey or San Francisco bays.

Every 20-30 years, the surface waters of the central and northern Pacific Ocean shift several degrees from the mean temperature. Such shifts in mean surface water temperature, known as the Pacific Decadal Oscillation, have been detected 5 times during the past century, with the most recent shift in 1998. The Pacific Decadal Oscillation impacts productivity of the eastern Pacific Ocean. Between 1977 and 1998, surface water temperatures were warmer than average and chlorophyll production decreased steadily during this period. In addition, the lowest macrozooplankton biomass of central California was recorded in 1998. In the same year, the average surface water temperature off the coast of Oregon dropped several degrees centigrade, leading to increased phytoplankton production and extraordinary recruitment of intertidal invertebrates. The shift in water temperatures off central and southern California has not been as dramatic and an increase in chlorophyll production has not yet been detected. However, since the shift to cooler water conditions, macrozooplankton in the central Pacific rebounded greatly to values near the 1951-84 long-term mean.

Growth and survival of upper trophic level species are affected directly by changes in primary productivity or indirectly through cascading changes to intermediate trophic levels. A period (1976-1978) of exceptional production for fishes off the Pacific coast from California to the Bering Sea may be associated with interdecadal changes in primary and secondary production. Since the late 1970s, Alaskan salmon catches and coastal sea surface temperatures remained above average, whereas populations of coho and chinook salmon declined. Sardine and anchovy population dynamics are closely associated with the Pacific Decadal Oscillation: anchovies replaced sardines during the 1950s and the trend reversed with the decadal shift to warm waters in the late 1970s. Similar oscillations between anchovy and sardine populations over a period of 1,500 years are evident in the paleontological record of fish scales on the sea floor. Climate-driven changes at lower trophic levels have significant impacts on seabirds and marine mammals. Seabird abundance has declined substantially within the California Current since the late 1970s. The decline is primarily a consequence of a 90% decline in numbers of sooty shearwaters. However, other species, including the Cassin's auklet, have decreased, in part, due to shifts in availability of prey species.

Ocean waters off the coast of California have warmed considerably over the last 40 years and it is not yet clear whether these changes are a consequence of an interdecadal climate shift or global warming. Some species have shifted their geographic ranges northward in response, altering the composition of local assemblages. For example, an assemblage of rocky intertidal invertebrates from Monterey Bay shifted over 60 years to include a greater number of southern species and fewer northern species. Composition of reef fish in southern California changed with ocean warming in a similar manner; dominance shifted from cold- to warm-water species. It is unclear how these ecological changes will be affected by the combination of apparent global warming, a shift to cooler waters with the Pacific Decadal Oscillation, and the likely onset of El Niño during 2002-2003.

Human impacts on marine and estuarine communities

Over the last 150 years, humans have modified the coastal and marine landscape. Coasts are being reinforced and filled to accommodate expansion of agriculture, industry, and residential districts. Over 90% of California's coastal wetlands have been converted, and less than 5% of the state's coastal wetlands remain intact. Structures such as wharves, piers, seawalls, and breakwaters, influence water currents, flushing, sedimentation, and sediment transport. Dredging may cause significant negative impacts to marine life, including the loss of benthic habitat and potential injury or death of sessile benthic species. Sediments are being removed from lagoons and estuaries, and transported and dumped elsewhere in the ocean. As a result of these activities, habitats that support estuarine and marine communities are changing and disappearing.

Rivers and streams transport pollutants from industrial, agricultural, and urban areas to estuaries, lagoons, and the ocean. Bacteria, viruses, and nutrients may be carried into watersheds from faulty septic systems and from domestic animal waste products. High levels of coliform bacteria occur in estuarine environments and along beaches, particularly after heavy rains. Elevated nutrient content of water can lead to harmful algal blooms and reduced oxygen concentrations. Nutrient input from dairy farms has caused severe oxygen depletion and eutrophication and shellfish contamination in Tomales and Bodega bays. Highly elevated nitrate levels have been found in the Pajaro, Elkhorn Slough, and Salinas watersheds. Agricultural runoff releases DDT into the Salinas River Lagoon and Monterey Bay at levels that have been deleterious to aquatic life. Chlorinated hydrocarbon compounds, primarily from agricultural runoff, accumulate and persist in marine food chains. Known effects of chlorinated hydrocarbons include immune suppression and reproductive failure in pinnipeds, and eggshell thinning in seabirds.

The coast of central and northern California is subjected to the threats of oil spills, and releases of oil and other toxic materials. The primary source of marine contamination is the chronic discharge of oil from tank washing and ballast discharge. The impacts of spilled oil on marine systems vary greatly between sites. Spilled oil readily adheres to vegetation in estuaries and salt marshes, potentially impacting resident invertebrates, fishes, and shorebirds. Organisms living in the beach sands may be smothered by oil in the interstitial water. Numerous species of rocky intertidal habitats may be covered by spilled oil, including barnacles, snails, mussels, clams, crabs, amphipods, polychaetes, and algae. Fish may be attracted to spilled oil because it resembles floating objects that generally provide shelter. Oil adheres to the fur and feathers of marine mammals and seabirds, causing them to lose body heat and suffer hypothermia. The combined effects of oil can result in severe loss of life and slow recovery of coastal and marine systems.

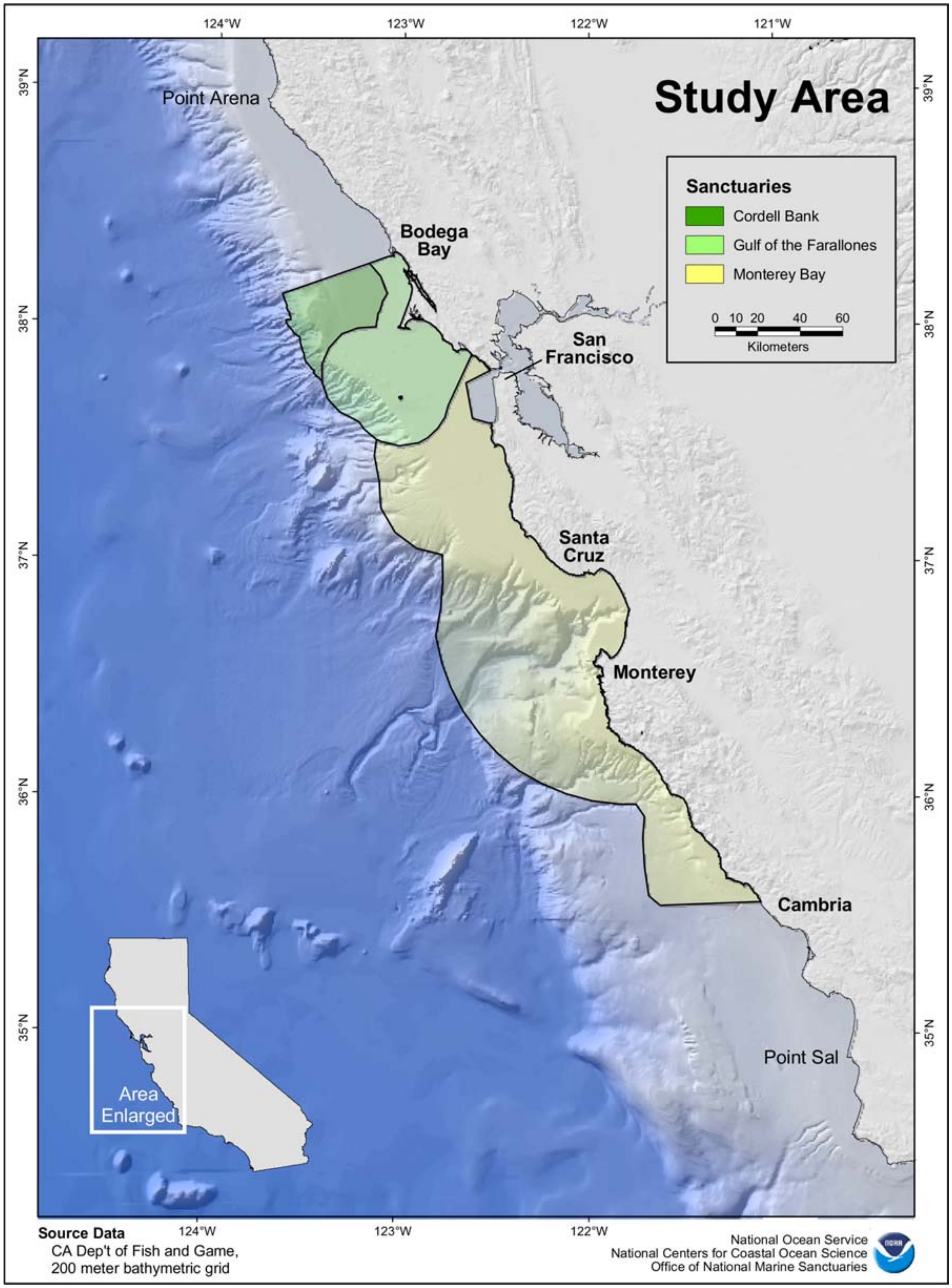
Discharge of ballast water in nearshore waters has introduced many non-native species to estuaries and coastal marine habitats. Commercial vessels are the primary vector for the spread of invasive species. In addition, people may release animals that were purchased for research, restoration, and education. Over 255 invertebrate and numerous plant species have been introduced to the San Francisco Bay, and over 55 to the Elkhorn Slough. Changes in species composition of these sensitive habitats can disrupt nutrient cycles and alter energy flows.

The level of noise pollution in the oceans has increased dramatically during the last 50 years. The primary source of ocean noise is commercial shipping. Many marine mammals respond to noise by altering their breathing rates, spending more time underwater before coming up for air, changing the depths or speed of their dives, shielding their young, changing their song note durations, and swimming away from the area affected by noise pollution. Noise pollution may cause marine mammals and other organisms to have temporary or permanent hearing loss. The disorientation and hearing loss may account for cases in which ships collide with marine mammals that are apparently unaware of the approaching vessel. Most strikes occur in coastal waters of the continental shelf where large marine mammals concentrate to feed.

Large numbers of recreational users are attracted to the spectacular scenery, moderate climate, abundance of marine life, and relatively clean waters of central and northern California. Recreational activities may destroy habitat and reduce survival and breeding success of marine and estuarine organisms. Recreational boaters can potentially disrupt feeding and breeding activities of wildlife, particularly marine mammals and shorebirds. Motorized personal watercraft cause noise pollution and release oil and gas during operation. Large numbers of recreational SCUBA divers may damage rocky reefs, kelp forests, and other subtidal habitats through accidental or intentional contact.

Commercial and recreational fishing has contributed to declines of many marine species. After heavy fishing and environmental fluctuations, the sardine fishery collapsed to relatively low levels in the 1950s. Reduction in fishing effort and a favorable climate shift have contributed to the restoration of the sardine population. Several runs of chinook salmon, coho salmon, and steelhead in central California have been listed as federally endangered and threatened since 1994. Many rockfishes have declined under fishing pressure and several species are considered overfished, including Pacific Ocean perch, cowcod, bocaccio, canary rockfish, yelloweye rockfish and darkblotched rockfish. Hunting of pinnipeds and sea otters for meat and fur in the 1800s and early 1900s contributed to declines of many species, including northern elephant seal, harbor seal, California and steller sea lions, northern fur seal and southern sea otter. Hunting of large whales during the last two centuries nearly extirpated several species, including gray, blue, humpback and fin whales.

Conservation measures have succeeded in restoring some species, including sardine, sea otter, some pinnipeds, and some whales. Restoration of most marine mammal species was achieved by establishing a complete ban on harassment and “take”. Similar measures have been taken to protect some fished species, such as rockfish on the continental shelf, and abalone south of Point Conception. However, few areas exist where the take of marine organisms is completely prohibited. The California Department of Fish and Game is considering additional protection for marine organisms under the Marine Life Protection Act.



Source Data
CA Dep't of Fish and Game,
200 meter bathymetric grid

National Ocean Service
National Centers for Coastal Ocean Science
Office of National Marine Sanctuaries

Figure 1. Seafloor off of northern/central California highlighting the complex bathymetry of the study region from Point Arena to Point Sal.

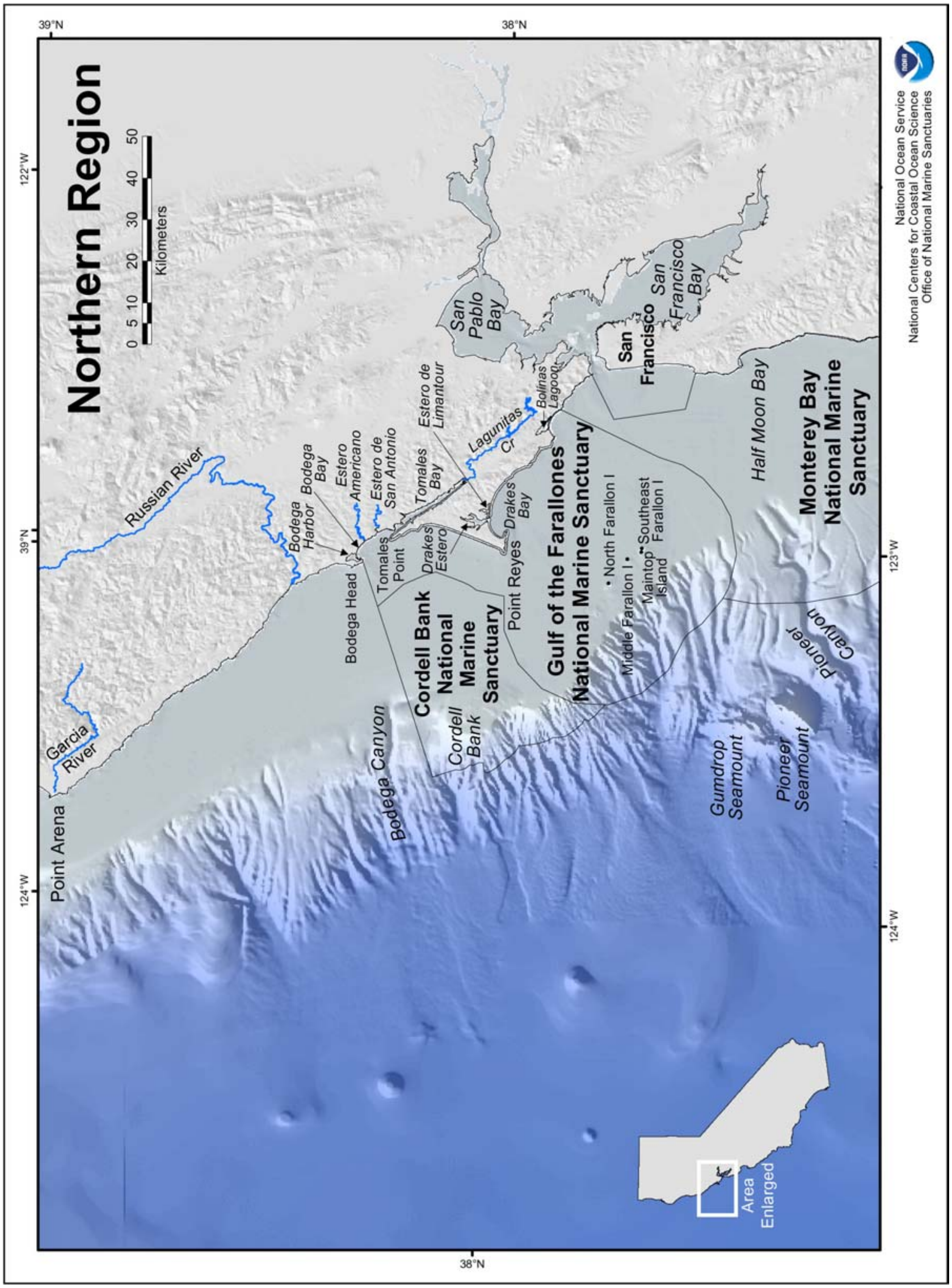


Figure 2. Locator map and regional bathymetry for the northern area of the study region (Point Arena to just south of Half Moon Bay).

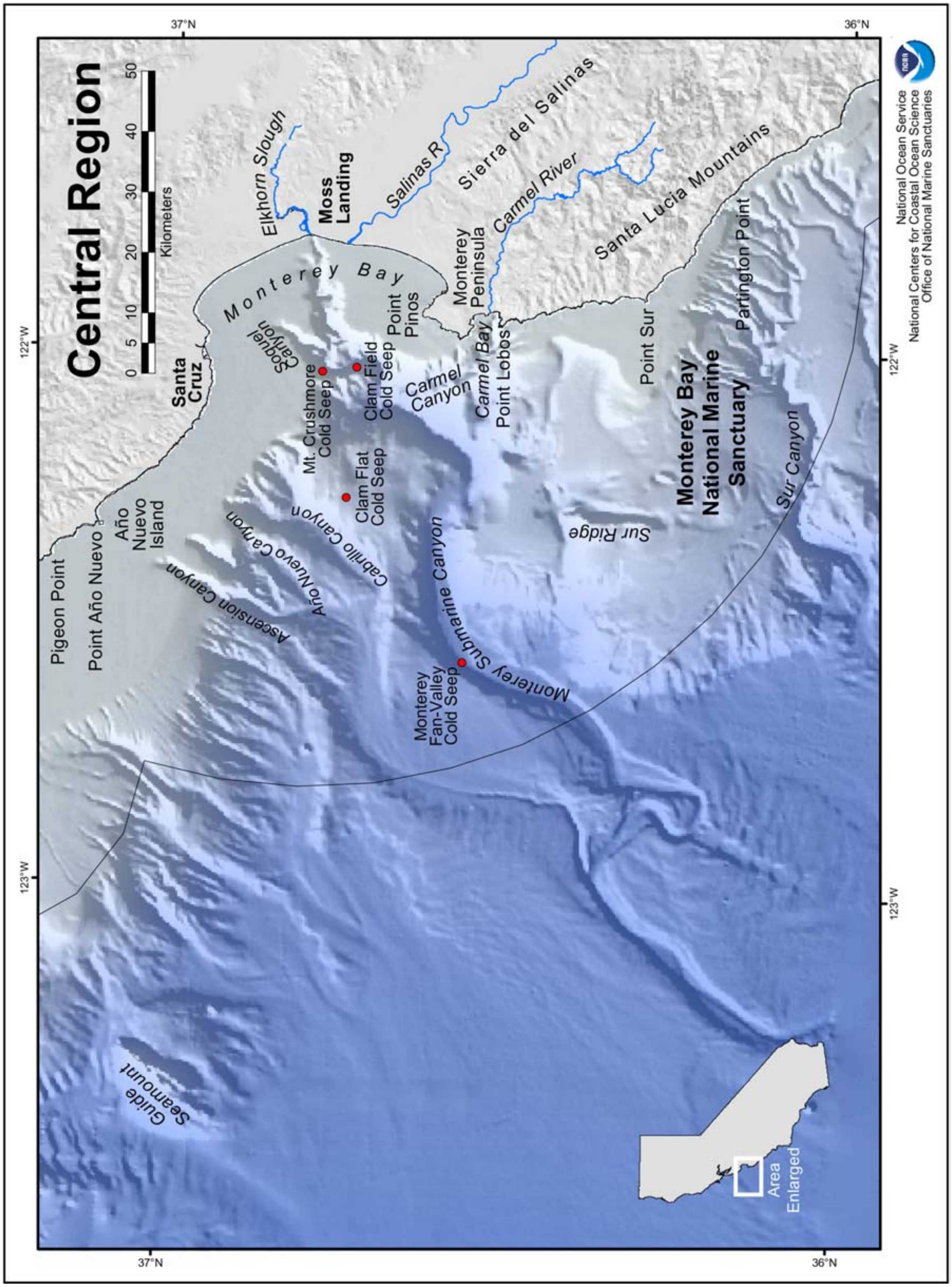


Figure 3. Locator map and regional bathymetry for the central area of the study region (Pigeon Point to just south of Sur Canyon).

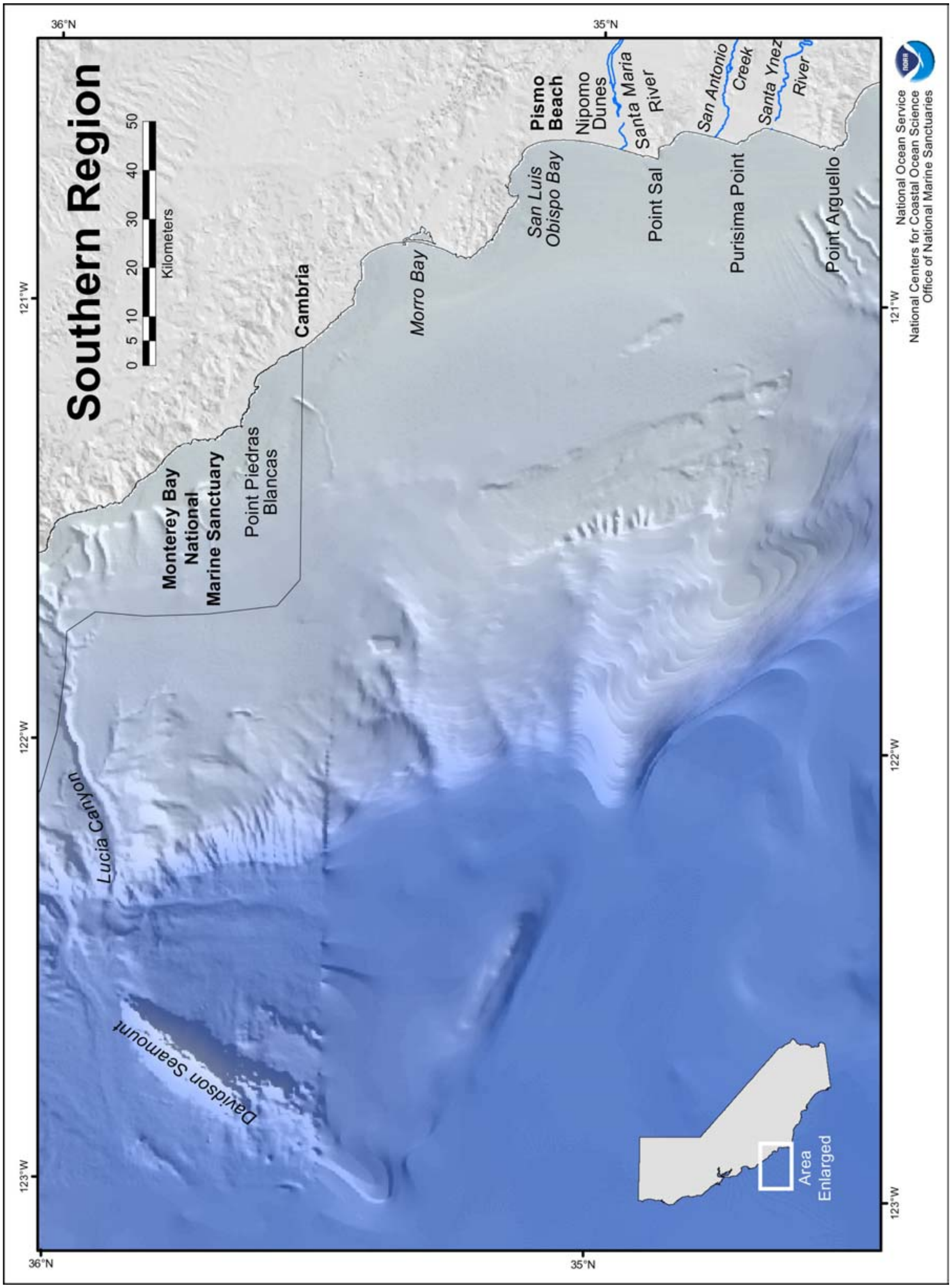
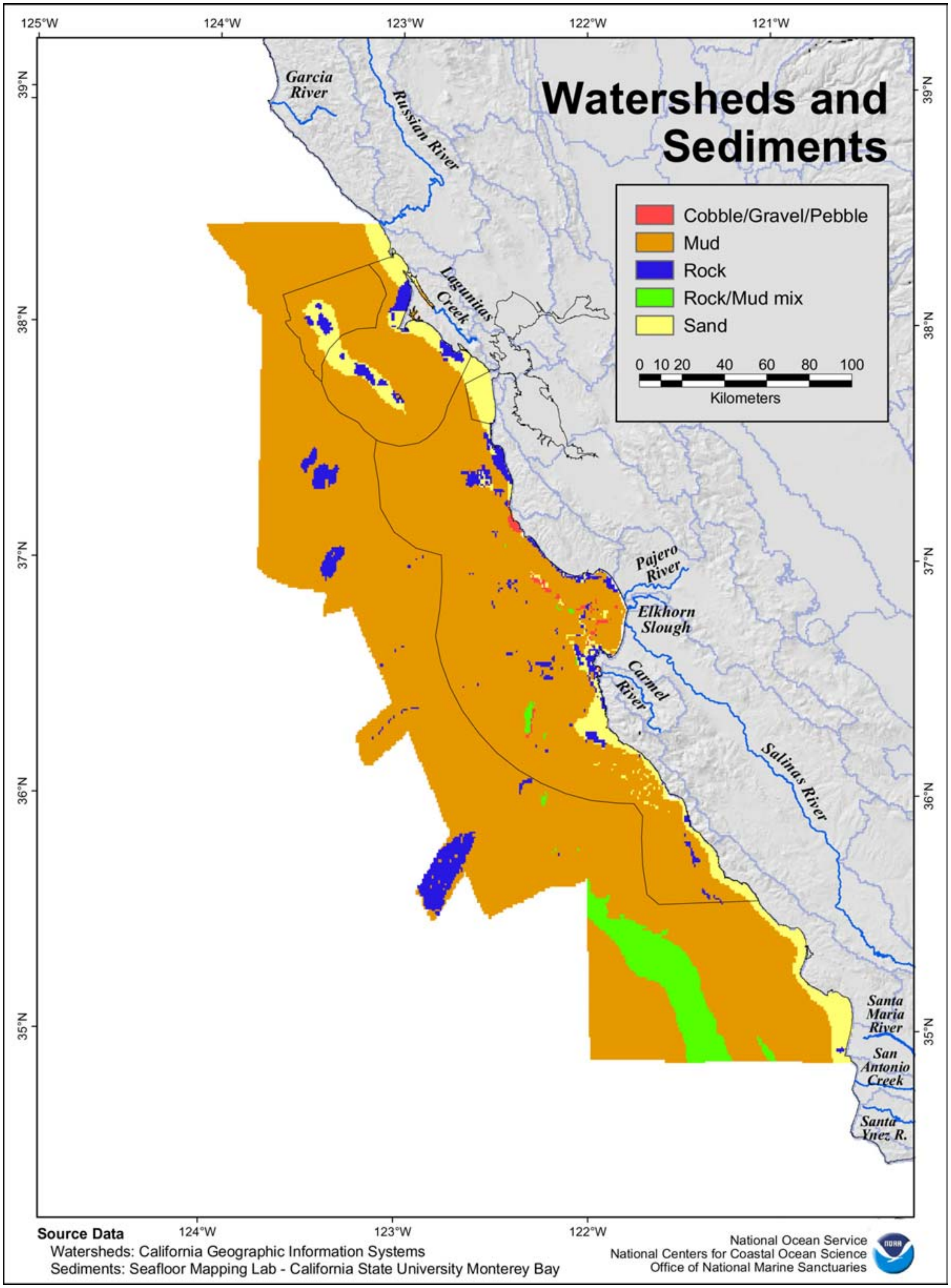
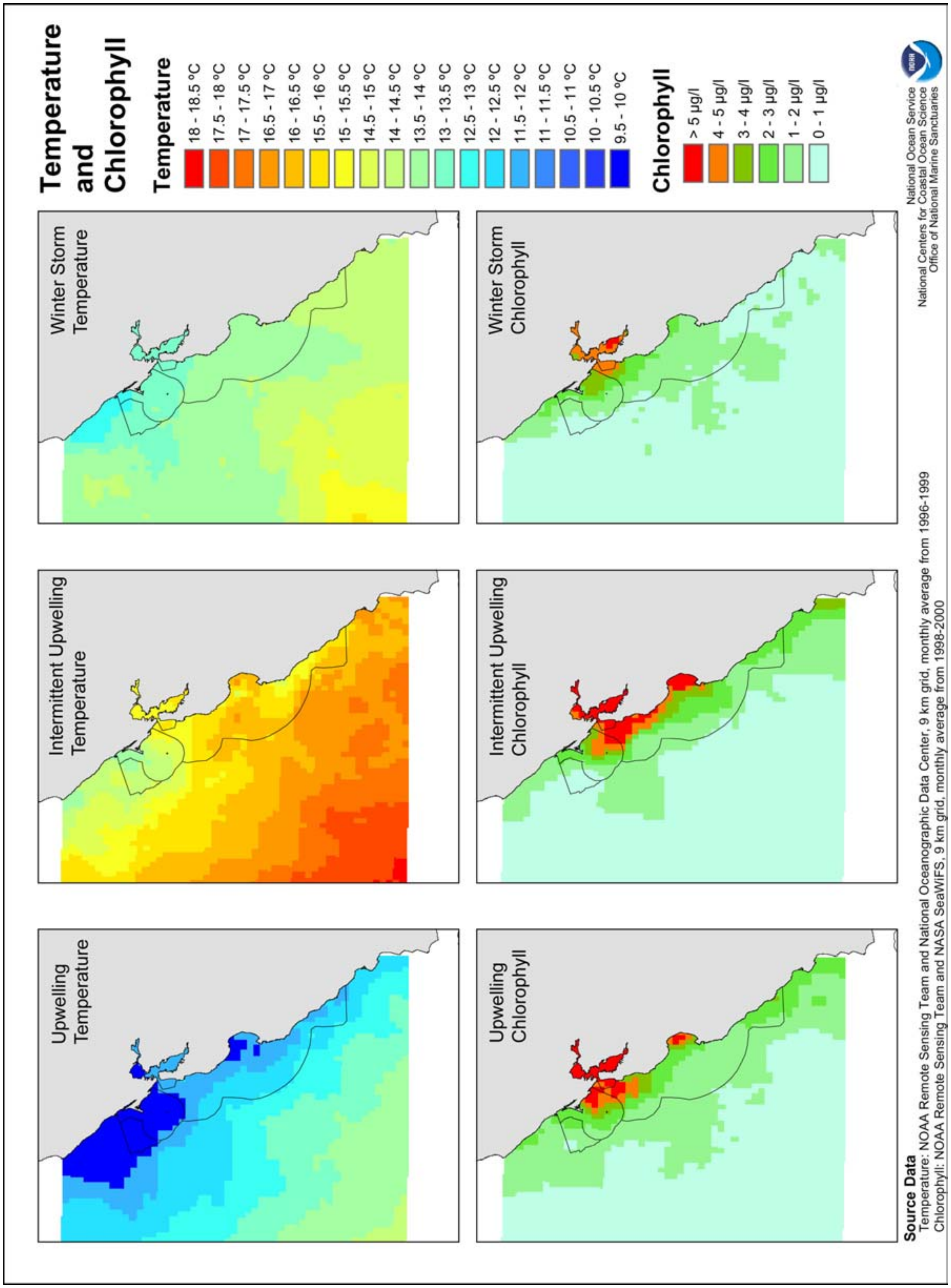


Figure 4. Locator map and regional bathymetry for the southern area of the study region (Lucia Canyon to Point Arguello).



Source Data
Watersheds: California Geographic Information Systems
Sediments: Seafloor Mapping Lab - California State University Monterey Bay

Figure 5. Watersheds and sediments of the study region. Sediment coverage was not available as far north as Point Arena.



Source Data
Temperature: NOAA Remote Sensing Team and National Oceanographic Data Center, 9 km grid, monthly average from 1996-1999
Chlorophyll: NOAA Remote Sensing Team and NASA SeaWiFS, 9 km grid, monthly average from 1998-2000

Figure 6. Seasonal sea surface temperature and chlorophyll. These maps were developed summarizing monthly averages for temperature (1996 – 1999) and chlorophyll (1998 – 2000) in a 9 km grid. Maps are representative of upwelling, intermittent upwelling and winter storm periods.

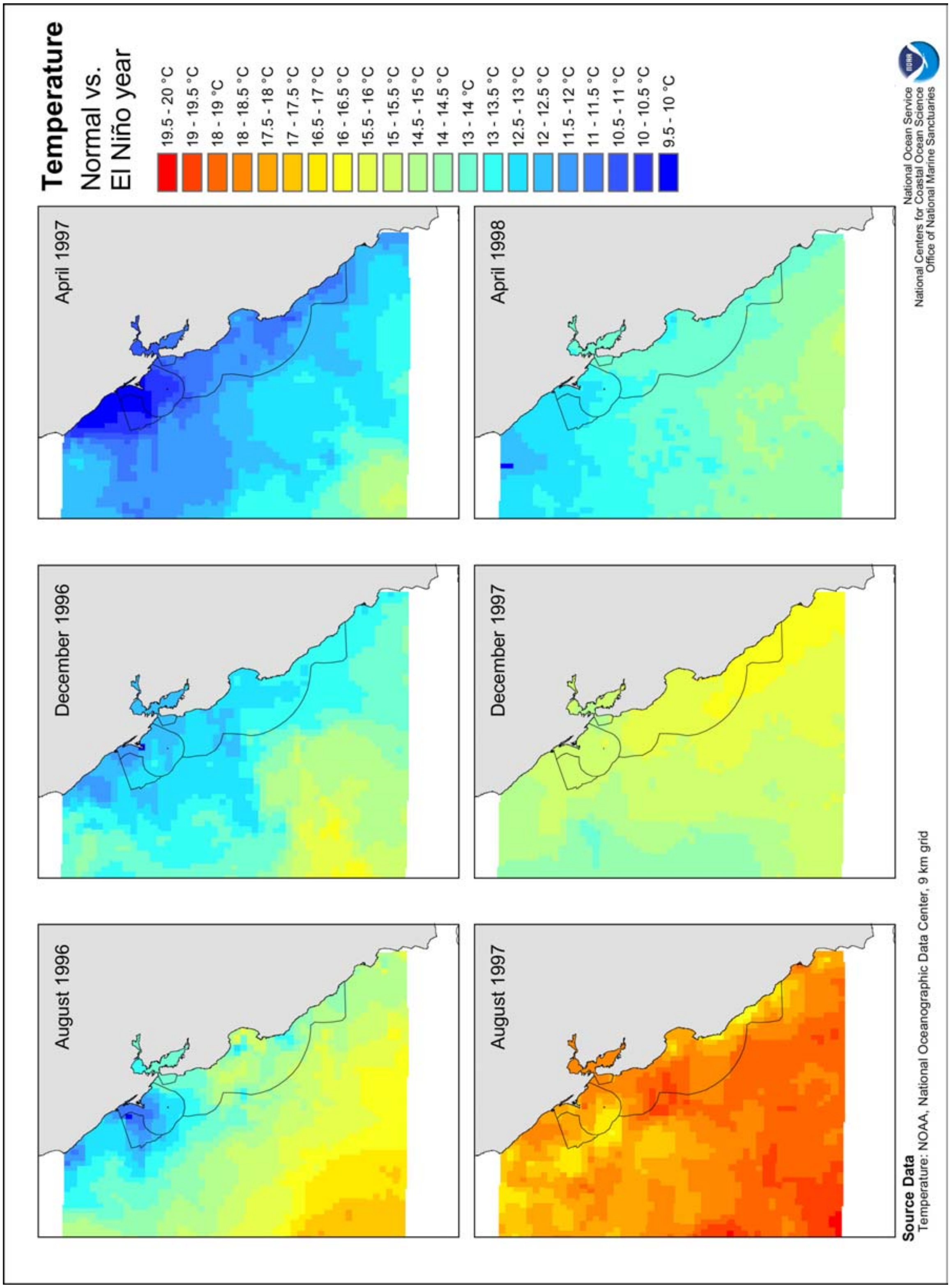


Figure 7. Sea surface temperatures prior to El Niño (August 1996 – April 1997) and during El Niño (August 1997 – April 1998). Data presented are averaged for the given month and summarized in a 9 km grid.

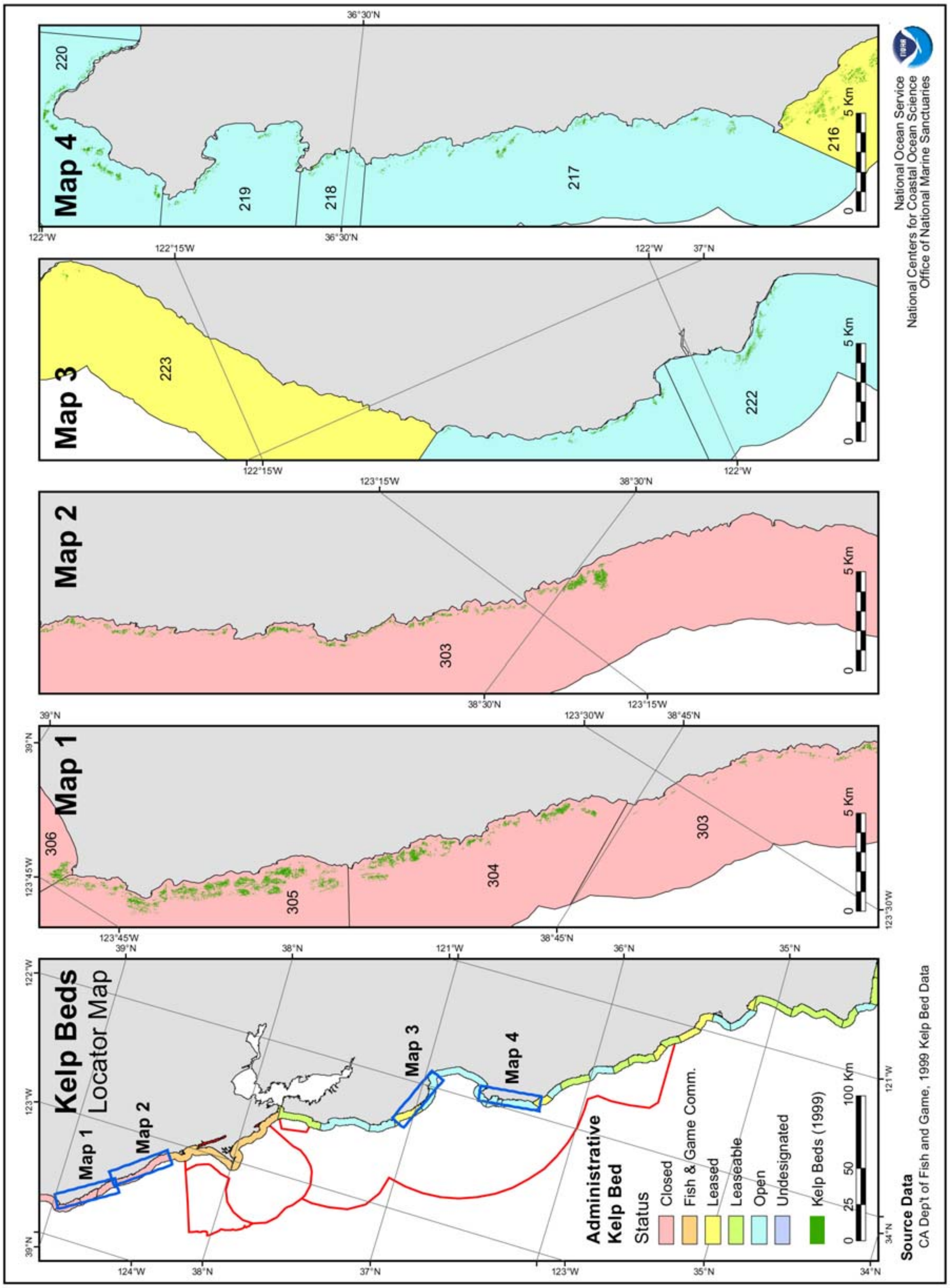


Figure 8a. Distribution of kelp from Pt. Sur north. The first map on each page shows the administrative kelp bed status along the coast and the following maps are enlarged areas of the coast showing actual kelp beds digitized from 1999 aerial photography.

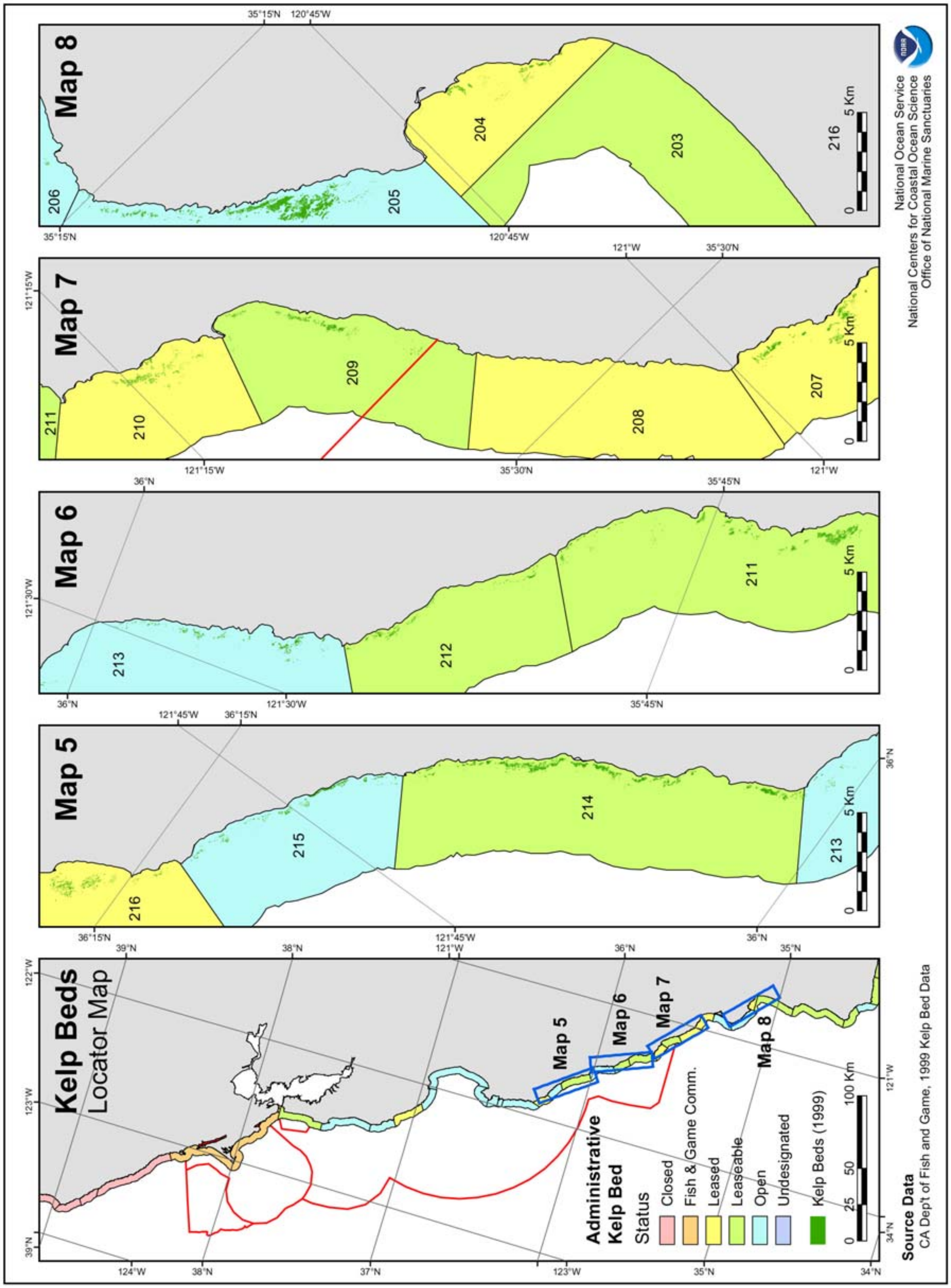


Figure 8b. Distribution of kelp from Pt. Sur south. The first map on each page shows the administrative kelp bed status along the coast and the following maps are enlarged areas of the coast showing actual kelp beds digitized from 1999 aerial photography.

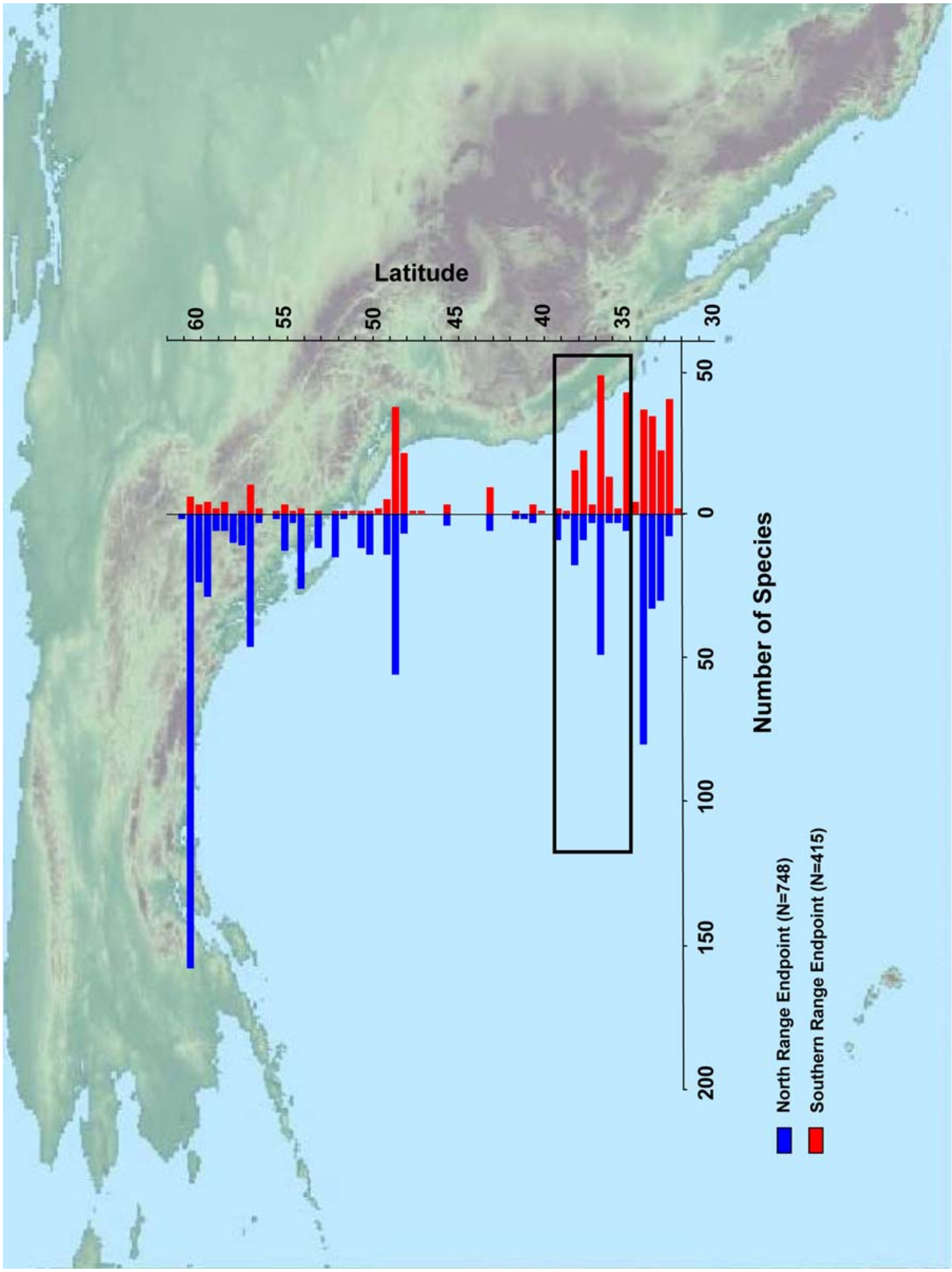


Figure 9. Range endpoints of selected marine benthic algae along the west coast of the United States shown in 1/2^{O} increments. The histogram was developed from a range endpoint analysis conducted by D. Sax (University of California, Santa Barbara) on over 830 species of marine benthic algae. The black box represents the study region.

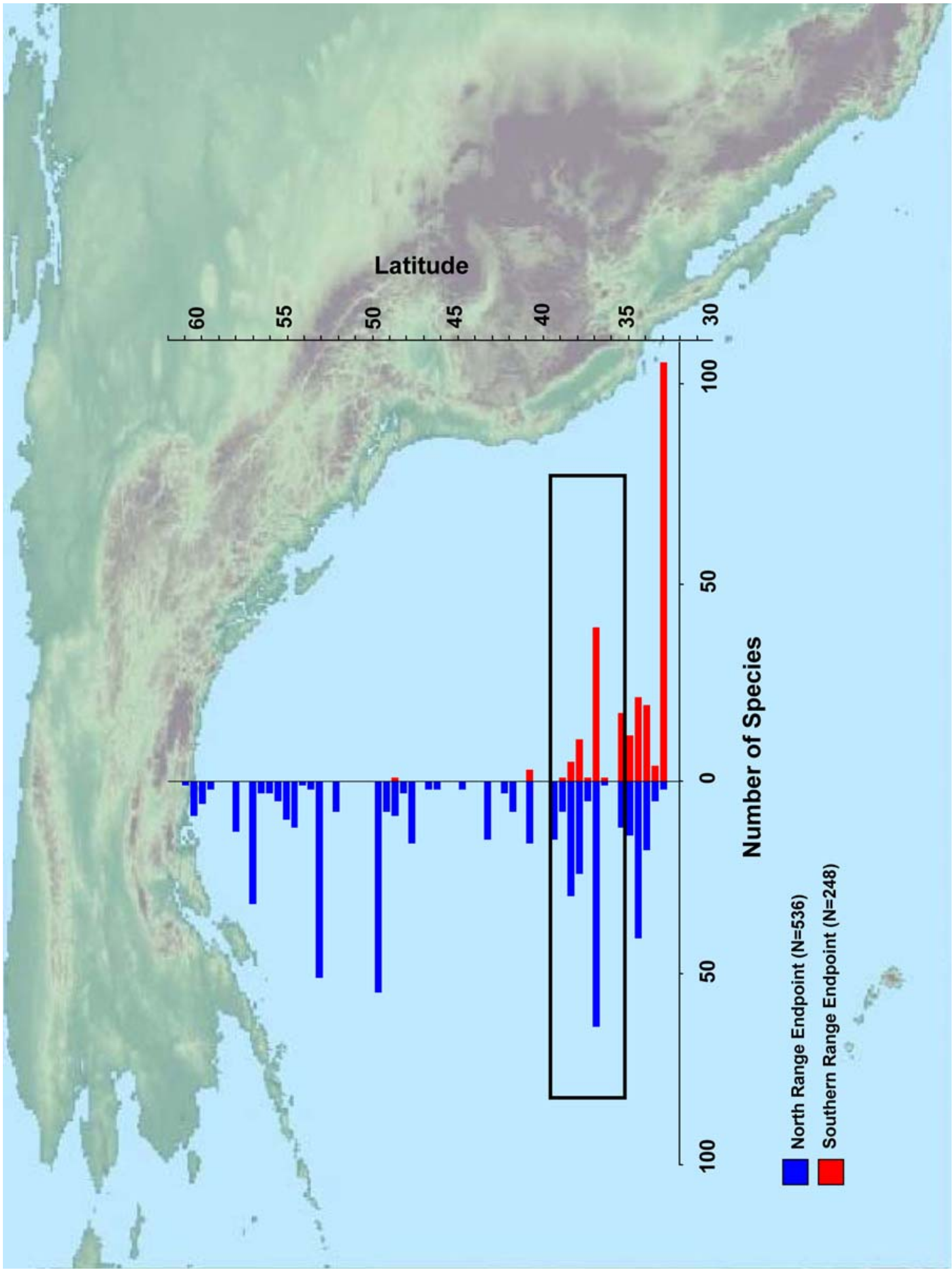


Figure 10. Range endpoints of selected marine invertebrates along the west coast of the United States shown in 1/2^{O} increments. The histogram was developed from data on over 770 species of marine benthic invertebrates provided by G. Eckert (University of Alaska Southeast). The black box represents the study region.

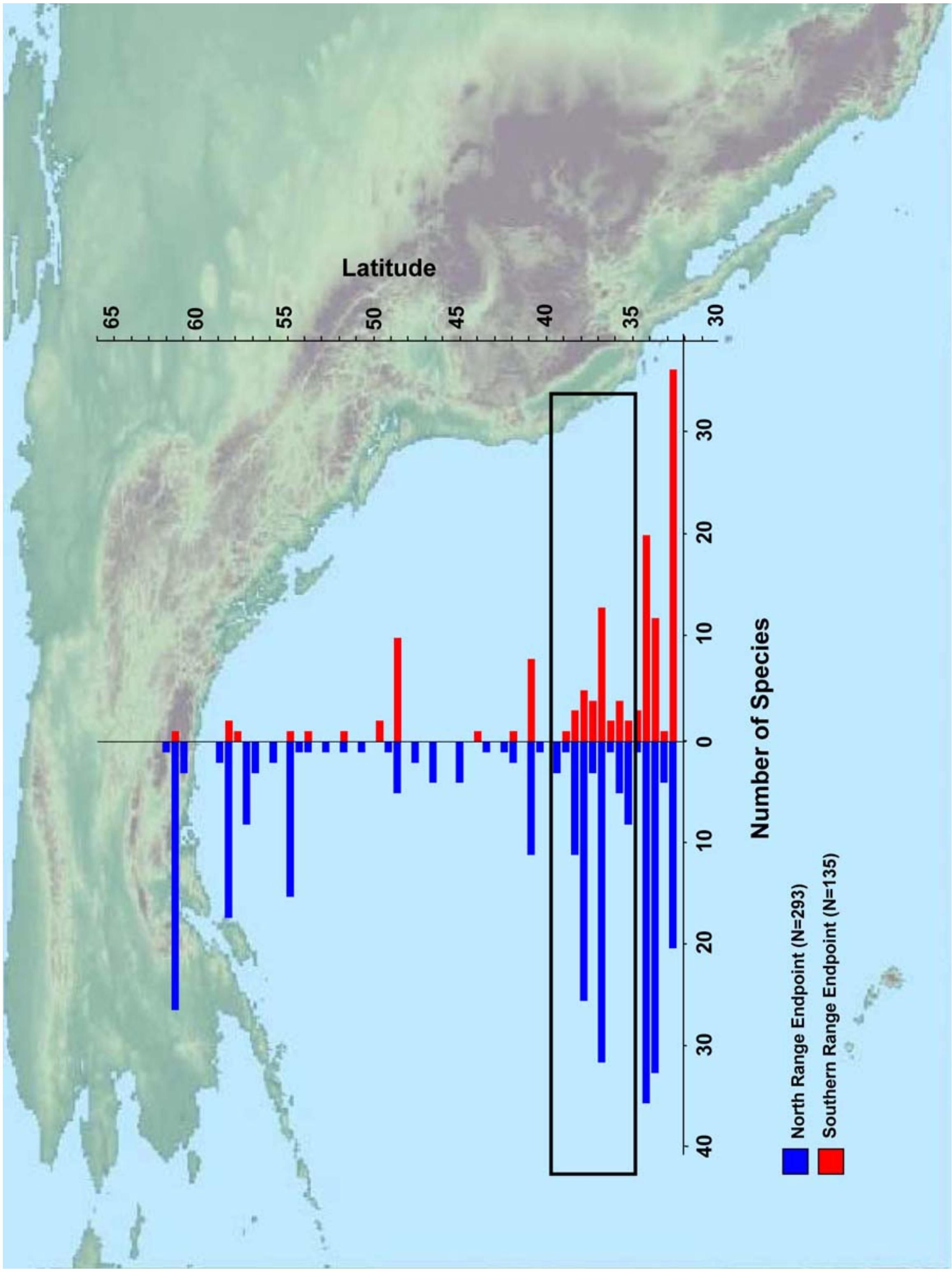


Figure 11. Range endpoints of selected marine fishes along the west coast of the United States shown in $1/2^{O}$ increments. The histogram was developed from data on species of 613 marine fishes compiled by the authors. The black box represents the study region.

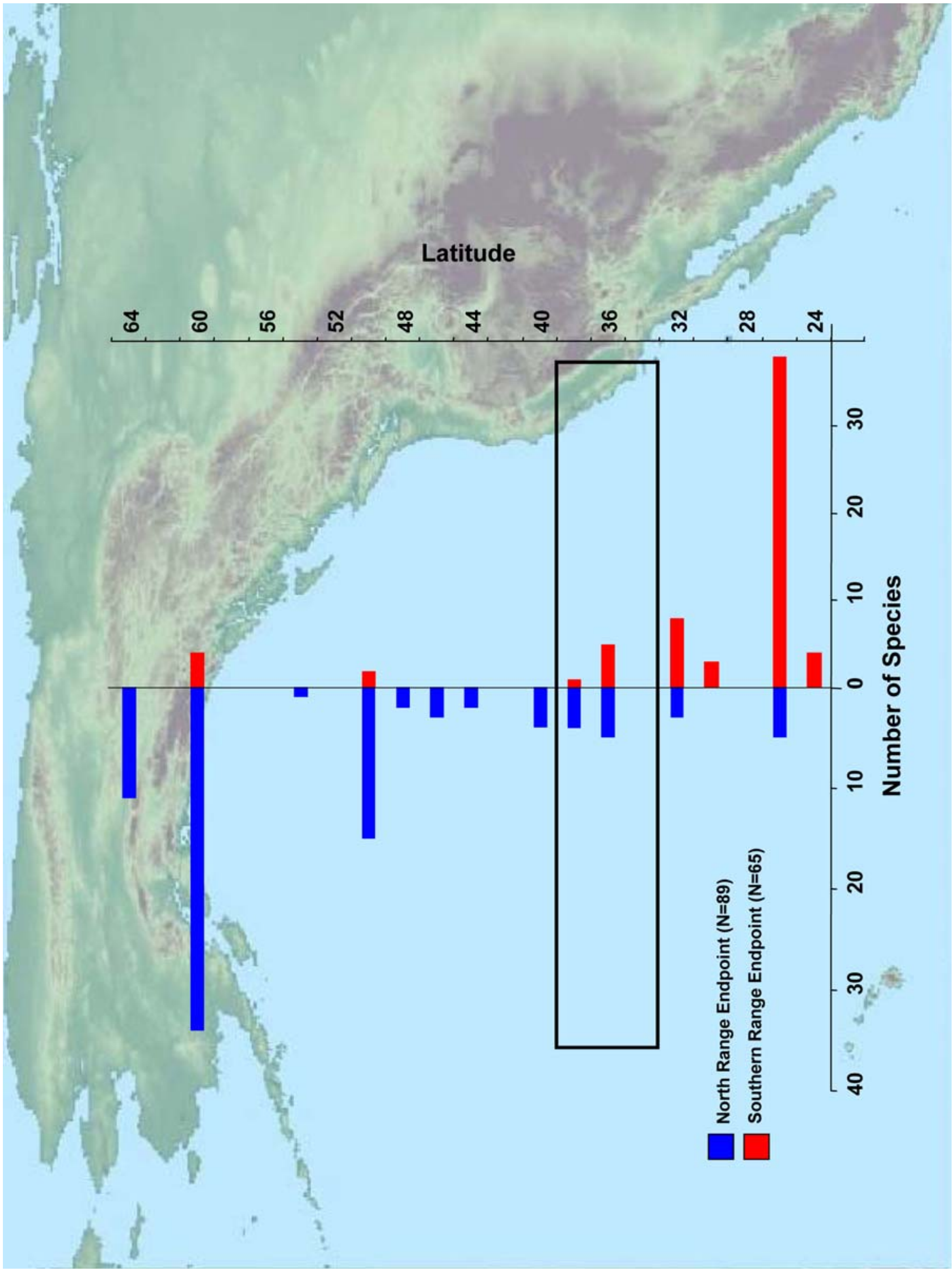


Figure 12. Range endpoints of selected seabirds and shorebirds along the west coast of the United States shown in 2 ^{O} increments. The histogram was developed from data on species of 131 seabirds and shorebirds compiled by the authors. The black box represents the study region and is drawn past Point Conception so that it includes the data representing the range termini at 35 ^{O}.

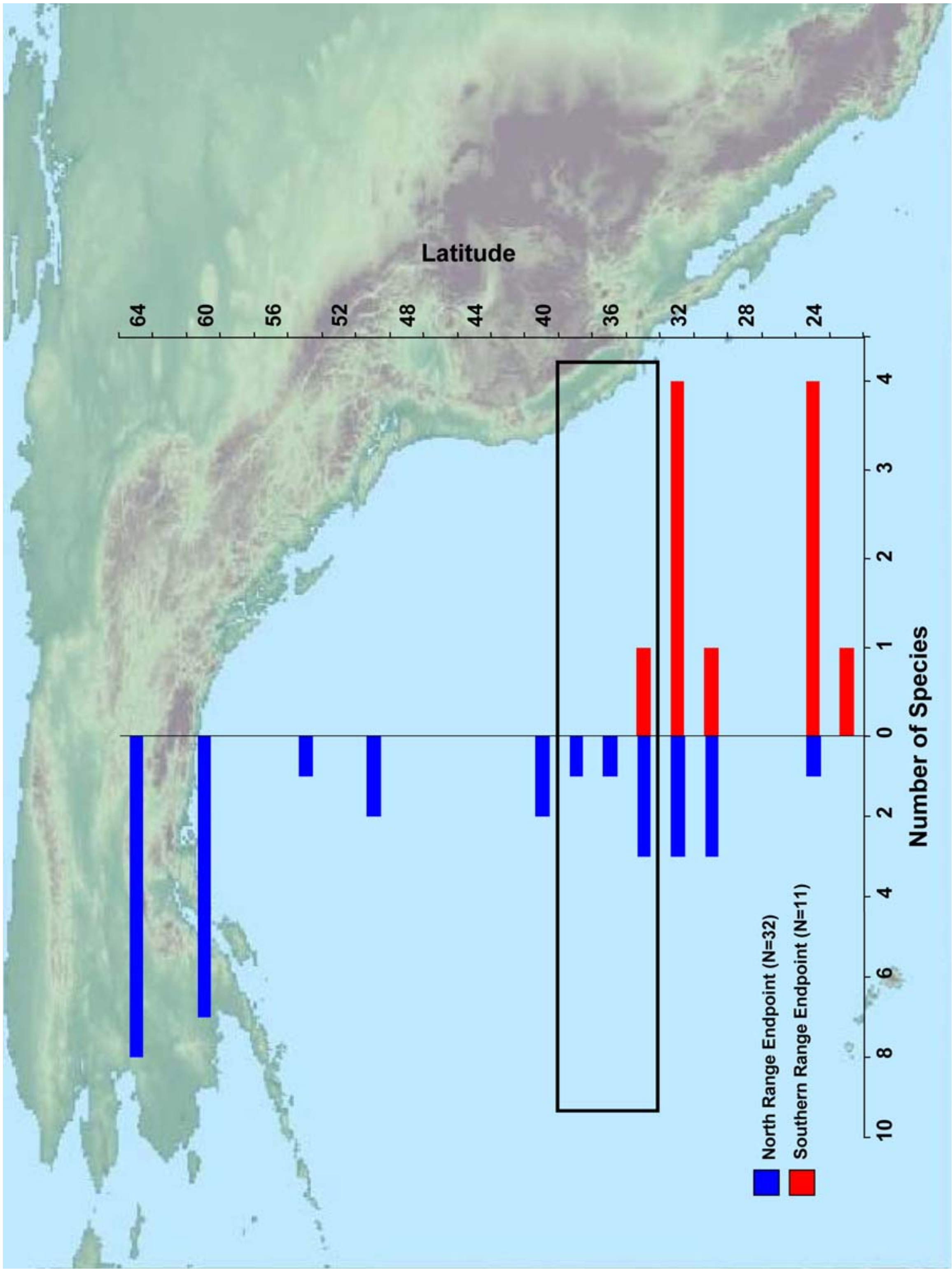


Figure 13. Range endpoints of selected marine mammals along the west coast of the United States shown in 2^{O} increments. The histogram was developed from data on species of 49 marine mammals compiled by the authors. The black box represents the study region and is drawn past Point Conception so that it includes the data representing the range termini at 35^{O}.

Table 1. Databases and Online Catalogs.

Database	Dates	Description
Aquatic Sciences and Fisheries Abstracts (ASFA)	1971-present	The premier reference for the aquatic sciences. Covers over 5,000 periodicals, books, reports, conference proceedings, and translations.
Biological Sciences Database	1982-present	Abstracts and citations to research in biomedicine, biotechnology, zoology, ecology, and some aspects of agriculture and veterinary medicine.
California Digital Library	variable	California Digital Library's extensive collections of digital resources, including electronic journals, databases, reference texts, etc. 1,138 journals on biological sciences.
Ecosystem Observations for the MBNMS	1998-2000	
Fishbase	variable	Fishbase.org. 27,310 Species, 76,310 Synonyms, 137,480 Common names, 34,475 Pictures, 29,175 References, 920 Collaborators.
MELVYL	variable-2001	Catalog of the University of California’s Libraries
MLML/MBARI Research Library	variable	MLML-MBARI Online Catalog Libraries (CSUMB, NPS, Hopkins, UCSC) MLML Reprints Faculty Publications Aquatic Sciences and Fisheries Abstracts GeoRef Zoological Record Biosis Lexis-Nexis Universe FirstSearch Look for Full-text Wiley Interscience ACS Web Editions Science Direct JSTOR Encyclopaedia Brittanica
ELPegasus	-present	Library catalog of the University of California, Santa Barbara

Table 1. Databases and Online Catalogs.

Database	Dates	Description
Science Citation Index (Web of Science)	1974-present	Meteorological & Geoastrophysical Abstracts (MGA) contains records drawn from the World's literature on meteorology, climatology, atmospheric chemistry and physics, astrophysics, hydrology, glaciology, physical oceanography and environmental sciences. Summaries from over 600 journal titles, as well as conference proceedings, books, technical reports and other monographs, are included.
Water Resources Abstracts	1967-present	Summaries of the world's technical and scientific literature on water-related topics covering the characteristics, conservation, control, pollution, treatment, use and management of water resources. Includes a link to Water Resources RouteNet, a collection of related Internet resources.
JSTOR	variable	American Midland Naturalist (1909-1999) Midland Naturalist (1909) American Naturalist (1867-1998) Annual Review of Ecology and Systematics (1970-1997) Biotropica (1969-1997) Conservation Biology (1987-1999) Diversity and Distributions (1998-1999) Biodiversity Letters (1993-1996) Ecological Applications (1991-1998) Ecological Monographs (1931-1998) Ecology (1920-1999) Evolution (1947-1999) Functional Ecology (1987-1999) Global Ecology and Biogeography (1999) Global Ecology and Biogeography Letters (1991-1998) Journal of Animal Ecology (1964-1999) Journal of Ecology (1913-1999) Journal of Tropical Ecology (1985-1997) Limnology and Oceanography (1956-1999) Paleobiology (1975-1998) Quarterly Review of Biology (1926-1997) Systematic Biology (1992-1999) Systematic Zoology (1952-1991)

Table 2. Selected journals available at the Davidson Library, University of California, Santa Barbara.

Journals Searched at UCSB Library	Dates Available
Acta Oecologia	v.1 (1980) - v.23 (2002)
Advances in Marine Biology	v.1 (1963) - v.43 (2002)
American Naturalist	v.1 (1867) - v.159 (2002)
American Zoologist	v.1 (1961) - v.42 (2002)
Annals of the New York Academy of Science	v.51 (1948) - v.982 (2002)
Annual Review of Ecology and Systematics	v.1(1970) - v.33(2002)
Beaufortia	v. 12 (1965) - v.41 (1990)
Biological Bulletin	v.132 (1967)-v.202 (2002)
Biological Conservation	v.1 (1968) – v .108 (2002)
Biological Oceanography	v.1 (1981) - v.6 (1989)
Biological Review	v.10 (1935) – v.77 (2002)
Botanica Marina	v.1 (1959) – v.45 (2002)
Bulletin of Marine Science	v.15 (1965) – v.71 (2002)
Bulletin of Scripps Institution of Oceanography	
Bulletin of the American Meteorological Society	v.48 (1967) - v.82 (2001)
Bulletin of the Southern California Academy of Science	v.40 (1941) – v.93 (1994)
California Cooperative Oceanic Fisheries Investigations Reports	v.20 (1979) – v.43 (2002)
California Fish and Game	v.1 (1914) - v.85 (1999)
Canadian Journal of Fisheries and Aquatic Science	v.37 (1980) - v.59 (2002)
Canadian Journal of Zoology	v.39 (1961) – v. 80 (2002)
Condor	v.3 (1901) – v.104 (2002)
Continental Shelf Research	v.1 (1982) - v.22 (2002)
Copeia	1920-1925,1944-2001
Deep-Sea Research	v.1 (1953)-v.8 (1961)
Deep-Sea Research Part I	v.40 (1993)-v.49 (2002)
Deep-Sea Research Part II	v.40 (1993)-v.49 (2002)
Ecological Applications	v.1 (1991) - v.12 (2002)

Table 2. Selected journals available at the Davidson Library, University of California, Santa Barbara.

Journals Available at UCSB Library	Dates Available
Ecological Monographs	v.1 (1931) - v.72 (2002)
Ecology	v.1 (1920) – v. (2002)
Eos (Transactions of the American Geophysical Union)	v.50 (1969) - v.83 (2002)
Estuaries	v.1 (1978) - v.25 (2002)
Estuarine, Coastal, and Shelf Science	v.12 (1981) - v.54 (2002)
Estuarine and Coastal Marine Science	v.1 (1973) - v.11 (1980)
Environmental Biology of Fishes	v.1 (1976) - v.64 (2002)
Environmental Science and Technology	v.1 (1967) - v.36 (2002)
Fishery Bulletin	v.68 (1971) - v.98 (2000)
Fisheries Oceanography	v.1 (1992) - v.3 (1994), v.6 (1997) - v.11 (2002)
Geology	v.14 (1967) – v.28 (1977)
Geological Society of America Bulletin	v.78 (1967)-v.114 (2002)
Geophysical Research Letters	v.1 (1974) - v.29 (2002)
Global Change Biology	v.1 (1995) - v.8 (2002)
Hydrobiologia	v.1 (1948) - v.486 (2002)
Journal of Biogeography	v.1(1974) – v.29 (2002)
Journal of Climate	v.1 (1988) - v.15 (2002)
Journal of Crustacean Biology	v.1 (1981) - v.22 (2002)
Journal of Experimental Marine Biology and Ecology	v.1 (1967) - v.280 (2002)
Journal of Geophysical Research	v.72 (1967) - v.107 (2002)
Journal of Mammalogy	v.1 (1919) – v.83 (2002)
Journal of Marine Research	v.1 (1937) – v.60 (2002)
Journal of Phycology	v.1 (1965) - v.38 (2002)
Journal of Physical Oceanography	v.1 (1971)-v.32 (2002)
Journal of Sedimentary Petrology	v.1 (1931) – v.63 (1993)
Journal of Zoology, London	v.146 (1965) – v.255 (2001)
Limnology and Oceanography	v.1 (1956) - v.47 (2002)
Marine Biology	v.1 (1967) - v.140 (2002)
Marine Ecology Progress Series	v.1 (1979) - v.238 (2002)
Marine Fisheries Review	v.34 (1972) - v.61 (1999)
Marine Mammal Science	v.1 (1985) - v.18 (2002)
Marine Resources Technical Report	1 (1972) - no.58 (1989)
Memoirs of the California Academy of Sciences	v.2 (1888) – no.11 (1988)
Nature	v.259 (1976)-v.419 (2002)
NOAA Technical Memoranda	
NOAA Technical Reports	
Northwestern Naturalist	v.70 (1989) - v.83 (2002)

Table 2. Selected journals available at the Davidson Library, University of California, Santa Barbara.

Journals Available at UCSB Library	Dates Available
Nova Hedwigia	v.11 (1966) - v.63 (1996)
Oceanography and Marine Biology	v.1 (1963) - v.40 (2002)
Oceanologica Acta	v.1 (1978) - v.25 (2002)
Oecologia	v.1 (1968) - v.133 (2002)
Proceedings of the American Philosophical Society	v.1 (1838) – v.146 (2002)
Proceedings of the National Academy of Sciences, U.S.A.	v.1 (1915) – v.99 (2002)
Progress in Oceanography	v.4 (1967) - v.54 (2002)
Remote Sensing of Environment	v.1 (1969) - v.83 (2002)
Science	v.24 (1906) – v.298 (2002)
Scientific American	v.181 (1949) – v.287 (2002)
Smithsonian Contributions to Zoology	no.1 (1969) – v.617 (2002)
South African Journal of Marine Science	no.18 (1997) – no.24 (2002)
Tellus	v.2 (1950) – v.34 (1982)
Trends in Ecology and Evolution	v.1 (1986) - v.17 (2002)
Underwater Naturalist	v.4 (1966) - v.24 (1999)
Western Birds	v.4 (1973) - v.33 (2002)

Table 3. Keywords for research on the National Marine Sanctuary Program.

Sanctuary	Topics of Research
Monterey Bay National Marine Sanctuary	Location, size, date established, features of ecological importance
Gulf of the Farallones National Marine Sanctuary	Location, size, date established, features of ecological importance
Cordell Bank National Marine Sanctuary	Location, size, date established, features of ecological importance

Table 4. Keywords for research on oceanography.

Keyword	Areas of Research
North Pacific Drift	Gulf of Alaska
California Current	Central and northern California, northeastern Pacific Ocean
Davidson Current	Central and northern California
Southern California Countercurrent	Central and southern California
Eddies	Pt. Arena, Pt. Reyes, Cordell Bank, San Francisco Eddy, Monterey Bay
Internal Waves	
Local currents	San Francisco Bay, Monterey Bay, general information
Freshwater Plumes	San Francisco Bay, Monterey Bay, general information
Upwelling	Central and northern California, northeastern Pacific Ocean
Relaxation	Central and northern California, northeastern Pacific Ocean
El Niño – Southern Oscillation	Central and northern California, northeastern Pacific Ocean
Pacific Decadal Oscillation	Central and northern California, northeastern Pacific Ocean
Global Warming	Central and northern California, northeastern Pacific Ocean

Table 5. Keywords for research on habitats.

Keyword	Areas of Research
Rivers and Streams	Russian River, Stemple Creek, Lagunitas Creek, Salinas River, San Lorenzo River, and Pajaro River, Soquel Creek, Aptos Creek, Carmel River, Chorro Creek, Los Osos Creek, Santa Maria River, San Antonio Creek, Santa Ynez River
Points	Pt. Arena, Bodega Head, Pt. Reyes, Tomales Pt., Pt. Año Nuevo, Pt. Pinos, Pt. Lobos, Pt. Sur, Pt. Piedras Blancas, Pt. San Luis, Pt. Sal, Pt. Arguello, Pt. Purisima, Pt. Conception
Bays	Bodega, Tomales, Drakes, Bolinas, San Francisco, Halfmoon, Monterey, Carmel, Morro, San Luis Obispo
Estuaries and Esteros	Drakes, Limantour, San Antonio, Americano, Bolians Lagoon, San Francisco, San Joaquin Delta, Elkhorn Slough, Doran Marsh
Beaches	Central and northern California, Pismo State Beach, Nipomo Dunes
Rocky intertidal	Central and northern California
Kelp forests	Giant kelp, *Macrocystis pyrifera,* bull kelp, *Nereocystis leutkeana*
Neritic and epipelagic habitats	Central and northern California, Northeastern Pacific Ocean
Benthic habitats	Central and northern California
Continental shelf	Central and northern California, northeastern Pacific Ocean, Gulf of the Farallones
Continental slope	Central and northern California, northeastern Pacific Ocean, oxygen minimum zone
Submarine canyons	Pioneer, Bodega, Ascension, Año Nuevo, Cabrillo, Soquel, Monterey, Carmel, Sur, Lucia,
Seamounts and other submerged features	Guide, Gumdrop, Pioneer, and Davidson seamounts; Cordell Bank
Deep sea	Central and northern California, northeastern Pacific Ocean
Cold seeps	Monterey Bay, Ascension fault zones, Clamfield, Mount Crushmore, San Gregorio, Pick-up Sticks, Horseshoe Head Scarps, Chimney Field, Tubeworm City, Camp Cup, Clam Flats
Islands and rocks	Farallon Islands, Año Nuevo Island, Bird Rock, Double Point, Point Resistance rocks, Devil's Slide rock, Hurricane rocks, Morro Rock

Table 6. Keywords for research on species. For each species, information was gathered on distribution, status, population size, spawning location and time, feeding locations, and predator-prey relationships, as available.

Group	Key Species
Bacteria	Chemoautotrophic bacteria, *Beggiatoa* spp
Plants/Algae	Beach Layia, *Layia carnosa* Brown alga, *Halidrys dioica* *Cystoseira osmundacea* Eelgrass, *Zostera* spp. *Egregia menziesii* *Eisenia arborea* *Endocladia muricata* *Enteromorpha* spp. *Fucus* spp. *Fucus distichus* *Gelidium coulteri* Geniculate (articulated) coralline algae *Bossiella* spp. *Calliarthron* spp. Giant Kelp, *Macrocystis pyrifera* *Gigartina canaliculata* *Macrocystis integrifolia* *Mastocarpus papillatus* *Nereocystis leutkeana* Nongeniculate (encrusting) coralline algae *Lithothamnium* spp. *Lithophyllum* spp. Northcoast Sand Verbena, *Abronia umbellata ssp. breviflora* *Pelvetia fastigata* Phytoplankton *Postelsia palmaeformis* *Pterygophora californica* *Rhodoglossum affine* Surfgrass, *Phyllospadix* spp. *Ulva* spp.
Invertebrates	Abalone, *Haliotis* spp. Amphipods (Ampeliscid and Lysianassid) Annelid worms, *Euzonus mucronata* Anemones Articulated brachypods, *Laqueus californianus* Barnacles, *Balanus glanula* Beach hoppers, *Megalorchestia* spp. Blue Mud Shrimp Boring snails, *Euspira* sp. Brittlestars

	Amphiura carchara *Amphilepis platytata* *Ophiocantha pacifica* *Ophiomusium glabrum* Chitons Cirolanid isopods, *Excirolana* spp Coleopteran beetles Coquina clams, *Donax* spp. Corallomorpharian anemones, *Corallimorphus rigidus* Crabs *Cancer* spp. *Paralomis verrilli* Tanner crabs, *Chionoecetes bairdi* Dogwhelks Euphausiids Euphilomedid ostracods *Monoculodes spinipes* *Synchelidium shoemakeri* Feather stars, *Florometra serratissima* Grass shrimp Harpacticoid copepods, *Tigriopus californicus* Hermit crabs Holothurians *Echinocucumis hispida* *Ypsilothuria bitentaculata* Honeycomb tube worms, *Phragmatopoma californica* Isopods Kelp flies (Diptera) Limpets California Spiny Lobster, *Panulirus interruptus* Mushroom corals, *Anthomastus ritteri* Mussels, *Mytilus californianus* Nematode worms Ochre seastar, *Pisaster ochraceus* Octopus, *Octopus dolfleini* Ostracods Pelagic red crab Periwinkles, *Littorina keenae* Pill bug, *Alloniscus perconvexus* Pismo clam, *Tivella stultorum* Polychaete worms, *Nephtys californiensis* Pogonophoran tube worms Predatory tunicates, *Megalodicopia hians* Razor clam, *Siliqua patula* Sand crab Sand dollars, *Dendraster excentricus*

	Sandy Beach Tiger Beetle, *Cicindela hirticollis gravida* Sea pens *Umbellula lindahli* *Kophoblemnon* sp Sea urchins, *Strongylocentrotus* spp. Seastars *Eremecaster* sp. *Eremicaster gracilis* *Pisaster brevispinus* *Pisaster ochraceus* *Pycnopodia helianthoides* Shrimp (*Crangon abyssorum*) Snails, *Neptunea amianta* Spiny mole crab, *Blepharipoda occidentalis* Squid, *Loligo opalescens, Architeuthis dux* Surf clam, *Spisula solidissima* Talitrid amphipods Vesicomyid clams *Calyptogena kilmeri* *C. pacifica* Vestimentiferan tube worms Zooplankton (Gelatinous) Appendicularia Ctenophora Heteropoda Hydromedusae Pteropoda Siphonophora Scyphomedusae Thaliacea
Fishes	Bat ray Blackeye goby, *Coryphopterus nicholsii* Blacksmith, *Chromis punctipinnis* Blennies Cabezon, *Scorpaenichthys marmoratus* Croakers Delta Smelt, *Hypomesus transpacificus* Dwarf surfperch, *Micrometrus minimus* Eelpouts, *Lycenchelys* spp. (Zoarcidae) Finescale codling, *Antimora microlepis* Flatfishes (Pleuronectiformes) Deep-sea sole, *Embassichthys bathybius* Dover sole, *Microstomus pacificus* English sole, *Pleuronectes vetulus* Petrale sole, *Eopsetta jordani* Rex sole, *Errex zachirus*

	Starry flounder Grenadiers, Macrouridae, *Coryphaenoides* spp. Grunion Hagfishes, *Eptatretus* spp. Jack Mackerel, *Trachurus symmetricus* Jacksmelt Lanternfish Lingcod, *Ophiodon elongaus* Longfin Smelt, *Spirinchus thaleichthys* Midshipman Monkey-face eel, *Cebidichthys violaceus* Moras, Moridae Night smelt Northern Anchovy, *Engraulis mordax* Pacific Halibut (California Halibut) Pacific Herring Pacific Lamprey, *Lampetra tridentata* Pacific Mackerel Pacific Sardine, *Sardinops sagax* Pacific Saury Pacific Whiting/Hake, *Merluccius productus* Pile Perch Rattails (Macrouridae) *Coryphaenoides armatus* *C. filifer* *C. leptolepis* Rock eel, *Pholis gunnellus* Rockfish spp. Rockweed gunnel, *Xererpes fucorum* Sablefish, *Anoplopoma fimbria* Salmon Chinook Salmon, *Oncorhynchus tshawytscha* Coho salmon, *Oncorhynchus kisutch*) Sanddabs Speckled Sanddab Pacific Sanddab Sculpin spp. Señorita, *Oxyjulius californica* Sharks Basking shark, *Cetorhinus maximus* Bigeye thresher shark, *Alopias superciliosus* Blue shark, *Prionace glauca* Cat sharks, Scyliorhinidae Common thresher shark, *Alopias vulpinus* Mako shark, *Isurus oxyrhinchus*

	Prickly sharks, *Echinorhinus cookei* Salmon shark, *Lamna ditropis* Soupfin shark, *Galeorhinus galeus* Spiny dogfish, *Squalus acanthias* White shark, *Carcharodon carcharias* Skates, Rajidae Snailfishes, *Paraliparis rosaceus* (Liparididae) Steelhead Trout, *Oncorhynchus mykiss* Stickleback, *Gasterosteus aculeatus leiurus* Sturgeon (Ascipenseriformes) White Sturgeon, *Acipenser transmontanus* Green Sturgeon, *Acipenser medirostris* Surfperch spp. Surf smelt Swordfish, *Xiphias gladius* Thornyheads, *Sebastolobus* spp Tidepool sculpin, *Oligocottus maculosus* Tidepool snailfish, *Liparis florae* Tidewater Goby, *Eucyclogobius newberryi* Topsmelt Tuna Bluefin Tuna, *Thunnus thynnus* Whiptails (Macrouridae) Wolf eel, *Anarrhichthys ocellatus*
Reptiles	Turtles Leatherback Turtle, *Dermochelys coriacea* Loggerhead Turtle, *Caretta caretta* Pacific Ridley Turtle, *Lepidochelys olivacea*
Birds	Aleutian Canada Goose American Peregrine Falcon Auklet (Cassin’s and Rhinoceros) Bald Eagle Black-footed Albatross Black Oystercatcher Black Rail Black Turnstone Black-legged Kittiwake Bristle-thighed Curlew California Black Rail California Brown Pelican California Least Tern California Clapper Rail Common Murre Cormorants (Brandt’s, Double-crested, Pelagic) Dark-rumped Petrel Ducks (Long-tailed, Harlequin, and Barrow’s Goldeneye)

	Geese Great Blue Heron Grebes (Red-necked, Western, Clark's) Gulls (Western, California, Herring, Glaucous-winged) Least Bittern Loons (Pacific, Red-throated, and Yellow-billed) Murrelet (Marbled and Xantus's) Phalaropes Pigeon Guillemot Saltmarsh Common Yellowthroat Saltmarsh Song Sparrow Sanderlings Sandpipers Scoters (White-winged and Surf) Shearwaters (Pink-footed, Sooty, Buller's, and Black-vented) Short-tailed Albatross Storm-petrels (Ashy, Black and Least) Terns (Caspian, Black, Elegant, and Forster's) Tufted Puffin Western Snowy Plover White-faced Ibis Willet
Mammals	Blue whale Bottlenose dolphin, *Tursiops truncatus* California sea lion, *Zalophus californianus* Common dolphin, *Delphinus* spp. Dall's porpoise, *Phocoenoides dalli* Dwarf sperm whale False killer whale Fin whale, *Balaenoptera physalus* Finback Whale Gray whale, *Eschrichtius robustus* Guadalupe Fur Seal Harbor porpoise, *Phocoena phocoena* Harbor seal, *Phoca vitulina* Hubb's beaked whale Humpback whale Killer whales, *Orcinus orca* Melon-headed whale Northern elephant seal, *Mirounga angustirostris* Northern fur seal, *Callorhinus ursinus* Northern Right Whale Northern right whale dolphin, *Lissodelphis borealis* Pacific white-sided dolphin, *Lagenorhynchus obliquidens* Pygmy killer whale Pygmy sperm whale

	Risso's dolphin, *Grampus griseus* Rough-toothed dolphin Sei Whale Southern sea otter, *Enhydra lutris* Sperm whale, *Physeter macrocephalus* Stejneger's beaked whale Steller sea lion, *Eumetopias jubatus*

Table 7. Keywords for research on anthropogenic pressures.

Fishing	Species, distribution of effort, trends in fisheries
Recreation	Activities, distribution of effort, impacts
Commercial Shipping	Types of vessels, distribution of vessels, potential impacts
Oil Pollution	Distribution of spills, impacts of spills
Mineral Extraction	
Non-point and point-source pollution	Types of pollutants, DDT and PCBs, locations of pollutants, potential impacts
Invasive Species	
Kelp Harvesting	

Table 8. Interviews conducted with research scientists.

Scientist	Affiliation
David Ainley	
Jim Barry	Monterey Bay Aquarium Research Institute
Greg Cailliet	Moss Landing Marine Laboratories
Mark Carr	University of California, Santa Cruz
Don Croll	University of California, Santa Cruz
Andrew DeVogelaere	Monterey Bay National Marine Sanctuary
Jim Estes	University of California, Santa Cruz
Ed Euber	Gulf of the Farallones National Marine Sanctuary
Karen Forney	Long Marine Laboratory, Santa Cruz
Rikk Kvitek	California State University, Monterey Bay
Jim Oakden	Moss Landing Marine Laboratories
Jeff Paduan	Naval Postgraduate School
Richard Parrish	Pacific Fisheries Environmental Laboratory
Pete Raimondi	University of California, Santa Cruz
Jan Roletto	Gulf of the Farallones and Cordell Bank National Marine Sanctuaries
Mark Silberstein	Elkhorn Slough National Estuarine Research Reserve
George Somero	Hopkins Marine Station
William Sydeman	Point Reyes Bird Observatory
Mario Tamburri	Monterey Bay Aquarium Research Institute Monterey Bay National Marine Sanctuary
Kerstin Wasson	Elkhorn Slough National Estuarine Research Reserve
Geoff Wheat	National Undersea Research Program
Mary Yoklavich	Long Marine Laboratory, Santa Cruz

Table 9. Interview questions regarding marine and estaurine environments of central and northern California.

1. Please identify the habitats or species with which you are most familiar.
2. What do you believe is the status of these habitats or species?
3. Do these habitats or species play an important role in structuring marine or estuarine communities? Please provide examples and/or references.
4. What is global distribution of the species or habitat? What is the core area of the distribution? What physical or biological factors are associated with the boundaries of the species or habitat distribution?
5. Are dispersal patterns of the species known? If so, what is the potential for dispersal and how does dispersal influence population structure?
6. Please identify selected literature, manuscripts, data, or other materials we should include in our description of the marine and estuarine environments of northern and central California. Feel free to use references to respond to any of the previous questions.

Table 10. Species of concern in marine and estuarine systems of central and northern California.

COMMON NAME	SCIENTIFIC NAME	STATUS	RANGE	BREEDING RANGE	BREEDING SEASON
PLANTS AND ALGAE					
Beach Layia	*Layia carnosa*	Endangered	Pt Conception-Humboldt		Mar-Jul
Northcoast Sand Verbena	*Abronia umbellata ssp. breviflora*	WA—possibly extirpated OR—endangered CA—Species of concern	Historical: BC-c.CA	Current: s.OR-n.CA	
Sea Palm	*Postelsia palmaeformis*	Species of concern	Vancouver I.-Morro Bay		
INVERTEBRATES					
Black Abalone	*Haliotis cracherodii*	Proposed	Pt Arena – Baja	San Francisco – Pt Arguello	Aug-Sep
Sandy Beach Tiger Beetle	*Cicindela hirticollis gravida*	Species of concern	SF Bay to N Mex		
				Jun	
FISHES					
White Sturgeon	*Acipenser transmontanus*	Endangered	n.Baja-AK+	n.Baja-AK+	Feb-Oct
Chinook Salmon	*Oncorhynchus tshawytscha*	Endangered	s.CA-AK+	s.CA-AK+	Feb-Oct
Coho Salmon	*Oncorhynchus kisutch*	Endangered (state) Threatened	Baja-AK+	Baja-AK+	Feb-Oct
Steelhead Trout	*Oncorhynchus mykiss*	Threatened	n.Baja-AK+	n.Baja-AK+	Feb-Oct
Delta Smelt	*Hypomesus transpacificus*	Threatened	Sacramento-San Joaquin estuary		
Lingcod	*Ophiodon elongaus*	Overfished	Baja-AK	Baja-AK	Feb-Oct
Cowcod	*Sebastes laevis*	Overfished	Baja-n.CA	Baja-n.CA	Feb-Oct
Bocaccio	*Sebastes paucispinis*	Overfished	Baja-AK	Baja-AK	Feb-Oct
Canary Rockfish	*Sebastes pinniger*	Overfished	Baja-AK	Baja-AK	Feb-Oct
				Feb-Jun	

Table 10. Species of concern in marine and estuarine systems of central and northern California.

COMMON NAME	SCIENTIFIC NAME	STATUS	RANGE	BREEDING RANGE	BREEDING SEASON
FISHES cont.					
Green Sturgeon	*Acipenser medirostris*	Species of concern	Ensenada, Mex-Bering Sea and Japan	Klamath and Sacramento R.; Feather, Yuba, and Am. R.	Mar-Jul
Pacific Lamprey	*Lampetra tridentata*	Species of concern	Baja-Bering Sea and Japan	Sacramento-San Joaquin R. Am. and Napa R., Sonoma and Walnut Cr.	Apr-Jul
Longfin Smelt	*Spirinchus thaleichthys*	Species of concern	Prince William Sound-Sacramento-San Joaquin estuary	Suisun Bay, Montezuma Slough, Sacramento San Joaquin R. and delta	Dec-Jun
Bluefin Tuna	*Thunnus thynnus*	Species of concern	S.Am-AK+	S.Am-AK+	Feb-Oct
Swordfish	*Xiphias gladius*	Species of concern	S.Am-OR+	S.Am-OR+	Feb-Oct
Tidewater Goby	*Eucyclogobius newberryi*	Proposed to delist	s.CA-n.CA	s.CA-n.CA	Feb-Oct
TURTLES					
Leatherback Turtle	*Dermochelys coriacea*	Endangered	Baja-AK+	C.Am	May-Sep
Loggerhead Turtle	*Caretta caretta*	Threatened	Baja-c.CA+	C.Am-Mex	May-Sep
Pacific Ridley Turtle	*Lepidochelys olivacea*	Threatened	C.Am-BC+	C.Am-Mex	May-Sep
Green Sea Turtle	*Chelonia mydas*	Endangered/Threatened	AK - Baja		

Table 10. Species of concern in marine and estuarine systems of central and northern California.

COMMON NAME	SCIENTIFIC NAME	STATUS	RANGE	BREEDING RANGE	BREEDING SEASON
BIRDS					
California Brown Pelican	*Pelecanus occidentalis californicus*	Endangered	Baja-WA+	Baja-s.CA	Feb-Jun
Short-tailed Albatross	*Phoebastria albatrus*	Endangered	Baja-AK+	Japan	Nov-Jun
Dark-rumped Petrel	*Pterodroma phaeopygia*	Endangered	S.Am-c.CA+	S.Am-HI	Mar-Sep
California Clapper Rail	*Rallus longirostris obsoletus*	Endangered	Historical: Humboldt-Morro Bay	Current: SF Bay	Year-round
California Least Tern	*Sterna albifrons browni*	Endangered	s.CA, Baja CA, Mex	s.CA	Apr-Aug
Marbled Murrelet	*Brachyramphus marmoratus*	Endangered (state) Threatened (federal)	n.Am., Japan, Kamchatka	old-growth forest	Apr-Aug
Bald Eagle	*Haliaeetus leucocephalus*	Endangered (state) Threatened (federal)	s.CA-AK+	n.CA-AK	Feb-Oct
California Black Rail	*Laterallus jamaicensis coturniculus*	Threatened (state)			
Marbled Murrelet	*Brachyramphus marmoratus*	Threatened	s.CA-AK	c.CA-AK	Apr-Sep
Western Snowy Plover	*Charadrius alexandrinus nivosus*	Threatened	Mex-WA+	Mex-WA	Mar-Sep
Xantus's Murrelet	*Synthliboramphus hypoleucus*	Threatened	I. off s.CA, Mex.	I. off s.CA, Mex.	
Black Tern	*Chlidonias niger*	Species of concern	Canada; n./c. USA		Apr-Sep
White-faced Ibis	*Eudocimus albus*	Species of concern	s. USA, Mex and c. Am.		
Saltmarsh Common Yellowthroat	*Geothlypis trichas sinuosa*	Species of concern	AK-Mex	Searsville Lake, CA	Apr-Sep

Table 10. Species of concern in marine and estuarine systems of central and northern California.

COMMON NAME	SCIENTIFIC NAME	STATUS	RANGE	BREEDING RANGE	BREEDING SEASON
BIRDS					
Harlequin Duck	*Histrionicus histrionicus*	Species of concern	AK-CA; n. Quebec-Long I.	Asia, AK-CA; Iceland, n. Quebec-Long I.	Apr-Sep
Bristle-thighed Curlew	*Numenius tahitiensis*	Species of concern	Micronesia, Polynesia, Marshall I., Kiribati, Tuvalu, Tokelau, Fiji, Tonga, Niue, w. Samoa, Am. Samoa, Cook I., Society I. and Tuamotu archipelago, Kermadec I., Norfolk I., Pitcairn I. Breeds: Yukon delta and c. Seward Peninsula		May-Sep
Ashy Storm Petrel	*Oceanodroma homochroa*	Species of concern	I. of c./s.CA., Baja	I. of c./s.CA., Baja	May-Oct
Elegant Tern	*Sterna elegans*	Species of concern	Gulf of CA and Baja to n.CA. Winter Peru to Chile	Gulf of CA, Baja, and San Diego	May-Sep
Aleutian Canada Goose	*Branta canadensis leucopareia*	Delisted	n.Baja-AK+	c.CA-AK	Mar-Oct
American Peregrine Falcon	*Falco peregrinus anatum*	Delisted	S.Am-AK	S.Am-AK	Mar-Oct

Table 10. Species of concern in marine and estuarine systems of central and northern California.

COMMON NAME	SCIENTIFIC NAME	STATUS	RANGE	BREEDING RANGE	BREEDING SEASON
MAMMALS					
Sei Whale	*Balaenoptera borealis*	Endangered	S.Am-AK+	S.Am-s.CA	Nov-Feb
Blue Whale	*Balaenoptera musculus*	Endangered	S.Am-AK+	S.Am-Baja	Nov-Feb
Finback Whale	*Balaenoptera physalus*	Endangered	S.Am-BC+	S.Am-Baja	Nov-Feb
Northern Right Whale	*Eubalaena glacialis*	Endangered	S.Am-AK+	S.Am-Mex	Nov-Feb
Humpback Whale	*Megaptera novaeangliae*	Endangered	S.Am-AK+	C.Am-Mex	Nov-Mar
Sperm Whale	*Physeter macrocephalus*	Endangered	S.Am-n.CA+	S.Am-Mex	Nov-Mar
Guadalupe Fur Seal	*Arctocephalus townsendi*	Threatened	n.Baja-c.CA	n.Baja	Feb-Jul
Southern Sea Otter	*Enhydra lutris nereis*	Threatened	c.CA-AK	c.CA-AK	May-Aug
Steller Sea Lion	*Eumetopius jubatus*	Threatened	s.CA-AK+	c.CA-AK	Apr-Jul
Gray Whale	*Eschrichtius robustus*	Delisted	Baja-AK	Baja	Dec-Mar

Geographic Setting of the Study Area

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