CHAPTER 2: ENVIRONMENTAL AND ECOLOGICAL SETTING

2.1 INTRODUCTION

The distribution and abundance of marine birds and mammals are strongly influenced by their environment. The purpose of this chapter is to provide a background on selected environmental and ecological features that influence the occurrence of marine birds and mammals off the north/central coast of California.

Most of the text in this chapter is excerpted or summarized from four NOAA reports, all developed by NOAA's National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment, for NOAA's Marine Sanctuary Program off California (Airamé *et al.,* 2003; NOAA NCCOS, 2003; Stumpf *et al.,* 2005; and NOAA NCCOS, 2005). Airamé *et al.,* 2003, was developed as an ecological background for Phase I of this Biogeographic Assessment off North/Central California. NOAA NCCOS, 2003 was the Phase I report of this Assessment off North/Central California. Stumpf *et al.,* 2005 was developed for the same study area to provide information on the state and variability of selected oceanographic parameters. And NOAA NCCOS, 2005 is a biogeographic assessment developed to evaluate boundary alternatives for the Channel Islands National Marine Sanctuary off southern California. When information was not from one of the four above documents, citations were provided.

2.2 ENVIRONMENTAL SETTING

The Study Area

The area of interest 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 unique in their assemblages of marine organisms. Three national marine sanctuaries, Gulf of the Farallones, Cordell Bank, and Monterey Bay, are located in coastal and marine habitats off central and northern California, from Bodega Bay, north of San Francisco, south to Cambria, near San Luis Obispo. 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. See Figures 2.2 - 2.5 for maps of bathymetry and selected marine physiographic features of the study area.

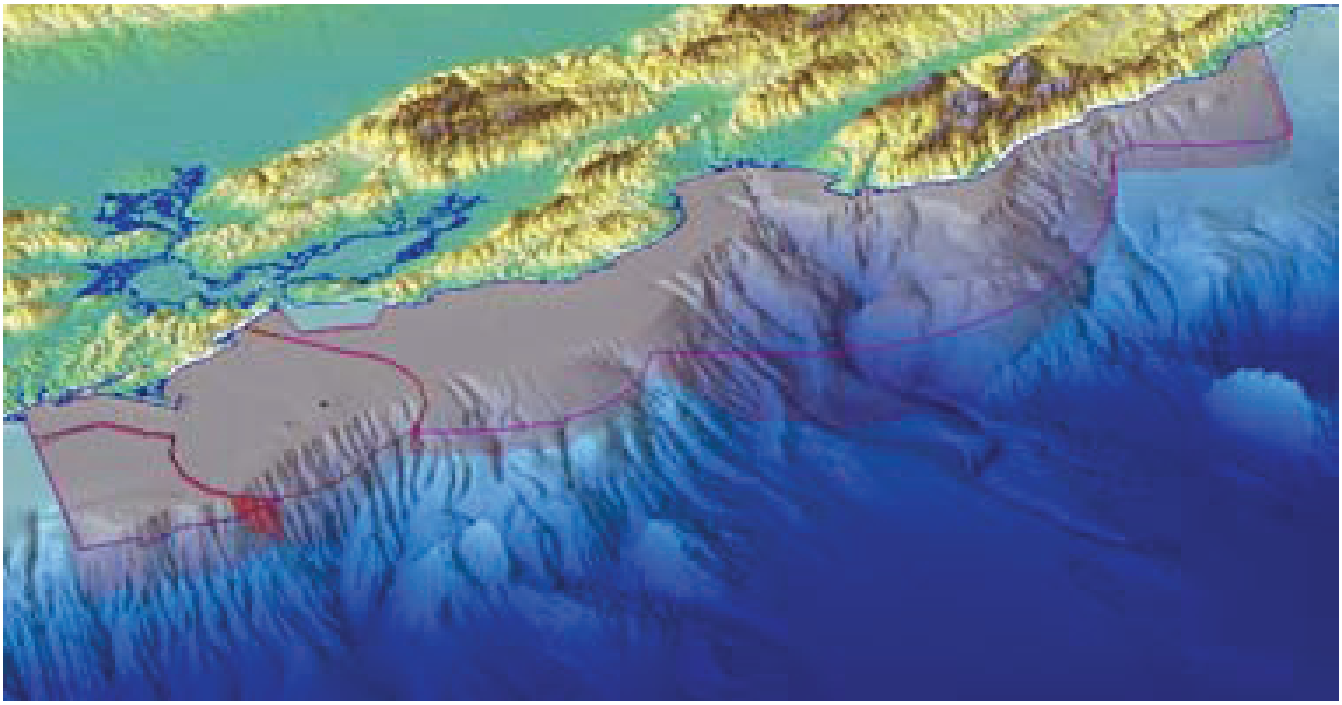
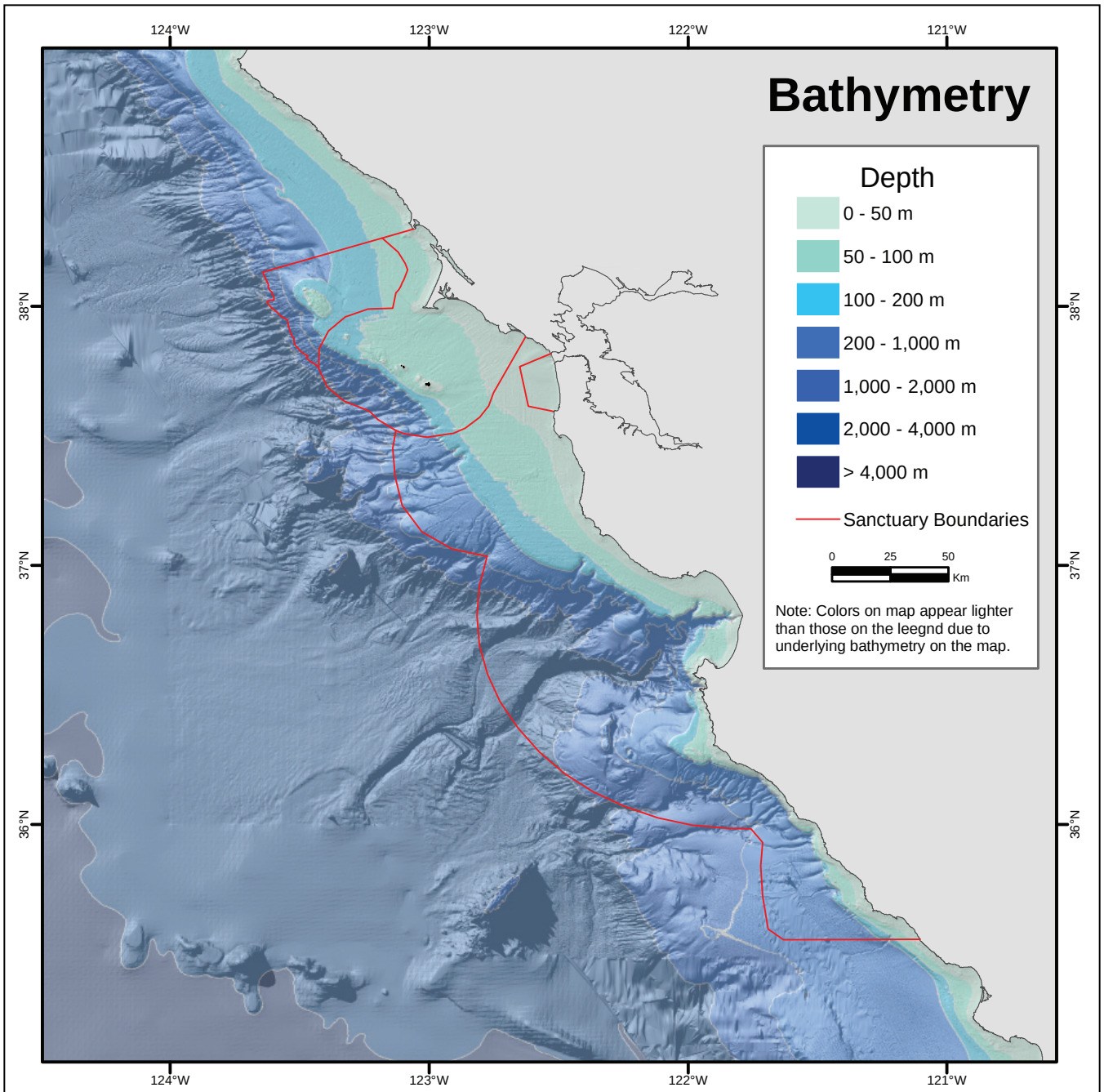


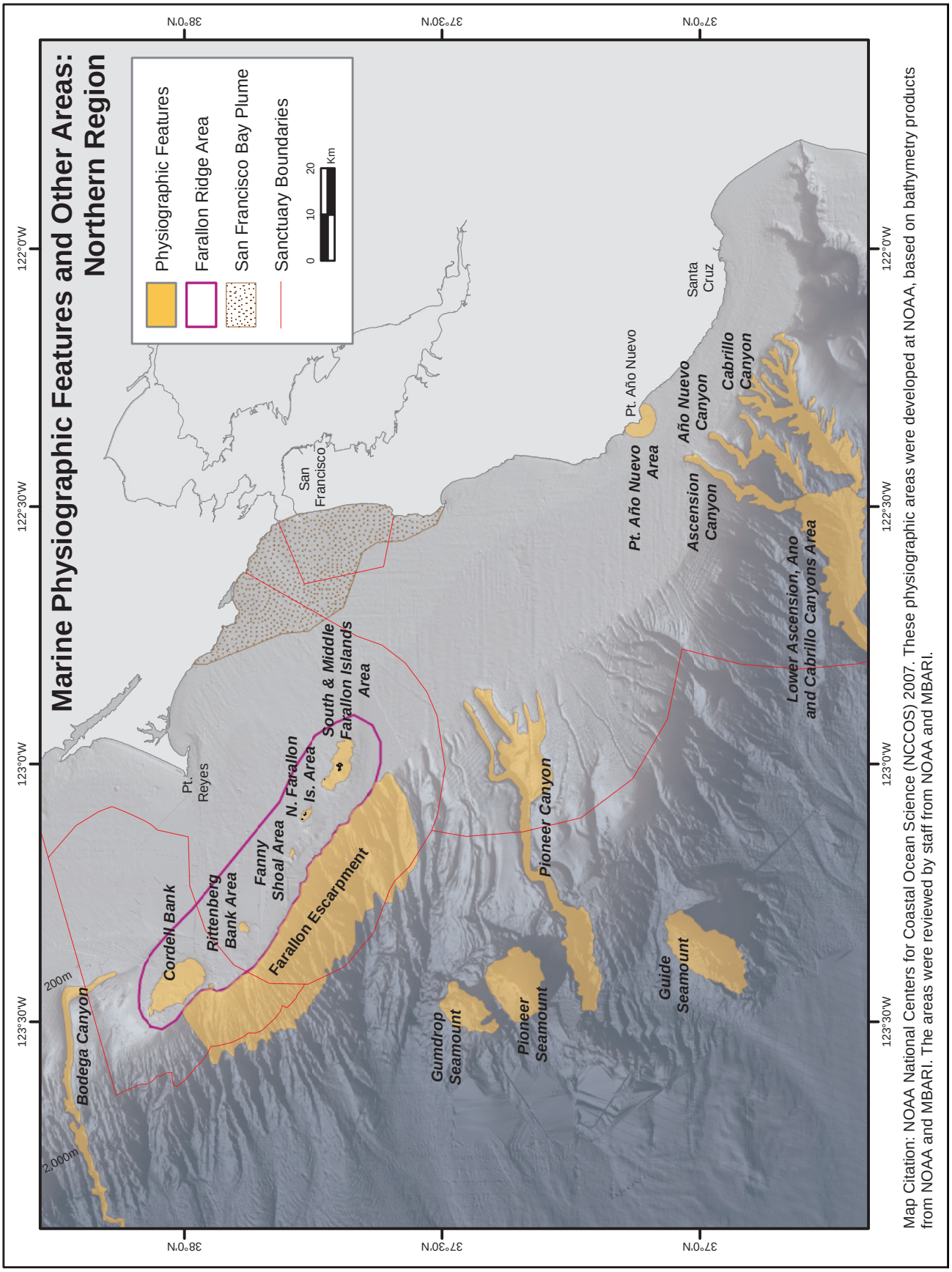
Figure 2.1. A three-dimensional view of bathymetric relief and the national marine sanctuaries off north/central California.



Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. Source Data: National Geodetic Data Center (NGDC) and Monterey Bay Research Institute (MBARI)

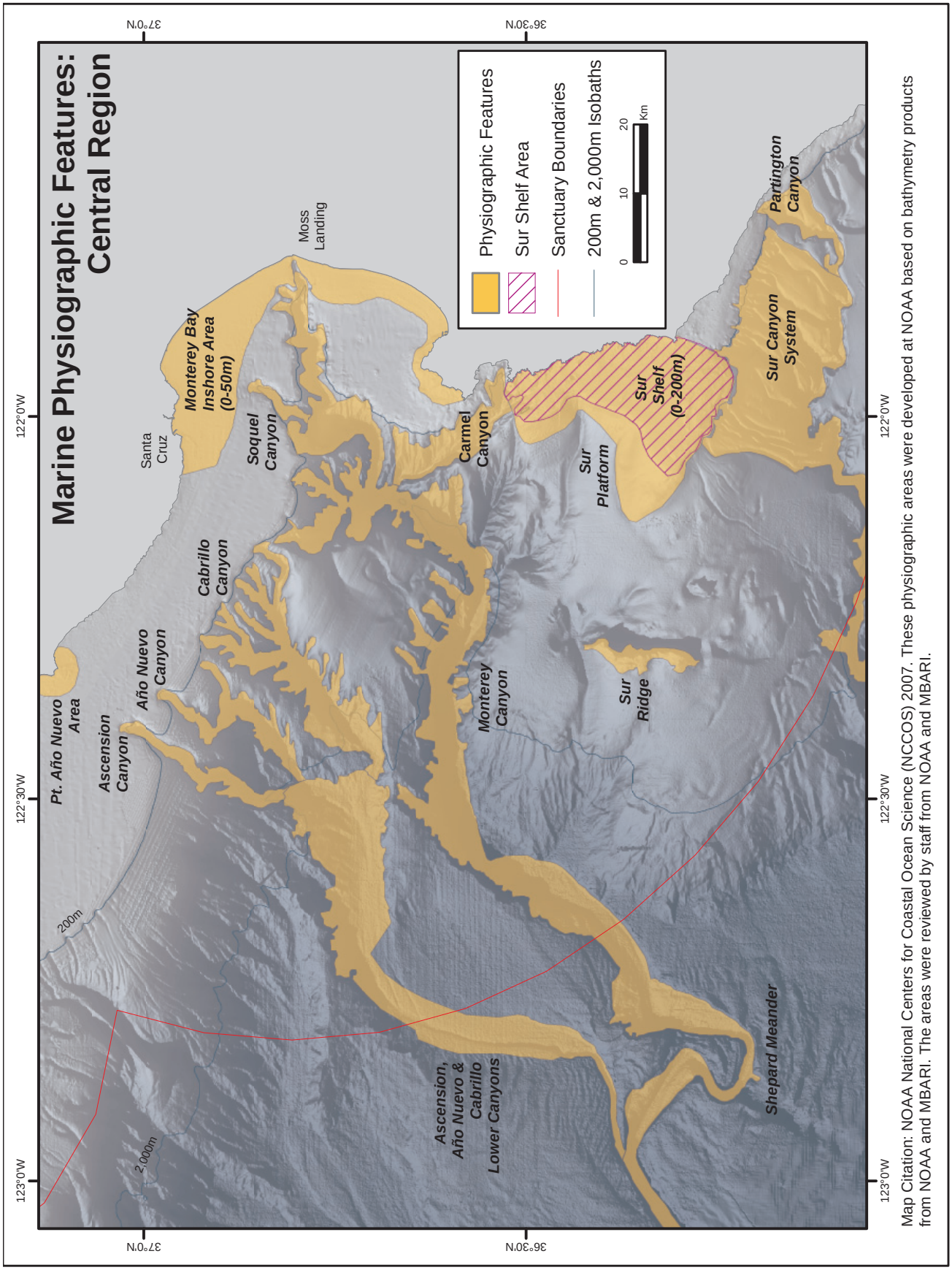
Figure 2.2. Bathymetry and depth zones of the study area.

Gulf of the Farallones National Marine Sanctuary. This marine sanctuary was established in 1981 and encompasses 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. Offshore, the Gulf of the Farallones National Marine Sanctuary extends farther south to waters west of San Mateo county. The Gulf of the Farallones extends beyond the Sanctuary's boundaries and is one of the broadest sections of the continental shelf along the lower U.S. West Coast. In addition to a relatively broad shelf, a second feature that affects this coastal ocean area is the San Francisco Bay Plume, which, under certain conditions, extends out to all areas of the Gulf (see Figure 2.3). Coastal upwelling is a third major feature, which supports tremendous phytoplankton production; upwelled water is advected offshore into the California Current as eddies and jets. These waters



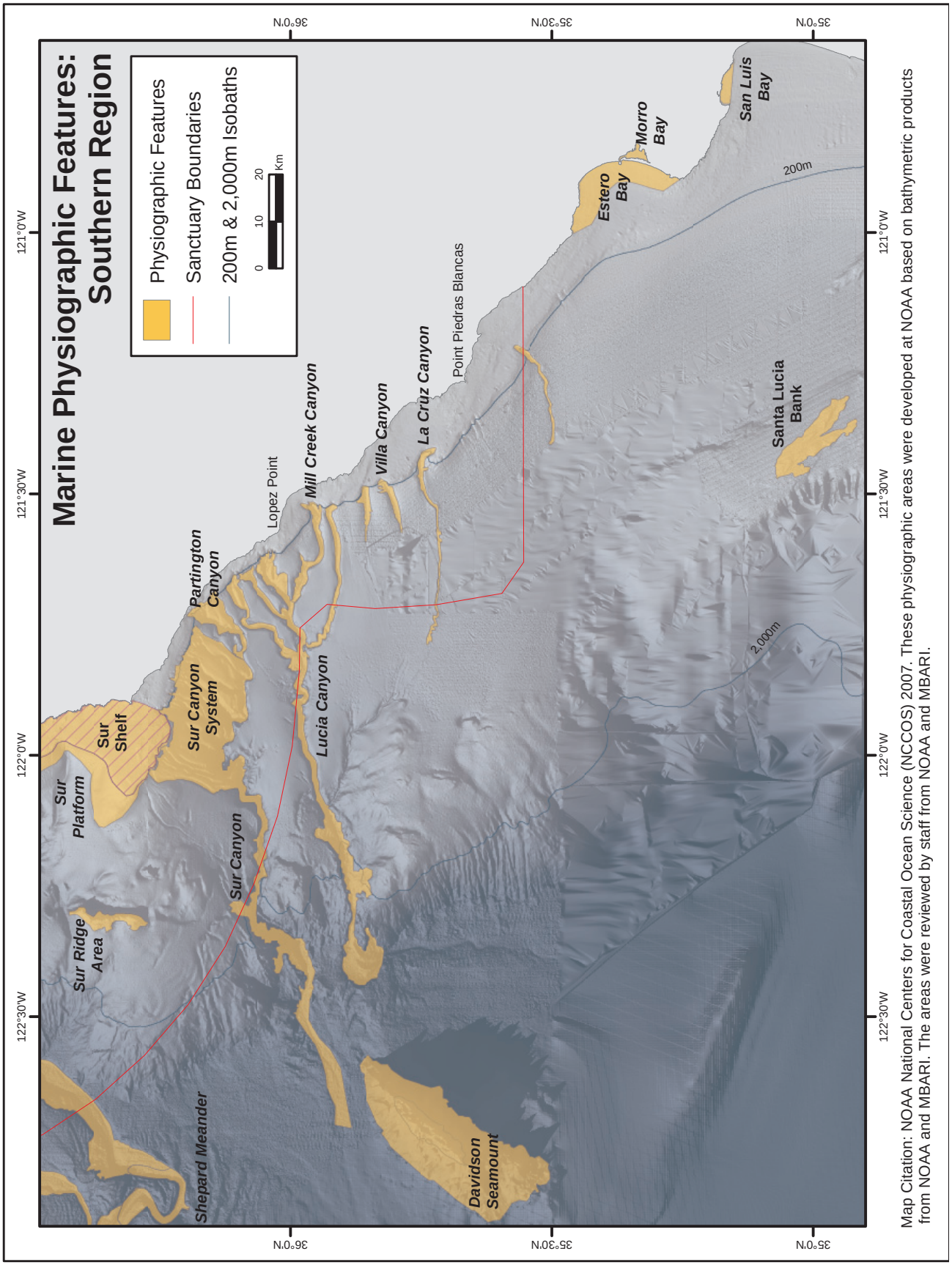
Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. These physiographic areas were developed at NOAA, based on bathymetry products from NOAA and MBARI. The areas were reviewed by staff from NOAA and MBARI.

Figure 2.3. Marine physiographic features - northern region.



Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. These physiographic areas were developed at NOAA based on bathymetry products from NOAA and MBARI. The areas were reviewed by staff from NOAA and MBARI.

Figure 2.4. Marine physiographic features - central region.



Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. These physiographic areas were developed at NOAA based on bathymetric products from NOAA and MBARI. The areas were reviewed by staff from NOAA and MBARI.

Figure 2.5. Marine physiographic features - southern region.

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 relatively important. A significant upwelling plume extends south from Pt. Arena along the shelf break influencing the outer waters of the Gulf. The fourth feature of this sanctuary is the Farallon Islands group, which are protected as a National Wildlife Refuge. These islands 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. Additionally, white sharks are attracted to marine mammal colonies on the Farallon Islands, Point Año Nuevo, and Año Nuevo Island.

Habitats within the Gulf of the Farallones National Marine Sanctuary include rocky shores, sandy beaches, estuaries, lagoons and bays, a broad continental shelf, the Farallon Islands, the subsurface Farallon Ridge and Escarpment, and the waters overlying these features.

Cordell Bank National Marine Sanctuary. This marine sanctuary was designated in May 1989, and includes an area of 1,362 km^2 off the coast of central California. 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 that reaches the shallowest depths of the Bank 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.

Monterey Bay National Marine Sanctuary. This marine sanctuary was established in 1992, and is the largest of the 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. Waters of the Sanctuary reach 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 that continues north into 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. The diverse array of habitats in the Sanctuary is home to over 30 species of marine mammals, 94 species of seabirds, at least 345 species of fishes, and numerous invertebrates, and plants, including kelp.

Ocean Seasons

While certain geological and biological features are evident along particular regions of the coast, the same oceanographic processes and climatic phenomena operate throughout the study area. Over a 12-month period, the study area has three distinct oceanographic periods or seasons that vary with respect to prominence and location of ocean currents. These periods, characterized by upwelling (spring/summer), wind relaxation (fall), and winter storms (winter), are associated with different degrees of upwelling and downwelling. The timing and intensity of these "ocean seasons" vary from year to year. The amount of production in surface waters and the ability of organisms to disperse is directly impacted by these processes. In response to these seasons, the abundance and types of organisms present in a given area change throughout the year.

Most of the data mapped in this document were organized by ocean season or all available data were averaged (year-round). See Figure 2.6 for maps of average sea surface temperatures (SST) during ocean seasons along with a map of an inter-annual SST average from 1985-2005. For purposes of data analysis for marine birds and mammals, the ocean seasons were defined as follows:

Upwelling Season (March 15 - August 14, or Spring/Summer). The upwelling season generally occurs between mid-March and mid-August. Strongest upwelling occurs during May and June. 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 identified as cool sea surface temperatures in satellite images. Although the duration and intensity of upwelling is variable, 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.

Oceanic Season (August 15 - November 14, or Fall). A period of wind relaxation generally occurs from mid-August through mid-November. 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. Relaxation disappears after the onset of upwelling winds or the return of winter storms.

Davidson Current Season (November 15 - March14, or Winter). The winter storm period generally occurs between late November and mid-March. 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 in the study area.

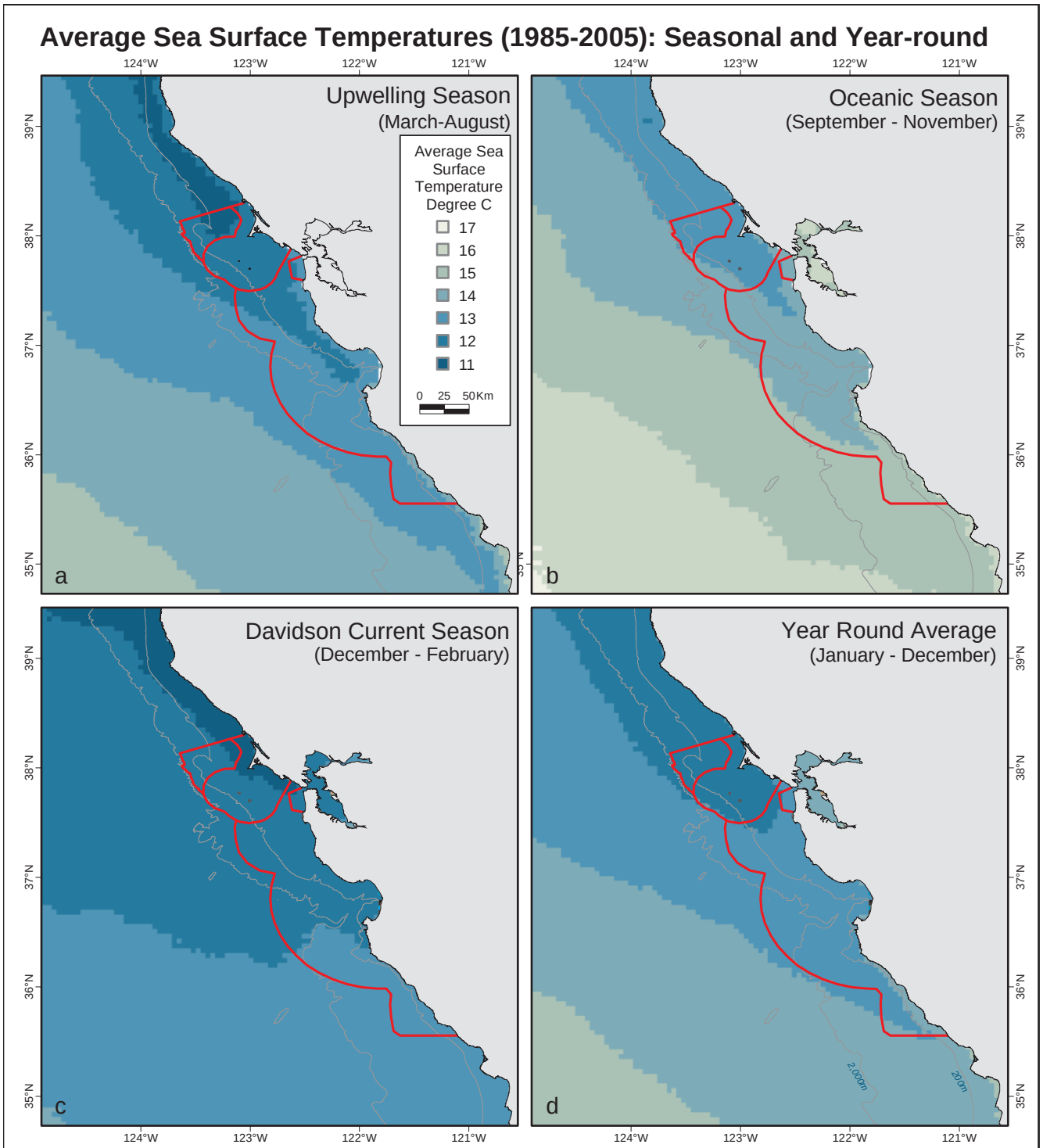
Longer-Term Cyclical Climate Perturbations

Longer-term climatic phenomena influencing the region include El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation, and global warming. The recurring ENSO pattern is one of the strongest in the ocean-atmosphere system. 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. 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, sometimes leading to widespread starvation, but usually decreased reproductive success.

Every 20-30 years, the surface waters of the central and north Pacific Ocean (20°N and poleward) shift several degrees from the mean temperature. Such shifts in mean surface water temperature, known as the Pacific Decadal Oscillation (PDO), have been detected five times during the past century, with the most recent shift in 1976. 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. In response to these three phenomena, some species have shifted their geographic ranges northward, altering the composition of local assemblages.

El Niño Southern Oscillation (ENSO). 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 and other portions of the world ocean. Particularly strong El Niño events occurred during 1957-1958 and 1982-1983, and one the strongest El Niños on record occurred in 1997-1998. The opposite of El Niño is La Niña, a relatively coolwater event, and also part of ENSO. Strong La Niñas occurred in 1974-1975, 1977-79, 1985-86, and 1998-2000. See Figures 2.8, 2.9 and 2.10 for graphs and maps illustrating ENSO and its effects.

Temperature changes and other environmental variables associated with El Niño and La Niña 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 up-



Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. Data Source: Varis Ransi of NOAA provided data and analysis from the Pathfinder version 5.0 Data Set, dervied from Advanced Very High Resolution Radiometer (AVHRR) satellite data, from NOAA polar-orbiting satellites, and NOAA's National Oceanographic Data Center (http://pathfinder.nodc.noaa.gov).

Figure 2.6. Average sea surface temperature (1985-2005): by ocean season and year-round average.

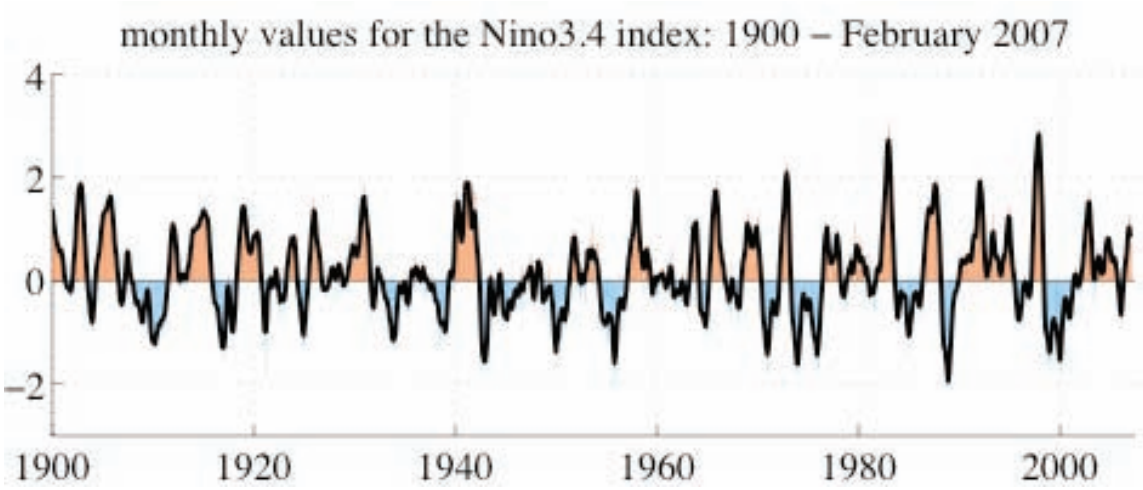


Figure 2.7. Tracking El Niño's and La Niña's in the North Pacific – red is warm and represents an El Niño, blue is cool and represents a La Niña. 1998 was a strong El Niño year. Figure provided courtesy of Nathan Mantua, University of Washington Climate Impacts Group, and Steven Hare, International Pacific Halibut Commission.

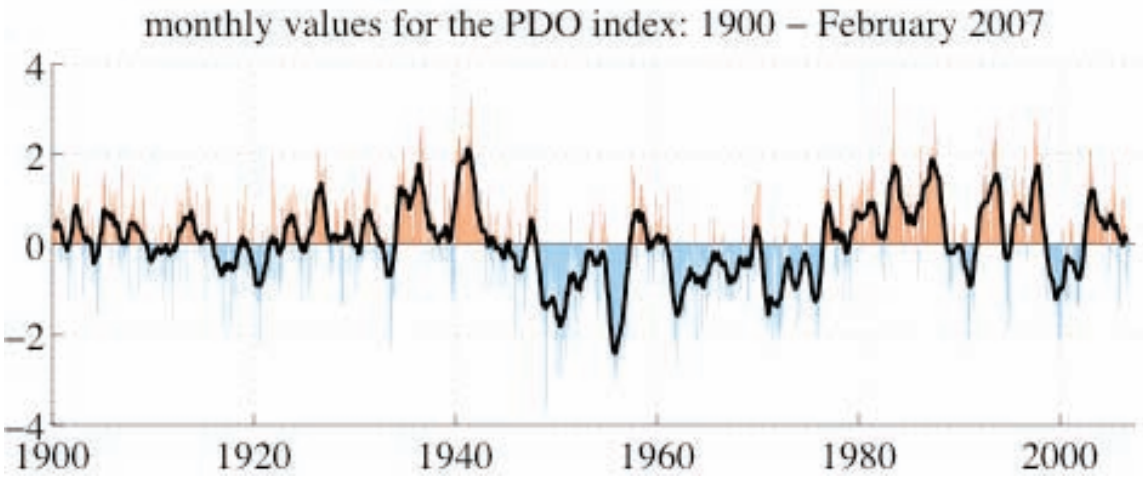


Figure 2.8. Tracking the Pacific Decadel Oscillation (PDO) Index. http://jisao.washington.edu/pdo/ A cool period occurred from 1947 to 1976, followed by a warm period from about 1977 to about 1998. Figure provided courtesy of Nathan Mantua, University of Washington Climate Impacts Group, and Steven Hare, International Pacific Halibut Commission.

welling regions of the eastern Pacific Ocean; the converse is true of La Niña. During El Niño, the thermocline that separates warm, nutrient poor surface waters from colder, nutrient rich waters below occurs much deeper than normal. 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 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. Examples of warm, cool and neutral periods of sea surface temperature affected by ENSO events are shown in Figure 2.9.

Without this flush of phytoplankton production, zooplankton biomass declines greatly. 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 events, seabirds 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 Pelag-

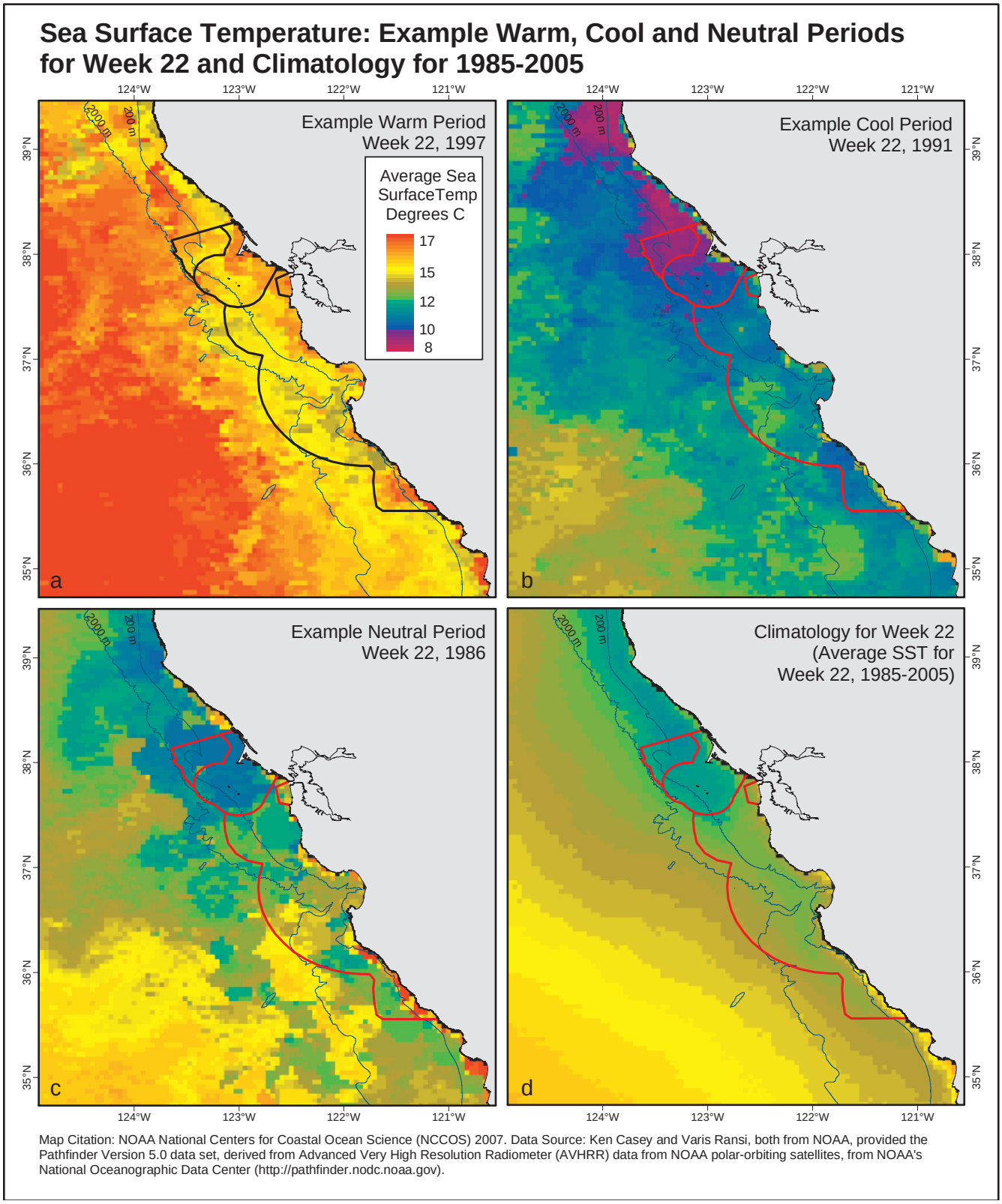


Figure 2.9. Sea surface temperature (1995-2005): examples of warm, cool and neutral periods for week 22 (in the upwelling season) and the 21-year average.

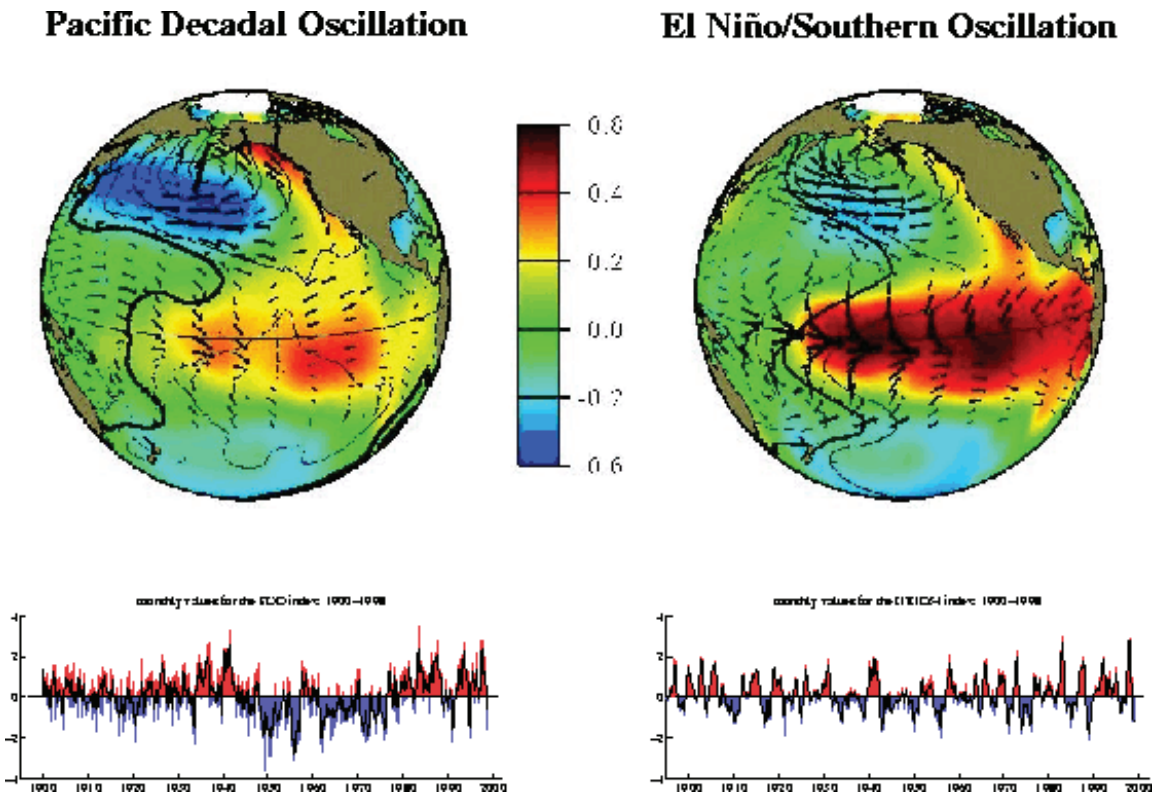


Figure 2.10. Comparing sea surface temperatures during a warm phase of the Pacific Decadel Oscillation and the El Niño Southern Oscillation. Figures provided courtesy of Nathan Mantua, University of Washington Climate Impacts Group, and Steven Hare, International Pacific Halibut Commission.

ic 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.

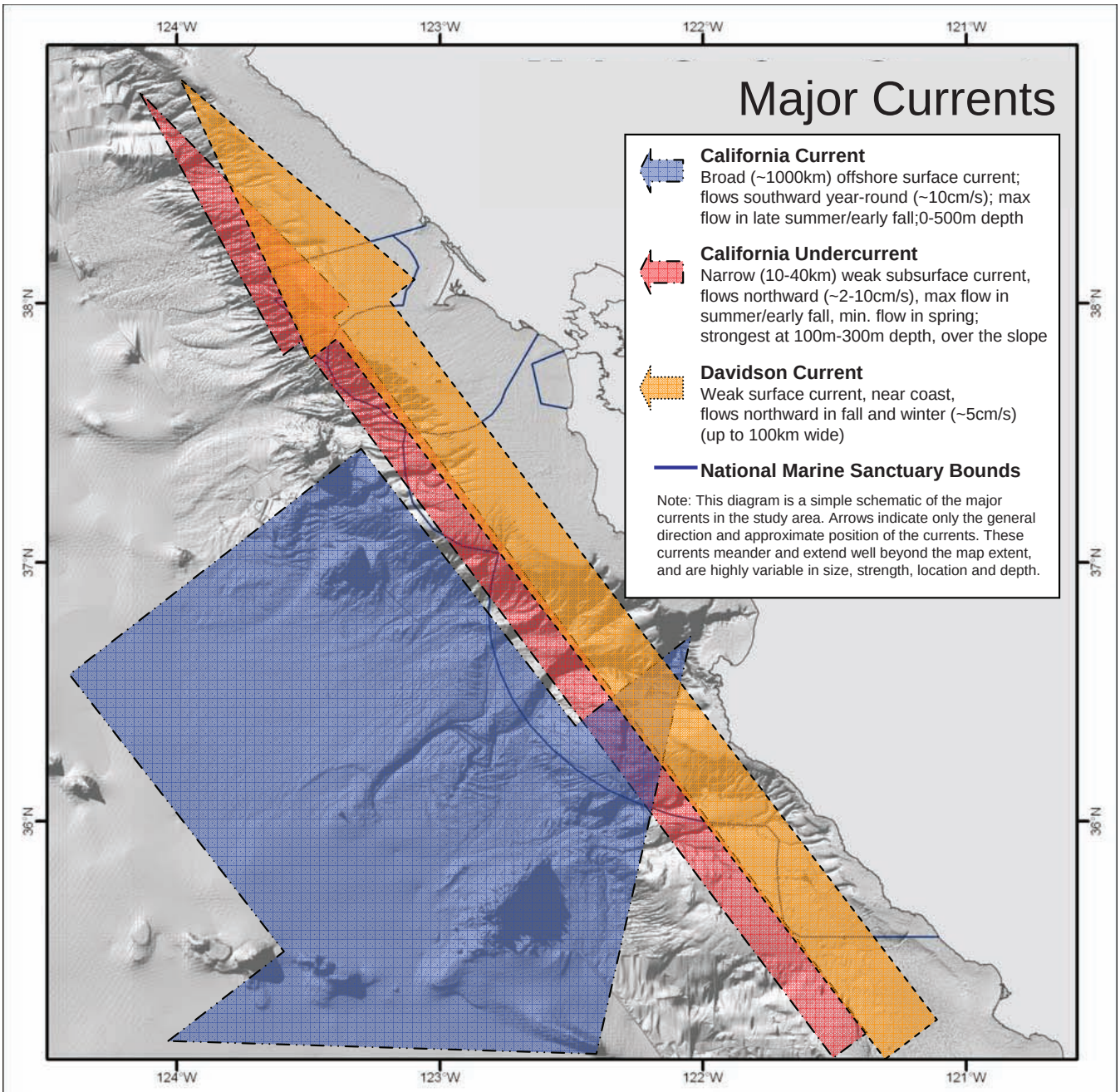
Breeding success among seabirds at the Farallon Islands depends on multiple variables, including the strength of the California Current, the intensity of upwelling, and interannual and interdecadal fluctuations. The numbers of warm-water species (including Black-vented Shearwater, and Black and Least 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 (e.g., dolphins and toothed whales) 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.

Cool water seabird species (e.g., Black-legged Kittiwake and Sooty Shearwater) migrate further off-



Map citation: NOAA National Centers for Coastal Ocean Science, 2007. After Batteen et al., 2003.

Figure 2.11. A schematic of two major surface currents and a subsurface current in the study area.

shore and north of their usual range during El Niño events. However, cool-water species return to the California coast with the onset of La Niña conditions and displace warm-water species prevalent during El Niño events.

The Pacific Decadal Oscillation. The Pacific Decadal Oscillation (PDO) is a recurring pattern of climate variability that is highly correlated with sea surface temperature in the northern California Current area; thus we often speak of the PDO as being in one of two phases, a “warm phase” or a “cool phase,” according to the sign of sea–surface temperature anomalies along the Pacific Coast of North America; see Figure 2.8 and 2.10. These phases result from winter winds in the North Pacific: winter winds blowing chiefly from the southwest result in warmer conditions in the northern California Current, and conversely, when winds blow chiefly from the north, upwelling occurs, leading to cooler

conditions in the northern California Current (Citation from: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/ca-pdo.cfm).

In Figures 2.8 and 2.10, a warm phase occurred from 1925 to 1946 (indicated in red), and a cool phase from 1947 to 1976 (in blue). From 1977 to about 1998, another 21-year warm phase occurred. However, since 1998 the PDO metric has been oscillating with no clear indication of warm or cool. It is not clear at this time what is driving this metric.

Numerous changes in terrestrial and marine ecosystems are associated with the PDO. 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 ever recorded occurred during the late stages of the warm phase of the PDO.

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 PDO, 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. In the return of cooler waters in 1999, macrozooplankton rebounded to the long-term mean for the period of 1951-1984.

Global Warming. Ocean waters off the coast of California have warmed considerably over the last 40 years. These changes appear to be driven by a complex interaction between natural climate cycles, such as the PDO, and perhaps 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). In the study area, some species appear to have shifted their geographic ranges north in response to increased water temperatures. 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 (Veit *et al.,* 1996). 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 PDO, may contribute to these biological changes.

Ocean Circulation and Currents

Circulation in the study area is dynamic and results from the interaction of wind, large-scale ocean currents, local geography, and the topography of the ocean bottom. The California Current System (CCS) forms the eastern portion of the clockwise North Pacific Subtropical Gyre; it is predominantly a wind-driven system and encompasses three major currents: the equatorward California Current, the poleward California Undercurrent and the poleward Southern California Countercurrent.

The prevailing wind system of the North Pacific Ocean is the mid-latitude Westerlies, a belt of winds that blow from west to east between 30°N and 60°N. These westerly winds create the North Pacific Current that pushes water away from Asia towards the west coast of North America. As this trans-Pacific flow converges toward the North American coastline, part of it is deflected equatorward forming the California Current, and part is deflected north to become the Alaska Coastal Current.

The California Current. The California Current has a significant effect on the study area; it is a surface current and is dominant year round, but slows generally in the late fall/winter. The Current appears as a broad, southeastern flow that transports cool, fresh, nutrient and oxygen-rich subarctic water equatorward. The California Current system extends about 3,000 km from north to south, from the Straight of Juan de Fuca (Vancouver Island) to

Baja California Sur. From east to west, the Current extends from the shelfbreak to an offshore distance of approximately 1,000 km, with strongest speeds at the surface and extending to at least 500 m in depth (Hickey, 1998), while the inshore section of the current is limited to the upper 200 m over the continental slope (Hickey, 1979). North of Point Conception, the core lies about 100-200 km from the coast, with maximum equatorward velocities of 5-10 cm/s (Chelton, 1984). South of Point Conception, the core of the California Current flows further from the coast, between 300-400 km offshore (Lynn and Simpson, 1987), with average speeds generally less than 25 cm/s (Reid and Schwatzlozse, 1962). Seasonal maxima in current speeds occurs in the summer to early fall.

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 east and the current continues southward and offshore.

The California Undercurrent. Underlying the California Current and the Southern California Countercurrent is a subsurface flow called the California Undercurrent, a narrow (10-40 km) poleward flow that extends the length of the coastline from Baja California to at least 50°N (Hickey, 1998). Originating in the eastern equatorial Pacific, the California Undercurrent can be characterized by a warm, saline, oxygen and nutrient-poor signature (Neander, 2001). Peak northward speeds of 30-50 cm/s usually occur in summer to early fall, being stronger at depths 100-300 m, and can be continuous over distances of more than 400 km along the continental slope (Collins *et al.,* 1996; Pierce *et al.,* 2000) or can break into separating, mesoscale jets (Cornuelle *et al.,* 2000; Barth *et al.,* 2000).

The Davidson Current. During winter, the inshore Davidson Current is observed at the surface north of Pt. Conception, when the flow of the California Current is reduced. From November through January, the northward-flowing Davidson Current is the dominant current below 100 m along the shelf break. 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 generally moving northwest in the study area. The return of winds from the northwest in January slows the northward surface expression of the Davidson Current.

The Southern California Countercurrent. This current draws warmer water from the south and forces the water northwest through the southern Channel Islands and the Santa Barbara Channel (Dailey *et al.,*1993). Additionally, some of the countercurrent is deflected west into the California Current south of the northern Channel Islands, resulting in a seasonal counterclockwise gyre in the Southern California Bight called the Southern California Eddy (Lynn and Simpson, 1987; Hickey, 2000). In spring, when the countercurrent is at its minimum northward flow, equatorward surface flow prevails in the Southern California Bight (Hickey, 1993). Hickey, 1979, suggested that the Southern California Countercurrent may combine with the poleward inshore Davidson Current north of Point Conception, the latter having peak flows during winter.

The ecology of the study area is closely tied to the processes of the California Current System (CCS). The CCS exhibits high biological productivity, diverse regional characteristics, and is populated with semi-stationary jets and eddies (Miller *et al.,*1999). The confluence of currents off Point Conception affects the abundance and distribution of species in the study area. Waters north of Point Conception have been classified as part of the Oregonian Province, characteristic of the coast of northern California, Oregon, and Washington. Waters south of Point Conception have been classified as the San Diegan, or Californian Province, characteristic of warm subtropical waters off southern California and Baja California, Mexico. Although many species are strongly separated by these biogeographic zones under “normal” conditions, species of the subtropical zone may occasionally extend their ranges north to central and northern California during unusually warm oceanographic events, such as El Niño or a warm phase of the PDO.

Eddies, Jets and Filaments. Ocean flows along the California coastline do not smoothly parallel the coastline. Rather, they are punctuated by eddies, jets, filaments (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 in the Gulf of the Farallones, known as the San Francisco Eddy. A second semi-permanent eddy extends out from Point Año Nuevo, and another eddy 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, for a distance of up to several hundred kilometers. These oceanographic features affect the distributions of chlorophyll and plankton. 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. Internal waves travel below the surface and can generate complex patterns of flow over the continental shelf and slope. These waves form as marine tides and concentrate over the shelf break, particularly near irregular features such as submarine canyons. 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. Although many oceanographic processes have been described in great detail, our understanding of their linkages to ecological processes is just unfolding.

Coastal Upwelling

Upwelling occurs primarily during the spring and summer along much of the California coast, and upwelling plumes expand southward from headlands. Strong coastal upwelling along central California arrests summer heating, depresses seasonal cycles of sea surface temperature (SST) within several hundred kilometers of the coast, and determines annual and semiannual phases inshore (Legaard and Thomas, 2006).

Circulation in the study area is strongly influenced by coastal upwelling, a process regulated by prevailing winds and the orientation of the coastline. In the northern hemisphere, Ekman transport causes surface water to move ~45 degrees to the right of the wind direction. Where surface water is pushed away from the coastline, deeper nutrient rich water rises to the surface creating an upwelling current. Along the north-south oriented coast of California, winds blowing from the north move surface water westward, away from the coastline, creating upwelling currents that bring colder water to the surface (San Francisco State University, 2000). North of Santa Cruz (>37°N), a strong seasonal contrast in winds results in favorable upwelling conditions in summer contrasted by downwelling during winter storms (Strub and James, 2000). From 35-37°N, modest storm activity results in monthly mean winds that remain favorable to upwelling year-round (Strub and James, 2000). In contrast, and south of the study area, upwelling is rare along the mainland coast of the Santa Barbara Channel because the headlands at Point Conception shelter the east-west oriented channel from the strong northwesterly winds that generate upwelling (Love *et al.,* 1999).

Upwelling is closely associated with coastal morphology and tends to occur off points along the eastern boundary of the North Pacific Ocean. Point Conception is the southernmost major upwelling center on the west coast of the United States, and marks a transition zone between cool surface waters to the north and warm waters to the south (Love *et al.,* 1999). Pt. Diablo, Oregon, is the northernmost point that generates an upwelling plume and eddy.

Major upwelling centers in the study area (i.e., those that generate plumes and eddies) are located near Points Arena, Reyes, Año Nuevo, and Sur; areas of upwelling tend to occur south of these locations. Particularly strong upwelling also occurs in the area between Point Arena and Point Reyes. Coastal mountains concentrate and intensify winds in this region, increasing the offshore movement

of water. Off Pt. Reyes, upwelling brings cool, nutrient-rich water to the surface, moving it 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. Chlorophyll abundance is also associated with fronts, eddies and regions of upwelling. Upwelled waters in some regions of the world are high in nutrients, but do not stimulate large blooms of phytoplankton because 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. Figure 2.12 highlights seasonal changes and year-round averages of chlorophyll-*a*, a key component of overall productivity in the study area.

Oceanic Fronts

Patterns in sea surface temperature (SST) influence the distribution of marine species and habitats, particularly in areas of persistent SST fronts. The convergence of currents, the boundaries of adjacent water masses and the process of upwelling result in dynamic biological and physical convergence zones, or fronts, which influence the abundance and distribution of many organisms, including pelagic juvenile fishes, plankton, seabirds and marine mammals. Fronts are often identifiable by dramatic shifts in the sea surface temperature. Since fronts are areas of convergence, biota are often concentrated either passively, in the case of plankton, or actively, as in the case of nekton seeking to feed more efficiently on the plankton. Large shifts in SST, and consequently frontal boundaries, affect the spatial and temporal distribution of organisms. Off central California, ocean fronts become especially evident during upwelling periods, when waters of different properties are brought together. The edges of an upwelling plume or eddy, for instance, form a front with adjacent water. As upwelling increases in the summer, the ocean fronts move offshore. In the fall, ocean fronts begin to decrease and there are relatively few in the winter (December-February). Figure 2.13 shows seasonal and year-round estimates of offshore sea surface temperature fronts.

2.3 MARINE BIOGEOGRAPHIC SETTING

There are two coastal oceanic biogeographic provinces along the California coast: Oregonian and San Diegan. The Oregonian Province extends primarily from southeastern Alaska to Point Conception and is part of the Eastern Boreal Pacific Region (Briggs, 1974, 1995). The Oregonian Province extends southward beyond Point Conception along the outer islands of southern California, and in part reappears in upwelling areas off Baja California (Hubbs, 1949).

The San Diegan Province (part of the warm-temperate California region, which also includes the Cortez Province of the Gulf of California) extends from Point Conception, California to Magdalena Bay, Baja California Sur, Mexico (Briggs, 1974). However, in warm-water years, some San Diegan species extend their ranges northward.

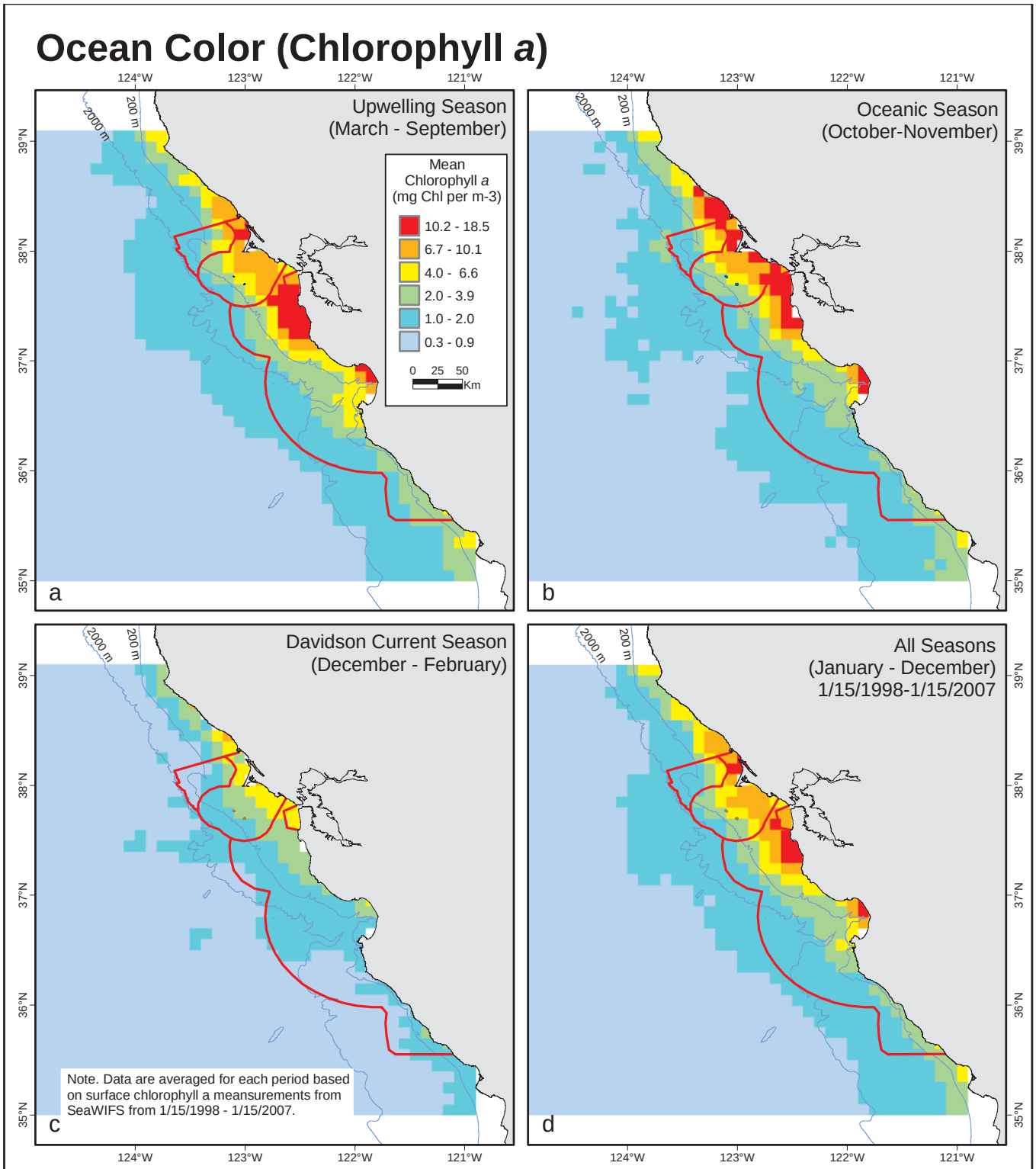
Coastal biogeographic provinces differ in their distribution with depth, with the Oregonian Province extending further south with each successive benthic life zone (Allen, 2006). For example, sometimes submergence occurs, with species that occur in shallow depth zones in central and northern California occurring in deeper life zones in southern California (Hubbs, 1949; Allen, 2006a and b).

Offshore, only one of two oceanic provinces of the cold-temperate, Ocean Boreal Pacific Region occurs in the study area (McGowan, 1971). The Subarctic Province extends south along the California coast to Cape Mendocino, just north of the study area, and the Transition Zone extends south from Cape Mendocino through the study area, to Magdalena Bay.

2.4 ECOLOGICAL SETTING: SELECTED MARINE HABITATS USED BY MARINE BIRDS AND MAMMALS IN THE STUDY AREA

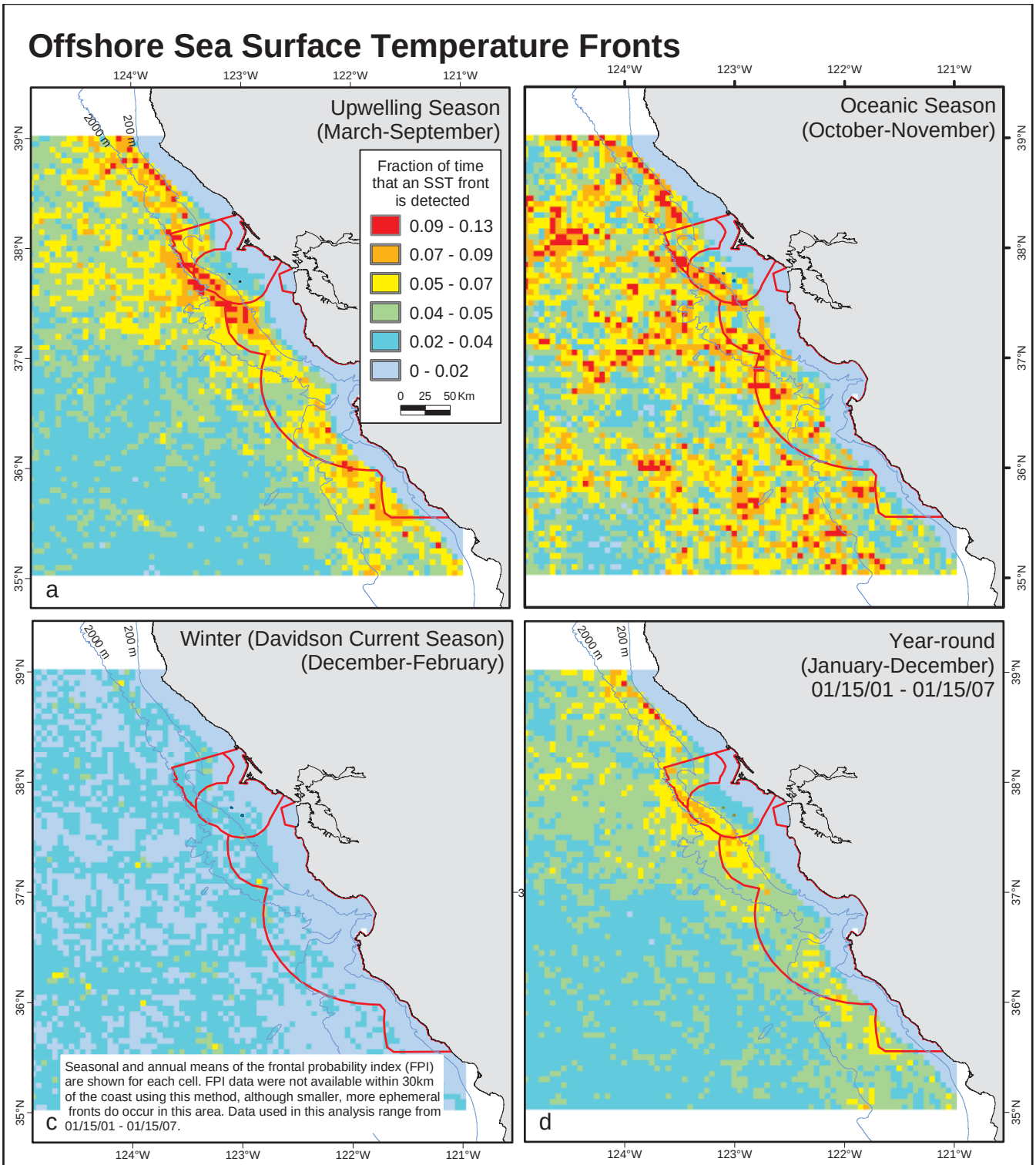
Below are discussions adapted from Airamé *et al.,* 2003 of three major marine habitats occupied by different assemblages of the marine birds and mammals of the study area:

- neritic and epipelagic ocean waters
- submarine canyons and waters above
- offshore islands and adjacent waters



Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. Data from the SeaWIFS sensor on the Orbview-2 satellite, provided by NASA/Goddard Space Flight Center and GeoEye, Inc. Regional analysis provided by NOAA CoastWatch, West Coast Node.

Figure 2.12. Ocean color (chlorophyll *a*), by ocean season and year-round.



Map Citation: NOAA National Centers for Coastal Ocean Science (NCCOS) 2007. Data products are courtesy of NOAA Coastwatch, West Coast Node. The maps are based on methods described in Breaker, L.C., T.P. Mavor and W.W. Broenkow, 2005 and Castelo, R.M., J.A. Barth and T.P. Mavor, 2005. These products are based on sea surface temperature (SST) data from the NOAA Geostationary Operational Environmental Satellites (GOES).

Figure 2.13. Offshore sea surface temperature fronts, by ocean season and year-round.

Other habitats that marine birds and mammals use include sandy beaches, lagoons and estuaries, sandy beaches, rocky intertidal, kelp forests, and coastal old growth forests. Descriptions of these habitats are not included here, but they can be found in Airamé *et al.,* 2003.

Neritic and Epipelagic Habitats

The vast majority of the three marine sanctuaries consist of open ocean habitats. These waters are classified into two primary zones, neritic (waters over the shelf, 0-200 m) and oceanic (waters beyond the shelf, from the surface to 200 m depth).

Several pelagic and benthic life zones occur in this region (Allen and Smith, 1988). Pelagic life zones consist of the Neritic Zone (water column over shelf to 200 m isobath) and three oceanic zones (over slope and basins): Epipelagic Zone (surface to 200 m); Mesopelagic Zone (200-1,000 m); and Bathypelagic Zone (1,000-4,000 m). Benthic life zones (Allen, 2006a and b) include Intertidal, Inner Shelf (0-30 m), Middle Shelf (30-100 m), Outer Shelf (100-200 m), Mesobenthal (Upper) Slope (200-500 m), and Bathybenthal Slope (500-1,000 m). A separate Estuarine Zone consists of both water-column and benthic species (Hedgpeth, 1957). Bathymetry of the study area is shown on Figure 2.2.

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, birds 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, the primary food for protozoans, zooplankton, bivalves, and larval fishes, such as anchovies and sardines. 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 plumes and jets may displace waters, nutrients, and phytoplankton production offshore. Throughout the year, phytoplankton are important. Microzooplankton depend on phytoplankton production for food, and in turn, 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.

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 offshore island habitats, below). 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 neritic and 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 and juvenile stages, which are important seabird and marine mammal prey. 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.

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 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 (killer whales), and sperm whales). The most important forage or prey species of squid along the California coast are *Loligo spp*., which concentrate in relatively shallow waters over the shelf, especially in Monterey Bay. Also, a large squid that initially invaded from waters to the south, *Dosidicus gigas*, is increasingly altering food webs owing to intense predation on fish, especially along the shelfbreak and outer shelf. 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 and predation pressure from fisheries. 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 (where upwelling, and hence offshore transport, is at a minimum) 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: humans; 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.

Sharks are predators of marine birds and mammals in the study area. 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 present in small numbers. 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 copepods as their pri-

mary 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 nonbreeding 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. Most of these seals are from the Pribilof Islands, with a small number of seals from the Channel and Farallon Islands. Harbor seals, which are found primarily 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 (or pelagic) waters, with occurrence patterns stratified by ocean depth. Common dolphins (*Delphinus spp.*) are the most abundant cetaceans off California, but most 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 (or killer whale, *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.

<u>Ecological Linkages of Neritic and Epipelagic Communities with Other Ecosystem Components</u>. 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.

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 catenell*a 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.

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). Euphausiids are a common source of food that may be the primary reason for aggregation of midwater species, such as the market squid, Pacific hake, plainfin midshipman, Pacific herring, juvenile rockfishes, Pacific butterfish, and speckled and Pacific sanddabs. The lowest macrozooplankton biomass of central California was recorded in 1998. In 1999, macrozooplankton abundance 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, 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.

Human activities in the epipelagic and neritic habitats, including recreational and commercial fishing and boating, may affect nontargeted species, including turtles, seabirds, and marine mammals. Seabirds, particularly albatross, are frequently caught on hooks set out on long-lines of commercial fisheries. In trawl fisheries, seabirds may be attracted to the catch and become tangled in nets as they are gathered. Industrial fishing has had profound effects on ocean food webs worldwide including the California Current. 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 many 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 in the North Pacific 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 stock off California/Oregon and Washington has increased to approximately 2,541 individuals. All three species are currently listed as endangered, as their numbers now are still estimated to be far below historical levels.

Hunting of pinnipeds for meat, oil and fur contributed to the decline 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 and other coastal fish stocks from over fishing; 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 Federally threatened species.

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. They were formed by river erosion when sea levels were approximately 200 m lower, during the Last Glacial Maximum and previous glacial periods. 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. Figures 2.3-2.5 show selected submarine canyons and other marine physiographic features in the study area.

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 of Submarine Canyons and Other Marine Ecosystems. Cool, nutrient-rich waters accumulate at upwelling regions such as Point Año Nuevo and Point Sur. These waters and associated nutrients can then be transported, in this example, 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 often, at least seasonally, feed on dense swarms of euphausiids near the Monterey Canyon.

Offshore Island Communities

The islands off 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 evolved as a consequence of their isolation and adaptation to conditions 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, Año Nuevo Island is a state reserve, and Pt. Reyes is protected within the Pt. Reyes National Seashore.

The Farallon Islands, located approximately 50 km west of San Francisco, are the only major offshore islands in central and northern California (see Figures 2.3 and 2.14). 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 off Point Año Nuevo and south of Half Moon Bay and Pigeon Point (see Figure 2.3). 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 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 of Offshore Islands with Other Ecosystem Components. 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; (Peregrine Falcons, which perhaps once bred there, are present for the fall-spring period). Smaller colonies of most of these species also breed at Point Reyes and Año Nuevo Island. Other than these locations, breeding

Figure 2.14. Aerial view of South Farallon Islands.

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 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 there in burrows on marine terraces and talus slopes; it also breeds 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). Tufted Puffins (*Fratercula cirrhata*) breed on the Farallon Islands each year; and a few pairs have attempted to breed at Point Reyes. After the breeding season, auklets and murres leave breeding sites and disperse along the coast.

Although several gull species may be observed around the Farallon Islands, only one species breeds there. 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 lower elevation flat areas of the Farallones, 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 of the Pt. Reyes National Seashore. 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. Pinnipeds haul out on shore to rest or breed. Northern elephant seals 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 is found on the Farallon Islands. Although the California sea lion 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 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 a significant portion of the California population of harbor seals.

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 only a 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 five 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 as well as alter composition of flora communities in areas around seabird colonies.

Many bird species occurring on offshore islands in California have declined during the last 150 years due to a variety of factors, including: depletion of food owing to overfishing, 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: 1) Southeast Farallon Island became a National Wildlife Refuge in 1969; 2) the Gulf of the Farallones National Marine Sanctuary was established in 1981; and 3) when the Channel Islands National Marine Sanctuary was established in 1980. Under protection, many marine bird and mammal populations have increased or recovered.

Offshore islands are an important component of the marine ecosystem off north/central California, providing breeding and resting habitat for thousands of birds and mammals.

2.5 CHAPTER SUMMARY

Many factors influence the distribution and abundance of marine birds and mammals of the study area, and much remains unknown about the dominant environmental drivers (e.g., climate, temperature) that influence species distributions and the habitats and ecosystems they occupy; this chapter was included to offer environmental and ecological context for the following chapters on marine bird and mammal distributions.

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