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California Naturalist Series

Natural History of the California Current

A humpback whale breaching in Monterey Bay.

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Goals:

- Understand the physical and atmospheric processes that create the California Current
- Explore the ecology of the California Current
- Become aware of threats to marine wildlife off the coast of California and ways in which wildlife is being protected

The Pacific Ocean is a principal part of California's unique natural environment and supports many aspects of the state's economy. The majority of Californians choose to live along the shore, drawn by mild climates, fresh air, and the happiness that swells inside them with each breaking wave. California's coastal cities create billions of dollars in revenue through recreation, tourism, energy development, importing and exporting goods, and fishing opportunities near and in the ocean. Without the endless expanse of blue stretching from its western edge, California would be a very different place.

Off the California shoreline is a dynamic, thriving collection of ecosystems. This region is a boundary zone that supports the seasonal upwelling of cold, nutrient-rich water to the surface, and is one of only five such zones in the world. Marine animals from the blue whale (*Balaenoptera musculus*)—the largest animal ever known to have lived on Earth—to small crustaceans called krill are connected through time and space to the seasonal patterns that create one of the planet's most productive ocean areas. In this publication, we dive into the ocean off California's shore and explore the physical oceanography, coastal ecology, and management practices that define it.

OCEANOGRAPHIC AND ATMOSPHERIC PROCESSES CREATE UPWELLING

Our planet has been described as "the blue marble" when viewed from space. From that vantage point, and as our living blue sphere rotates on its axis, land, ocean, and atmosphere appear locked in unison. However, the physical rotation of the Earth affects land, ocean, and atmosphere very differently. Composed of gases and fluids, the atmosphere and ocean move in response to the planet's rotation and are constrained by the solid landmasses that alter what would otherwise be their paths of least resistance. The study of these physical forces, their interactions, and the complex chemical, biological, and ecological systems within the ocean is called oceanography.

Two principle physical processes that influence the movement of the ocean along the 1,100 miles of California's coast are the Coriolis effect and Ekman transport. The Coriolis effect occurs as the counterclockwise rotation of the Earth causes the ocean and atmosphere to exhibit a circular motion relative to stationary landmasses. The resulting clockwise circulation of air masses and ocean currents in the Northern Hemisphere, and counterclockwise rotation in the Southern Hemisphere, are commonly seen in satellite images of storm systems over the ocean. The large ocean circulatory patterns caused by the Coriolis effect are called gyres. The North Pacific Gyre circulates northward along the eastern coast of Asia, then eastward across the northern Pacific Ocean. This massive gyre turns south as it collides with North America, and this portion of the North Pacific Gyre is known as the California Current (fig. 1).

Ekman transport is the term given to the phenomenon by which wind forces pushing along the surface of the ocean, and influenced by the rotational Coriolis effect, cause the surface layer of water to move 90 degrees perpendicular to the wind direction. However, when wind direction, ocean current direction, and ocean depth are plotted in three dimensions, a more complex pattern of movement and mixing of ocean layers, called the Ekman spiral, is revealed (fig. 2). Wind-driven ocean mixing has profound effects on the creation of ocean habitat patches that support marine life.

The North Pacific High is a persistent high-pressure atmospheric pattern that strengthens every summer. The pressure difference in the atmosphere between the North Pacific High and a persistent low-pressure center over the southwestern United States typically results in strong winds that blow along the California coast from north to south. Similarly, the California Current

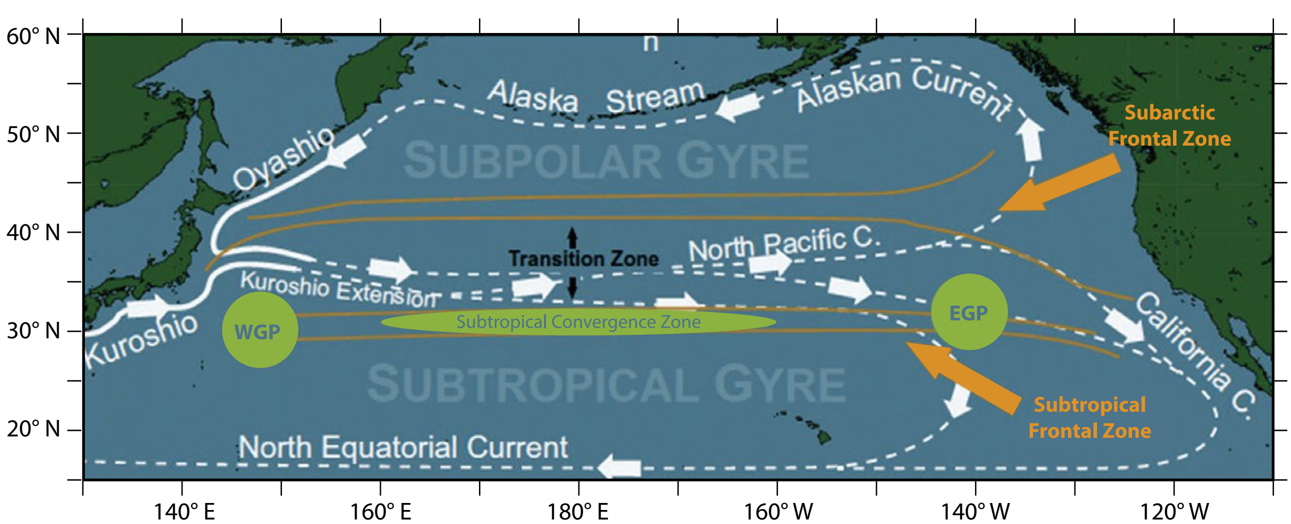

Figure 1. Circulation of the North Pacific Ocean. *Source:* NOAA Pacific Islands Fisheries Research Center.

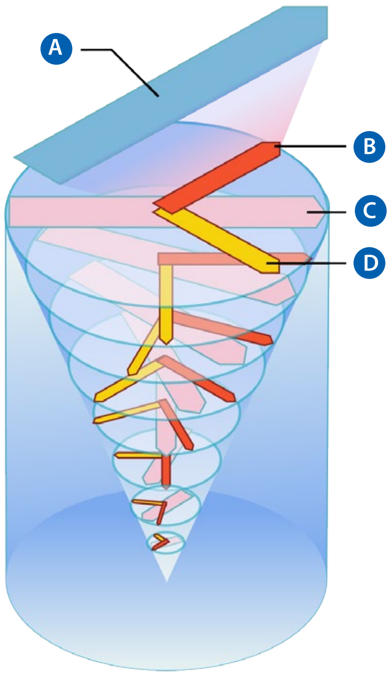

Figure 2. Ekman spiral and ocean surface movement. Wind (A), force from above (B), effective direction of the current (C), and the Coriolis effect (D).

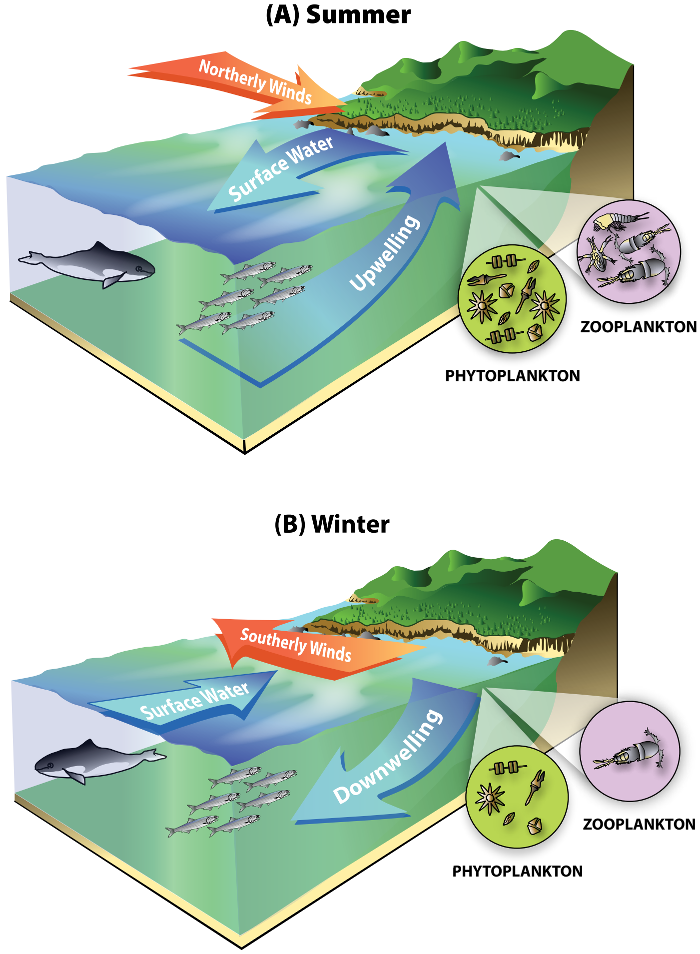

Figure 3. Upwelling (A) and downwelling (B). *Source:* Oregon Department of Fish and Wildlife.

predominantly moves from north to south. When strong and persistent winds blow south, the Ekman Transport results in a westward, or offshore, movement of the surface of the ocean. When the surface layer is pushed offshore, water from the deepest reaches of the ocean moves up along the continental shelf to replace it. This process of ocean mixing is called upwelling (fig. 3). It is the foundation for the rich ecological productivity observed off the shore of the Golden State.

Coastal upwelling mixes oxygen-rich water at the surface with nutrient-rich water found in the deepest ocean layers, creating conditions that allow life to flourish. In general, the surface layer of the ocean, where light can penetrate, is high in oxygen. This is due to the presence of photosynthetic algae, which function as primary oxygen producers in the food web. Rapidly growing organisms, such as blooms of krill, can quickly consume available nutrients at the surface, limiting productivity for high–trophic level vertebrates in the surface layer. Deep ocean water is rich in nutrients, which are supplied by decaying organisms that constantly rain down from above. However, it is low in oxygen due to a lack of sunlight, and therefore photosynthesis, deeper than 600 feet. Consequently, areas of mixing—where nutrients from below reach the oxygenated environment closer to the surface—provide the richest ocean habitat, where schools of small fish flourish and support complex biological communities. Just as underlying geology and soil types can dictate habitats and the biodiversity that results from them in terrestrial systems, the spatial and temporal mixing of diverse ocean layers off the coast can be predictive of marine wildlife patterns of California.

Areas of coastal upwelling are among the most biologically productive marine zones on the planet. Five ocean upwelling zones, which represent only 5 percent of the total ocean area, produce 25 percent of the world's seafood! The extent of upwelling strengthens as winter wanes, reaching its peak in spring and summer (see figs. 3A and 3B). The variability of atmospheric pressure gradients can bring strong upwelling in some years and weak

Deep ocean water is rich in nutrients, supplied by decaying organisms that constantly rain down from above.

upwelling in other years. Recent models of climate change predict that upwelling events will become more intense in the spring and less intense in the summer, particularly in the northern part of the California Current, due both to changes in atmospheric pressure and the overall impact of climate change on ocean temperatures. The extent of upwelling each year can have major implications for the health and abundance of marine wildlife in the California Current. Life forms large and small that rely on these cycles of productivity make up the California Current Ecosystem.

THE CALIFORNIA CURRENT ECOSYSTEM

The California Current begins below the Alaskan Gyre in the North Pacific and travels south along the entire West Coast before it dissipates, merging with the North Equatorial Current south and west of Baja California, Mexico. The current's flow extends several hundred miles offshore and is most swift at the surface, averaging 0.2 to 0.4 miles per hour. The California Current really contains three main currents that vary in size and strength as the seasons change. These are:

- the primary north-to-south California Current, which stretches broadly across the surface of the ocean and predominates in the spring
- the California Undercurrent, which flows weakly south to north in a narrow band along the continental slope at a depth of approximately 600 to 900 feet
- the Inshore Countercurrent, commonly known as the Davidson Current, which flows south to north, hugging the coast north of Point Conception in the fall and winter (fig. 4)

Coastal headlands, seamounts (underwater mountains), deep undersea canyons, and seasonal countercurrents can cause eddies to form, which can break off from currents and generate small areas of increased mixing and upwelling. Seasonal changes in the California Current can result in some unusual wildlife observations, as warm-water tuna, seabirds, and sea turtles driven north by the Davidson Current are found off the shore of Northern California in the fall and winter.

Within the California Current Ecosystem, and across the ocean in general, marine habitat areas are classified according to their depth and their relationship to the sea surface and shoreline. Areas close to land constitute the nearshore environment; offshore, open-water areas are referred to as pelagic. Within pelagic systems, the photic zone—which extends to about 600 feet in depth, and into which most wavelengths of light can penetrate—is distinguished from the lower depths. (From an ecological perspective, the photic zone is referred to as the epipelagic.) The region from 600 to 3,000 feet in depth, into which only the longest wavelengths of green and blue light

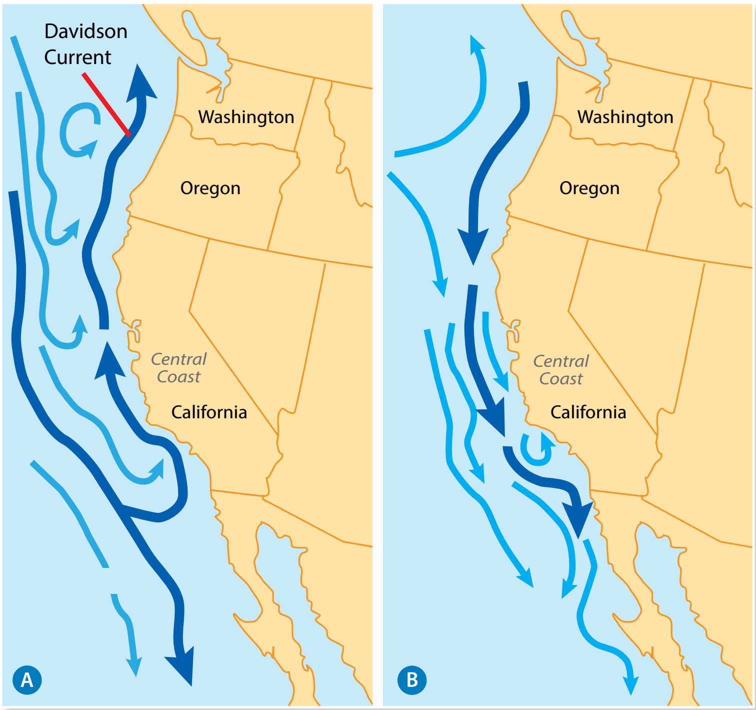

Figure 4. Seasonal variability in the currents of the California Current Ecosystem, winter (A) and spring (B). *Source:* Strub, P.T., and C. James. 2000. Deep-Sea Research Part II: Topical Studies in Oceanography 47(5–6):831–870.

Areas of coastal upwelling are among the most biologically productive marine zones on the planet.

can penetrate, is the "twilight," or mesopelagic, zone. In the darkness that extends from a depth of 3,000 feet to just above the ocean floor are the bathypelagic and, finally, abyssal zones.

Within the photic (or epipelagic) zone, the term *plankton* refers to many organisms that primarily float along with ocean currents, rather than using their own muscular activity to swim. Larger organisms like crustaceans and fish—which swim under their own volition and may move between the epipelagic and mesopelagic zones—can be collectively referred to as nekton.

Phytoplankton (fig. 5), which are photosynthetic unicellular algae, deserve most of the credit for the primary production in the California Current Ecosystem. Like terrestrial plants, these microorganisms use photosynthesis to create their own food from inorganic substances, using the energy found in light. Diatoms, dinoflagellates, and cyanobacteria dominate the phytoplankton community. Diatoms are eukaryotic cells—that is, they contain a true nucleus. They have hard silica-based shells measuring a few micrometers in diameter (1 micrometer is 0.001 millimeter)—but they can also form chains of these cells, with several hundred individuals bound together as one unit. Diatom blooms dominate areas of strong upwelling, making them the most productive phytoplankton group and the most significant food resource for many ocean-dwelling species.

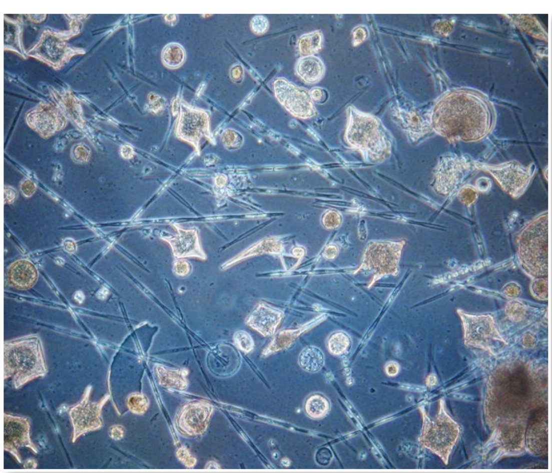

Figure 5. The dinoflagellate *Protoperidinium* along with *Pseudo-nitzschia*, a diatom associated with harmful algal blooms. *Source:* California Department of Public Health.

Their frustules (or silica casings) and their large size can protect them from predation by small zooplankton—but when silica is limited, other phytoplankton outcompete them.

Dinoflagellates are another type of eukaryotic phytoplankton that prefers stratified ocean layers. Many are motile—that is, by undulating their appendage-like flagella, they can propel themselves to areas of improved habitat. Their lack of a silica casing and relatively enriched nutrient content make them the preferred prey of small zooplankton. Cyanobacteria are prokaryotic cells (very simple cells, lacking a nucleus) that account for about 20 percent of phytoplankton productivity in nearshore regions and predominate in offshore regions. Their relatively small size and high productivity can cause rapid nutrient turnover in offshore zones, quickly depleting resources when they bloom.

Primary consumers in the California Current Ecosystem eat phytoplankton, the most abundant of which are the unicellular microzooplankton. Within many areas of the California Current, nonphotosynthetic dinoflagellates—such as ciliates and choanoflagellates—consume more phytoplankton than all crustaceans and fish combined. Microzooplankton are key prey for gelatinous zooplankton, copepods, and other planktonic crustaceans. The overall biomass of unicellular microzooplankton fluctuates with the rise and fall of primary productivity, which is correlated with upwelling. In areas further offshore than the main wind-driven upwelling front, a large portion of the energy within microzooplankton is retained in a "microbial loop," transferred to other predatory or scavenging microzooplankton without ever reaching higher trophic levels.

Small crustacean zooplankton are the main secondary consumers in the California Current Ecosystem. From smallest to largest, the main types are copepods, mysids, and euphausiids. Numerically, copepods often dominate the zooplankton. They prey on phytoplankton and microzooplankton, and are preyed upon by organisms big and small. Copepods do not tend to form large schools but, to avoid visual predators such as fish, undergo daily vertical migrations from several hundred feet deep in the daytime to near the surface at night. A great example of the value of zooplankton is the mysids, small shrimp-like crustaceans that are abundant in nearshore waters, where they are an important food source for out-migrating salmon smolts. Another important food source for salmon, whales, and seabirds is krill, or euphausiids, which are shrimp-like crustaceans (fig. 6). Their high feeding and fast growth rates allow them to form large, conspicuous schools during periods of upwelling. The primary species comprising these krill blooms in the California Current are *Euphausia pacifica* and *Thysanoessa spinifera*. Like copepods, krill migrate to the surface at night. When krill blooms ascend from the bottom of the continental slope, at depths of 2,000 to 3,000 feet, to the shallower continental shelf, at depths of 200 to 300 feet, they become much more concentrated and more attractive to predators. Krill play a critical role in the overall flow of energy through the California Current Ecosystem due to their seasonal abundance—and because many predators from upper trophic levels rely on krill biomass.

Figure 6. Krill and copepods under the microscope. *Source:* NOAA.

Gelatinous zooplankton, known collectively as jellies, are beautiful to watch move through the ocean as they passively prey on zooplankton and larval fish. Recent increases in their abundance have caused concerns about their potential impacts on fisheries resources. Ctenophores, medusae, doliolids, apendicularians, and salps are representative forms of jellyfish. They can vary greatly in size and life history. Gelatinous zooplankton have high growth rates and high feeding rates, and several species can experience population blooms in oligotrophic environments (areas of very low nutrient density), offshore environments, or warm nearshore environments. Their bodies are usually translucent and are mostly composed of water, making them poor prey for most species.

In addition to crustaceans and gelatinous zooplankton, another portion of the planktonic community is composed of larvae of the many animals that, as adults, become pelagic swimmers or benthic organisms. These are called meroplankton, and include larvae of many broadcast spawning mollusks, larger crustaceans such as many crabs, and echinoderms—sea stars and urchins. The abundance of these larval types reflects the health of the ocean community, as they are essential to restocking depleted mussel beds, rocky or coral reefs, and other habitats.

Fish larvae, called ichthyoplankton, only exist in this early life stage for several weeks to a few months, but they can temporarily outnumber all other primary and secondary consumers and have a major impact on food-web dynamics. Larval fish are the main pathway of energy flow in the California Current Ecosystem from phytoplankton to larger fish. Other small pelagic fish such as sardines (fig. 7), anchovies, smelts, and herring are collectively known as forage fish. They are relatively small as adults, form large schools, and feed on

Figure 7. A school of Pacific sardines, *Sardinops sagax*.

phytoplankton and small pelagic crustaceans. These forage fish, when they are superabundant, form the foundation of the food web for many apex predators, and they influence the distribution of species along the coast. In response to concerns that forage fish could be overexploited as a fishery resource for human consumption, and in order to protect their essential ecosystem functions, recent policies have placed limits on the harvest of forage fish.

Spring and summer upwelling off the coast of California and elsewhere in the California Current Ecosystem creates a surge in primary production that allows a massive transfer of energy up the food chain to tertiary and quaternary consumers like salmon and sharks. In spring, rapid increases in primary productivity along upwelling fronts can be seen in satellite images (fig. 8). Coastal upwelling hotspots in California occur around the dominant promontories along the coast and include the areas from Cape Mendocino to Point Arena, Bodega Head to Point Reyes, Pigeon Point to Point Sur, and Cape San Martin to Point Arguello. Blue whales (*Balaenoptera musculus*), leatherback sea turtles (*Dermochelys coriacea*), and seabirds such as the Sooty Shearwaters (*Puffinus griseus*)—all of which have life histories adapted to the seasonal upwelling—migrate long distances to the California coast to feed. Weaker and later upwelling typically occurs along California's North Coast, and weak upwelling persists year-round south of Point Conception in the Southern California Bight. However, prolonged upwelling periods can be detrimental; during such periods, blooms of primary productivity along continental shelf margins are continually transported farther offshore and diluted. When upwelling productivity is followed by a relaxation period, all trophic levels have time to reap the benefits.

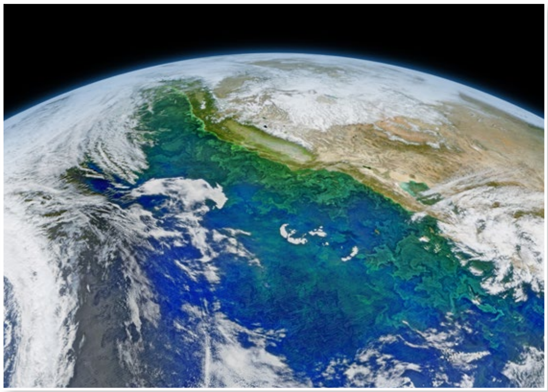

Figure 8. Coastal upwelling is apparent in this image; bright green areas are phytoplankton blooms. *Source:* NASA Visible Infrared Imaging Radiometer Suite (VIIRS).

Naturalist profiles: Women naturalists of the California Current Ecosystem

Sarah Preston Monks (1841–1926) and **Martha Burton Williamson** (1843–1922) were naturalists active in the early 1900s in the San Pedro Bay around the Port of Los Angeles. They contributed to the marine research conducted at the Terminal Island laboratories established by the University of California's William Ritter.

Monks—a transplant from New York and Philadelphia, where she studied vertebrates at the Academy of Natural Sciences—initially came to California to teach at the College of Santa Barbara before moving to Los Angeles to teach botany, zoology, physiology, and drawing at the Los Angeles Normal School. She published research on diatoms and spiders, but focused on how sea stars reproduce through regeneration, showing that the thin-rayed sea star (*Phataria unifascialis*) can regenerate the entire body disc from a single severed ray.

Sarah P. Monks, left, at her waterside research laboratory called Phataria. The group is looking toward San Pedro across the main channel of the Port of Los Angeles from Terminal Island.

Williamson was an avid shell collector. A transplant as well, she was born in England but grew up in Cincinnati.

Naturalist profiles: Women naturalists of the California Current Ecosystem, continued

She worked professionally as a journalist and shared her love of science through public presentations, particularly to women's clubs. She also wrote of her collecting trips in Popular Science News. She shared her observations and her shell collections with malacologists in Southern California and at Stanford University, as well as with the Smithsonian Institution. In 1912, she donated some 3,000 specimens to the newly founded Los Angeles Museum of History, Science, and Art (now the Natural History Museum of Los Angeles County). She was also an early advocate for conservation of abalone.

While both women had homes in other parts of the Los Angeles basin, they spent much of their time naturalizing from squatter's cottages—along with a ramshackle collection of hermits, fishermen, and artists and other bohemians on the East Jetty in San Pedro. Built by the Army Corps of Engineers to protect Los Angeles Harbor, the jetty ran from the tip of Rattlesnake Island (now known as Terminal Island) to Deadman's Island (now underwater). As sand built up, a community of waterfolk built wooden shacks out of driftwood and other flotsam and jetsam that washed up. There were no services, save those provided by the sea. Monks lived along Sea Pansy Bay, where she often spent evenings visiting her neighbor, Charles Lummis, a notable Angeleno who founded the Southwest Museum in Mt. Washington. She named her cottage Phataria, after the sea star, and maintained aquaria that she replenished each day—which required a daily ferry ride and a walk along a broken boardwalk. The City of Los Angeles eventually evicted the community of the East Jetty.

Dawn Peterson in the laboratory.

Dawn Peterson (1949–2010) was an exemplary naturalist who pushed boundaries. She was a self-taught ostracodologist who was transgender. Ostracods, also known as seed shrimp, are a group of tiny animals that make up part of the zooplankton. Peterson's interest in modern and fossil ostracods began in her freshman year at the University of Minnesota but bipolar disorder interfered with her ability to complete her studies. Years later, she moved to San Francisco to start a new life as Dawn. She worked as a volunteer in the marine paleontology lab at the California Academy of Sciences, later volunteering at at the University of California Museum of Paleontology in Berkeley. Her paleontological interests were evident in her one-room apartment in city-subsidized housing, where she crammed in numerous flats of marine fossils and a desk for her microscope. Peterson's work as a volunteer scientist brought her fulfillment, and her dedication, knowledge, and effort were acknowledged with her appointment as an associate researcher at the Museum of Paleontology. While she worked on fossils from Chile and the Galapagos, she also studied the ostracods of Lake Merritt, a tidal lagoon in downtown Oakland, and coauthored the ostracod section of the 2007 update to the storied *Light and Smith Manual: Intertidal Invertebrates from Central California to Oregon*.

The Farallon Islands, which occupy just 0.16 square miles, are home to the largest seabird colony in the continental United States.

PELAGIC WILDLIFE IN THE CALIFORNIA CURRENT ECOSYSTEM

Like their terrestrial counterparts, species of wildlife in the ocean adapt to specific habitats and evolve to fill specific ecological niches. Along the large latitudinal expanse of the California coast, the many islands, underwater seamounts, and submarine canyons that exist within the California Current Ecosystem interact with seasonal currents to create a diverse and dynamic environment. Oceanographers have mapped areas of distinct latitude, currents, and physical features and have classified these areas as ecoregions—three of which lie off the California coast. Off the coast of the northernmost part of the state is the southern tip of the Columbian Pacific ecoregion. The Montereyan Transition ecoregion lies off the North and Central Coasts. Off Southern California is the northern edge of the Southern Californian Pacific ecoregion. These ecoregions lie over the continental shelf, an elevated expanse of seafloor that broadens along Southern California and acts to concentrate upwelling productivity.

Within these ecoregions, several special locations draw naturalists from around the world. The granitic Farallon Islands, which occupy just 0.16 square miles and lie 30 miles

Some rockfish can live to be more than 100 years old, with the record being a 205-year-old rougheye.

off San Francisco Bay, are home to the largest seabird colony in the continental United States. The eight Channel Islands of California, which occupy 350 square miles off the coast of Southern California, intersect the currents and create eddies that increase mixing of ocean layers throughout the Southern California Bight. They also host the largest seal and sea lion (or pinniped) colonies south of Alaska, as well as many terrestrial endemic species. The Monterey Submarine Canyon reaches a depth of 12,700 feet only 95 miles west of Moss Landing harbor, before fanning out onto the seafloor—making this an ideal location for marine biologists embarking to discover new species that emerge from the uncharted abyss. By observing and documenting changes in this dynamic environment, a naturalist can draw many comparisons between California's onshore and offshore diversity of topography and habitats.

The California Current Ecosystem supports highly diverse and abundant wildlife that resides in the ecosystem year-round, and also supports top predators that migrate over long distances to forage in the area seasonally. Recent advances in wildlife satellite tracking have unlocked many of the secrets of the seasonal movements of California's marine wildlife. While a comprehensive review of these top predators is not possible here, we discuss some of the most important and abundant species below.

Fish

Rockfish are a diverse and colorful family of over 70 species found in nearshore kelp forests and in deeper water. Some rockfish can live to be more than 100 years old, with the record being a 205-year-old rougheye (*Sebastes aleutianus*)! In the case of rockfish (fig. 9), old females are more productive than young ones, producing more and better-quality eggs. Rockfish support important recreational and commercial fisheries in California. However, fishing pressure over the long term has resulted in decreases in the average rockfish size and changes in the species composition of rockfish communities in California.

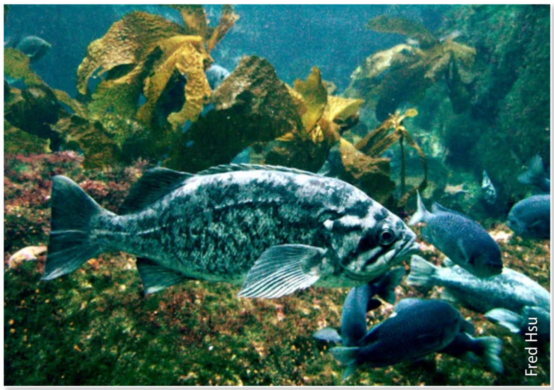

Figure 9. Blue rockfish (*Sebastes mystinus*).

Salmon serve as an iconic link between inland and ocean ecosystems, and their annual abundance is directly correlated to the health and productivity of each of their essential habitats. California's salmonid species include coho (*Oncorhynchus kisutch*), chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), and oceangoing steelhead (*Oncorhrynchus mykiss*). These are anadromous fish that spawn in fresh water and mature in the ocean, returning to spawn in their natal streams when 3 to 6 years old. For most of these species, this is their final act before perishing along the rivers and creeks where they hatched, though steelhead can migrate and spawn more than once. All California salmonid species are listed as either threatened or endangered under the federal Endangered Species Act. In the California Current Ecosystem, juvenile salmon consume copepods, euphausiids, and small fish and are consumed by seabirds, marine mammals, and the large Humboldt squid (*Dosidicus gigas*). Salmon recovery efforts around the state, often undertaken by dedicated volunteers, include removing dams and other passage barriers; restoring cover, structure, and gravel in spawning habitats and estuaries; ensuring sufficient water flow in streams; and taking steps to monitor, preserve, and improve water quality.

Large predatory fish such as albacore tuna (*Thunnus alalunga*), Pacific bluefin tuna (*Thunnus orientalis*), swordfish (*Xiphias gladius*), striped marlin (*Tetrapturus audax*), thresher shark (*Alopias vulpinus*), blue shark (*Prionace glauca*), shortfin mako shark (*Isurus oxyrinchus*), and white shark (*Carcharodon carcharias*) (fig. 10) are all found off the coast of California. Satellite tagging data from

Figure10. White shark.

Adult leatherbacks complete a round trip between the California Current Ecosystem and nesting beaches in Indonesia and Papua New Guinea.

albacore and bluefin tuna show they consistently return to the same feeding grounds. Large predatory fish and sharks such as these occupy a wide range of foraging niches and exhibit a high degree of resource specificity. Mako and blue sharks feed on pelagic fish and Humboldt squid when this prey is abundant. Thresher sharks consume forage fish. White sharks congregate at seal and sea lion haul-outs to target young marine mammals. Basking sharks (*Cetorhinus maximus*) and megamouth sharks (*Megachasma pelagios*) feed only on zooplankton. The abundance of these two species has significantly declined due to fisheries harvest and by-catch in drift gill nets. Of these large fish species, and many more, only white sharks enjoy protection from commercial harvesting off the coast of California.

The California Current Ecosystem's mesopelagic region, below the photic zone, contains an abundance of diverse fish that often exhibit daily vertical migrations from dark depths, where they spend their days, into the productive photic zone, where they forage at night. When sound waves produced by sonar are directed into the ocean depths, they disperse off this mobile blanket of fish, creating the impression of a "false bottom"—which is why this area is known as the deep scattering layer. The fish's daily vertical migration is believed to minimize their risk of being consumed by the visual predators common above the mesopelagic zone. These fish are an integral part of the ecosystem's food web, but their ecology remains poorly understood (fig. 11). Several species of marine mammals, particularly those living offshore, follow the movement of the deep scattering layer. Northern fur seals (*Callorhinus ursinus*), for example, are shallow divers and can only feed on prey associated with this layer as they rise to the surface at night. Northern elephant seals (*Mirounga angustirostris*) feed continuously, day and night, far offshore, but their dives are deeper during the day than at night as they follow their prey up and down the water column.

Figure 11. Plainfin midshipman (*Porichthys notatus*), a mesopelagic fish from the California Current. White spots are bioluminescent organs—a common feature among organisms living at dark depths. *Source:* U.S. Geological Survey.

Sea Turtles

Yes, there are sea turtles in California! The productive California Current Ecosystem serves as an essential foraging area for Western Pacific leatherback sea turtles (*Dermochelys coriacea*)—and as an opportunistic foraging area for a small population of green sea turtles (*Chelonia mydas*) and, occasionally, loggerhead sea turtles (*Caretta caretta*) and olive ridley sea turtles (*Lepidochelys olivacea*). Leatherbacks have evolved to forage in cold areas like the California Current, whereas all other sea turtle species are more likely to be observed when warm ocean currents push northward, such as during El Niño years or the seasonal strengthening of the Davidson Current. In Southern California, resident green sea turtles have been found in the South San Diego Bay National Wildlife Refuge and in the urban San Gabriel River near Long Beach (fig. 12), where they make use of warm-water releases from an electrical power plant.

The leatherback sea turtle is the largest, fastest-swimming, and deepest-diving of any sea turtle species, and critically endangered West Pacific populations of these turtles have a special connection to California. Approximately every other year, adult leatherbacks complete a 13,000-mile round trip between the California Current Ecosystem foraging habitat, where they gorge on abundant jellyfish, and nesting beaches in Indonesia and Papua New Guinea. This is the longest migration of any reptile on Earth! Globally, nesting beach development and degradation of beach habitat, illegal poaching of adults and eggs, and by-catch in commercial fisheries have caused Pacific leatherback populations to decline by 95 percent over the last several decades. To combat this decline, 16,910 square miles of protected critical habitat were established, under the U.S. Endangered Species Act, off the coast of California in 2012. The area is protected as foraging habitat. Activities that would impact jellyfish populations, the leatherback's primary food source, are prohibited. In 2013, following the creation of leatherback critical habitat, a unanimous vote in the California Legislature designated the Pacific leatherback as the state's official marine reptile and—to increase awareness of these emblematic marine reptiles and demonstrate the conservation ethic that underlies statewide efforts to protect them—declared October 15 every year as Pacific Leatherback Conservation Day. These recent efforts in California demonstrate how scientists, conservation advocates, and elected officials can work together to protect the unique resources within the California Current Ecosystem.

Figure 12. Green sea turtle in the San Gabriel River near Long Beach.

Pinnipeds

What's that barking sound you hear at the beach? Probably a California sea lion, some of which reside year-round in the California Current Ecosystem and others of which migrate there seasonally. Six pinniped species have been observed in California. From most abundant to least, they are the California sea lion (*Zalophus californianus*), northern elephant seal (*Mirounga angustirostris*) (fig. 13), harbor seal (*Phoca vitulina*), northern fur seal, Steller sea lion (*Eumetopias jubatus*), and Guadalupe fur seal (*Arctocephalus townsendi*). The easiest to observe are California sea lions, often seen sunbathing along many of California's beaches and coastal jetties. They typically consume fish, large crustaceans, and squid along the continental shelf—but are sometimes observed foraging several hundred miles offshore when upwelling conditions are delayed or weak. California sea lions occupy

Figure 13. Elephant seal.

the entire California Current Ecosystem, all the way from Canada to Mexico. They are a good indicator species for the California Current Ecosystem. Conditions in the marine environment usually affect California sea lions before they affect human communities. Such conditions include environmental perturbations like El Niño and the Pacific Marine Heat Wave (commonly referred to as the "Blob")—as well as the presence of toxins produced by the algae that cause "red tide." Strandings may be the first sign of trouble many human Californians see, as humans and pinnipeds both utilize beaches. California sea lions are also a good indicator species for overfishing, which causes the sea lions' prey to become more scarce, as well as a good indicator of the impacts of plastic pollution. Indeed, a recent study by a team of researchers from Hawaii, Washington, and Alaska found microplastics in the feces of northern fur seals on the remotest Channel Island, San Miguel, and at rookeries in Alaska.

Northern elephant seals are known to exhibit long-distance migratory feeding strategies offshore, with most individual males traveling to the Aleutian Islands and back during a single year and most females foraging in the North Pacific Gyre. Pinnipeds typically give birth in spring or summer (with the exception of elephant seals), and poor productivity then or during the preceding winter in the California Current Ecosystem is known to result in high mortality among sea lion and fur seal pups. Fur traders in the 1800s decimated California pinniped populations, but the Marine Mammal Protection Act, passed in 1972, banned hunting of all marine mammals and triggered their recovery. California sea lion and northern elephant seal populations have rebounded, but fur seals and Steller sea lions are still severely depleted.

Science and conservation of marine mammals in the CCE: A profile of Dr. Tony Orr

Not many kids from Ohio grow up to study the sea lions, seals, fur seals, and whales of the California Current. Tony Orr is one who did.

When Orr was a boy in the Midwest, spending time outdoors meant hiking and observing terrestrial wildlife. Not a sea lion in sight. But Orr discovered an interest in marine science and wildlife biology through television shows—*The Undersea World of Jacques Cousteau* and *Mutual of Omaha's Wild Kingdom*.

When Orr attended The Ohio State University for college, he started by studying terrestrial animals—then changed his focus to examining organisms in the aquatic ecosystem, exemplified by studies on plankton inhabiting Lake Erie. But with his interest in marine biology growing, he came to the West Coast to study at Moss Landing Marine Laboratories in Monterey County. Eventually he joined the Marine Mammal Laboratory in Seattle, Washington, within the National Oceanic and Atmospheric Administration. While working at the laboratory, he pursued work toward a Ph.D. from the University of Washington. Today, Orr is project lead for studies on the California stock of northern fur seals for the Marine Mammal Laboratory's California Current Ecosystems Program. Orr directs studies of northern fur seals—but he also studies California and Steller sea lions, Guadalupe fur seals, Pacific harbor seals, and gray and humpback whales.

Navigating the classroom, the laboratory, and the field as a Black scientist, Orr has encountered few mentors of color—or even colleagues of color. "It was a challenge,"

Science and conservation of marine mammals in the CCE: A profile of Dr. Tony Orr, continued

Orr says, "going through zoology and marine science programs without people who looked like me. Even in 2020, I can still count on one hand the number of Black researchers who study marine mammals, and there are few other people of color." Orr reports that, because of a culture in which some assume that Black people only excel by benefitting from racial or quota-based policies, "I feel like some people doubted how hard I have worked." As a result, he had to work even harder to get ahead.

Orr and his team conduct a lot of their research on San Miguel Island—the farthest offshore of the California Channel Islands (located off the coast of Santa Barbara and Ventura counties). The team, focusing on California sea lions and northern fur seals, researches topics such as population abundance, demography and survivorship, health, and foraging ecology.

Foraging ecology is the study of how animals search for, capture, and consume food resources needed for survival (and reproduction). Orr and his colleagues, as they investigate these issues on San Miguel Island, annually examine the diet and behaviors of northern fur seals and California sea lions; study how diet and behavior relate to environmental changes; compare the two species; and compare age and sex classes within the species. Differences in sex and life stage (adults, juveniles, and pups) are also relevant to demography (the study of births, deaths, and incidence of disease) and survivorship. Causes of illness and death on San Miguel Island can include reduced food availability, diseases such as leptospirosis, and entrapment in fishing gear or marine debris. (The team's population studies are mandated by the Marine Mammal Protection Act of 1972, which requires that trends in marine mammals' abundance and mortality be reported.)

Asked what community members can do to assist in conservation and restoration of pinniped communities, Orr responds that "most Californians really appreciate their marine mammals—however, some activities can be to the detriment to the animals. For example, a pup may be on shore while the mom is off hunting, so don't try to take it to a rescue facility, but call instead. Let us know if you see entangled animals. Contact your elected representatives to support efforts to improve fishing practices that reduce entanglement, and vote. If you have the time, help with beach clean-ups—and enjoy the show!" In reference to trained, retired volunteer naturalists, Dr. Orr notes that they are sometimes involved in pinniped conservation efforts on San Miguel Island (and other islands), leading hikes for the National Park Service and discussing with the visitors the importance of conservation and diversity. "Retirees sharing their experiences have been really valuable," Orr says. "Plus, it's inspiring to see passion for conservation still with them—not just in words but in action."

The ideas expressed in this article reflect Dr. Orr's personal thoughts—not any official position of the National Oceanic and Atmospheric Administration.

Cetaceans

Whale watching is one of the most popular types of ecotourism along the coast of California. Thirty-nine species of cetaceans, a group of marine mammals consisting of porpoises, dolphins, and both toothed and baleen whales, can be seen occupying the offshore habitat. The presence of most cetaceans in the California Current Ecosystem is closely linked to dynamic variables such as sea surface temperature and food web productivity but is also associated with permanent features, such as sea mounts and islands, around which upwelling is persistent. Common toothed whales, known as odontocetes, are seen off the coast of California. From smallest to largest, they include the harbor porpoise (*Phocoena phocaena*), Dall's porpoise (*Phocoenoides dalli*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) (fig. 14), common dolphin (*Delphinus delphis*), bottlenose dolphin (*Tursiops truncates*), Risso's dolphin (*Grampus griseus*), killer whale (*Orcinus orca*), and sperm whale (*Physeter macrocephalus*). Odontocetes have a single blowhole and use echolocation, or sonar, to detect objects in their environment. Most odontocetes forage on pelagic fish and squid. Killer whales eat fish and other marine mammals; beaked whales forage on deepwater mesopelagic fish and squid; and sperm whales can dive over 6,000 feet to hunt squid!

Figure 14. Pacific white-sided dolphins at Moss Landing, Santa Barbara Channel.

Baleen whales have two blowholes and lack teeth, instead relying on hundreds of comb-like plates (baleen) for filter-feeding on krill, copepods, and forage fish. Common baleen whales off the coast of California, from smallest to largest, are the minke whale (*Balaenoptera acutorostrata*), gray whale (*Eschrichtius robustus*), humpback whale (*Megaptera novaeangliae*) (fig. 15), fin whale (*Balaenoptera physalus*), and blue whale. Although the biomass of baleen whales in the California Current Ecosystem is two and a half times the biomass of odontocetes, baleen whales require only 13 percent as much primary production as toothed whales need. This is because they feed at a lower trophic level.

Seabirds

The life history of over 140 seabird species—some that breed locally and some that migrate over long distances—is intimately linked to

Figure 15. Humpback whales foraging in Monterey Bay. Note the baleen on the whale's upper jaw and small white rings caused by barnacles on the whale's skin.

The brown pelican can be observed along much of California's coast, making crash landings and scooping up fish stunned by the impact.

the seasonal productivity of the California Current Ecosystem. The common murre (*Uria aalge*), pigeon guillemot (*Cepphus columba*), and rhinoceros auklet (*Cerorhinca monocerata*) are all seabirds that nest in California colonies. The annual breeding success of each of these populations is directly linked to forage fish productivity, particularly juvenile rockfish, and krill abundance. Sooty shearwaters, black-footed albatross (*Phoebastria nigripes*), and Laysan albatross (*Phoebastria immutabilis*) depend on seasonal wind patterns for their migration to the California Current Ecosystem's foraging areas. They spend more than half the year in the ecosystem, consuming fish, squid, and krill. Black-footed and Laysan albatross in the ecosystem breed in the northwest Hawaiian Islands, and a subpopulation of Laysan albatross migrates to the California Current Ecosystem from breeding grounds on Guadalupe Island off Baja California, Mexico. In one of the most amazing migrations found in the kingdom Animalia, sooty shearwaters voyage to California along an annual route that spans 40,000 miles across the Pacific Ocean in both the Northern and Southern Hemispheres, crisscrossing from New Zealand to California, Peru, and Japan, and back down to New Zealand! The black-vented shearwater (*Puffinus opisthomelas*) (fig. 16), does quite the opposite. A true native to the California Current Ecosystem, this bird nests on islands off northwestern Mexico, traveling north up the California coast. It is usually found just a few miles offshore. Once rare due to pesticide pollution, the brown pelican (*Pelecanus occidentalis*) (fig. 17) can now easily be observed along much of California's coast, making crash landings on the water and then scooping up fish stunned by the impact.

Figure 16. Black-vented shearwater.

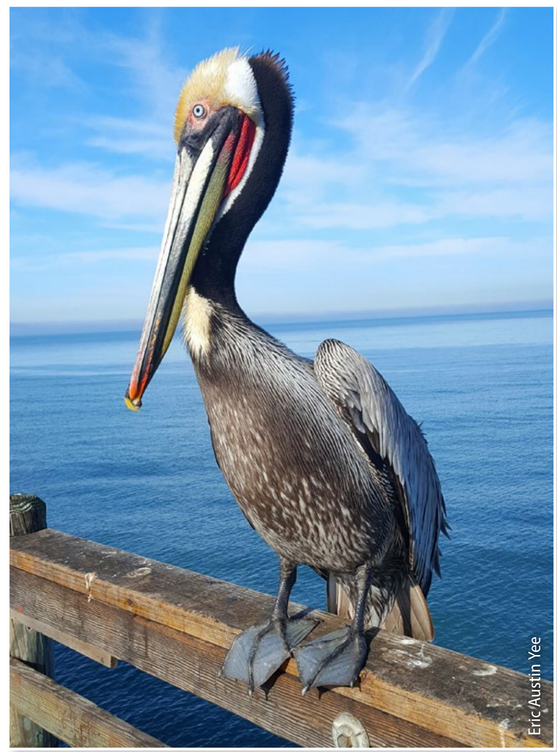

Figure 17. California brown pelican at Oceanside Pier.

THE SOUTHERN CALIFORNIA BIGHT

Ocean conditions in the section of the California Current Ecosystem that lies off the coast of Southern California—a region known as the Southern California Bight—differ from those along the Central and North Coasts. The Bight is fringed by 400 miles of coastline that bends southeast from Point Conception, continues along Santa Barbara, Ventura, Los Angeles, Orange, and San Diego counties to Cabo Colnett, about 100 miles south of Ensenada, Mexico. Within the Bight, the cold, southbound California Current mixes with subtropical waters flowing north close to the shore, forming an ecological transition zone that supports an extremely diverse assemblage of northern and southern species. The seasonal wind patterns and associated upwelling in the Bight differ from those in Central and Northern California. Winds are generally weaker and highly variable. Upwelling typically peaks in winter and early spring but occurs year-round because of seafloor topographic complexity. The Bight also contains the largest island chain off the coast of California, the beautiful Channel Islands. From the amazing arches and sea caves along Anacapa Island to the historic and current uses of tourist-friendly Catalina Island (fig. 18), and the military installations that make San Clemente and San Nicolas Islands off limits to the public, the Channel Islands support some of California's most unique marine and terrestrial ecosystems.

The mixing of cold and warm currents in the Southern California Bight creates many large and small eddies, or swirls, formed when the two currents collide with each other and with the complex continental and island shorelines. Phytoplankton growth is stimulated in surface waters on small, local scales by eddy pumping, a mechanism whereby cold, nutrient-rich waters are driven upward within an eddy. The combination of upwelling and eddy pumping in the Bight increases biological productivity year-round. This supports some of the state's largest kelp forests and most lucrative fisheries, as well as some of the world's most abundant aggregations of blue whales.

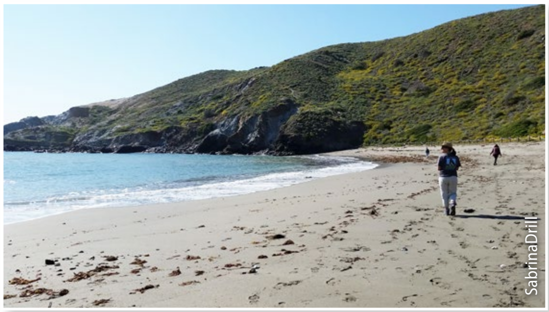
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Figure 18. Little Harbor, Catalina Island.

Southern California Giant Kelp Restoration Project

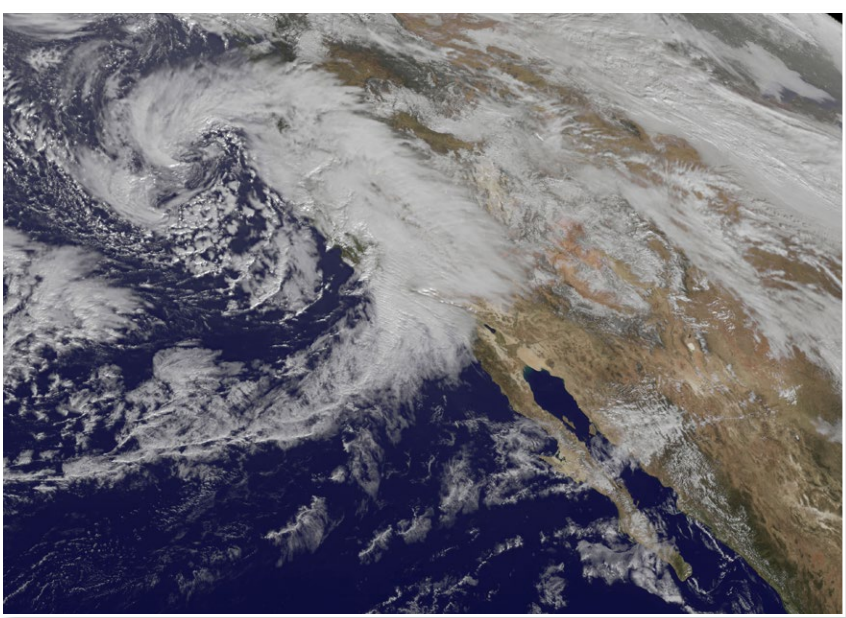
Kelp forests are among the dominant features of nearshore systems in Southern California and provide much of the structure that supports a great diversity of fish and invertebrates. As Charles Darwin put it while studying kelp in South America's Tierra del Fuego, "[I]f in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here from the destruction of kelp." Since 1900, kelp in California has suffered an 80 percent reduction due to a combination of factors, including stormwater pollution, increased sediment runoff as a result of coastal development, harvest, and the loss of top predators due to overfishing and intensive hunting of sea otters. Predators, especially otters, feed on sea urchins—and with the loss of creatures at the top of the food chain, kelp-eating urchin populations have exploded. In natural systems, urchin densities are on the order of two per square meter, but without predation, purple urchin (*Strongylocentrotus purpuratus*) densities may reach up to seventy individuals per square meter. Urchins preferentially feed on the base of kelp. While they rarely consume the entire blade, they separate blades from the holdfast, leaving them to wash away into the deeper ocean or ashore. The areas that result are known as urchin barrens, and after loss of the kelp community, the crowded urchins are usually undernourished and may themselves succumb to wasting and disease. Often, El Niño events also cause significant damage to kelp populations. Anthropogenic conditions make it extremely unlikely that recovery from these disturbances will proceed naturally. In 2001, the National Oceanic and Atmospheric Administration and the California Coastkeeper Alliance launched a project to involve hundreds of volunteer divers in controlling urchins and replanting kelp. Between 2001 and 2007, trained volunteers restored 18,500 square meters of kelp off Santa Barbara, Los Angeles, Orange, and San Diego counties. Activities included involving schoolchildren in tank-raising the algae, replanting, urchin removal, and monitoring of forest communities. While the initial project ended in 2007, work continues with various partners—from 2014 to 2018, the Santa Monica Bay Foundation restored over 46 acres of kelp forest along the Palos Verdes Peninsula. This work continues with the involvement of professional biologists, trained volunteers, and commercial urchin harvesters.

Kelp forest in the Santa Monica Bay. *Source:* **The Bay Foundation.**

CLIMATE AND THE CALIFORNIA CURRENT

Atmospheric and oceanographic anomalies such as El Niño have been documented to alter the abundance of fish and wildlife, including species of commercial importance. El Niño conditions in the California Current Ecosystem are characterized by cessation of the east-to-west equatorial trade winds, resulting in a backwash of warm equatorial waters eastward to the continental shore that then pushes northward against the California Current. This flood of warm seawater elevates the sea level and causes increased stratification of ocean layers, a decrease in the mixing caused by normal upwelling, and an overall decrease in primary production. El Niño events have caused some of the largest physical and biological perturbations observed in the ecosystem, but not all years characterized as El Niño events trigger the same responses. *El Niño–Southern Oscillation* (ENSO) is the term used by oceanographers to describe what is—among phenomena that involve coupled effects of the ocean and atmosphere and that cause global climate variability on interannual time scales—the most important in the Pacific Ocean (fig. 19). La Niña is the opposite phase in the ENSO cycle, during which cold conditions prevail. Each phase of the ENSO cycle can last 9 to 12 months, or longer, and ENSO cycles occur every 3 to 5 years, with El Niño events more common than La Niña. During mild El Niño conditions in 2005, upwelling was delayed by 1 month. The result was warmer waters, lower nutrient levels, reduced primary productivity, and fewer copepods. This led to reduced fish abundance and a complete breeding failure in Cassin's auklet (*Ptychoramphus aleuticus*). Conversely, when anomalous wintertime upwelling occurs, increases in rockfish growth and salmon survival can result.

Figure 19. The frequency and severity of storms can be affected by ocean cycles and the changing climate. *Source:* NASA Geostationary Operational Environmental Satellite program.



The California Current Ecosystem is therefore very sensitive to the timing and magnitude of seasonal climate conditions, and the onset of climate change is already increasing risks to important ecological and economic resources. Rising sea levels and small increases in sea temperature are measurably affecting the ecosystem. So is a decrease in pH of the ocean, a phenomenon known as ocean acidification, which is caused by excessive carbon entering the ocean from the atmosphere. Acidification is already affecting sensitive invertebrates that form the foundation of some food webs. Ocean acidification disrupts the shell formation of corals and the early life stages of mollusks and fish, and can impact algal communities. Ocean acidification represents an emerging threat to the ecosystem, which may prove to be detrimental to some wildlife communities and to commercial aquaculture. Overall, recent estimates predict that the cumulative impacts of climate change on the California Current Ecosystem will be greater in the northern reaches of the ecosystem than in the central and southern areas.

MANAGING A HEALTHY FUTURE FOR CALIFORNIA'S OCEAN

Effectively managing ocean ecosystems requires characterizing the threats, impacts, and management needs of the system and developing appropriate management tools. Decades of work in California by scientists, ocean conservation advocates, and public trust agencies have led to the establishment of four national marine sanctuaries, a

Pollution enters the California Current Ecosystem from vessels and offshore operations—but primarily from land.

coastline protected as the California Coastal National Monument (managed by the Bureau of Land Management), several ocean and coastal national parks, a new state network of marine protected areas—and, for the Western Pacific leatherback sea turtle, the largest area in the Pacific Ocean to be designated as critical habitat under the Endangered Species Act. California is considered a global leader in ocean management and conservation. But even with all these protections in place, risks to the long-term health of the California Current Ecosystem still exist.

Vessel traffic in California—related to commercial shipping, recreational cruise lines, offshore energy operations, and military activity—results in vessel strikes and introduces engine noise, invasive species from foreign habitats, oil pollution, and other discharged pollution (such as trash and sewage). Engine noise from ships can impair cetaceans' navigation, prey detection, and communication, as well as their ability to detect relevant noises that they use to gauge their behaviors. It is believed that chronic impacts from engine noise may cause stress in individual cetaceans and affect their reproductive fitness. Commercial shipping vessels over 240 feet long and traveling faster than 14 knots can deliver a lethal blow to large baleen whales, the most susceptible of cetaceans to ship strikes. Between 2004 and 2008, reported ship strikes by large and small vessels in California were implicated as the cause of death for two humpback, four gray, and four blue whales, as well as one sperm whale. Since many whales hit by vessels may not strand on land following injury or death, and collisions may not be reported or even noticed by large container ships, the number of ship strikes is likely underestimated.

Oil and gas production in California began in 1896, and by 1902 there were over 180 offshore drilling wells. Currently, 16 percent of the state's oil and gas extraction occurs offshore, involving nine platforms located in the Southern California Bight between Santa Barbara and Long Beach Harbor. An oil spill of 4 million gallons in the Santa Barbara Channel in 1969 resulted in a heightened awareness of the risks of offshore oil drilling, which led to the nationwide establishment of protective measures along coastlines, including creation of the national marine sanctuaries. Oil spills have direct, deadly impacts on seabirds and marine life (fig. 20), and their long-term toxic effects can result in deleterious consequences through a trophic cascade. Almost every day, California's major ports receive oil tankers carrying up to 1 million barrels of foreign petroleum products. The size of these vessels has increased faster than infrastructure for oil spill response in receiving ports, causing concern among environmentalists. A new wave of offshore energy technology to harness the energy of ocean winds, tides, and waves is currently being engineered and tested in California.

Pollution enters the California Current Ecosystem from vessels and offshore operations—but primarily from land, through both point-source discharges such as municipal sewer outfalls and non–point sources such as rivers and streams that carry polluted stormwater runoff. Water pollution from inland sources has had a detrimental impact on nearshore kelp forests throughout the densely populated Southern California Bight. Despite a complete ban on dumping of plastics at sea by the International Convention for the Prevention of Pollution from Ships (also known as MARPOL 73/78), plastic waste has fouled rocky reefs, deepwater canyons, and shorelines in California. Eighty percent or more of the debris in the ocean starts as land-based litter, and upwards of 85 percent is composed of plastics that may persist for decades to centuries.

Figure 20. After a 2015 oil spill in Santa Barbara, the U.S. Fish and Wildlife Service conducted a project to retrieve oiled wildlife. *Source:* EPA.

Perils of Plastic in the Ocean

Marine debris is one of the many forms of pollution that threaten the health of the California Current Ecosystem. Marine debris is defined by the National Oceanic and Atmospheric Administration as "any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment." Marine debris exists floating on the ocean surface, suspended in the water column, and on the seafloor. The plastic pollution component of marine debris—consisting of littered bags, bottles, and utensils, as well as derelict fishing gear and tiny microplastic particles produced by the degradation in the environment of polyester garments and all other plastic items—is the most problematic form of marine debris due to its persistence in the environment and toxic properties. The deleterious effects of plastic pollution in marine ecosystems have been known for over 40 years, and despite this, industrial production of plastics has risen every year. Many plastics, such as carcinogenic polyvinylchloride (PVC), contain toxic


Bilyjan

chemicals in their composition. Plastic litter in the ocean can also adsorb other toxic compounds from the environment, such as metals, PCBs, and DDT. When worms, fish, and other organisms accidentally ingest plastic fragments, effects such as decreased growth and stress to organs can result. Scientists studying the problem have detected chemicals found in plastics in both seawater and sand samples from California. The U.S. Environmental Protection Agency (EPA) assesses the ecological risk of plastic pollution in ocean ecosystems in order to better understand the toxicology of this persistent, ubiquitous pollutant.

Seafood consumption fuels the arms race for fishery resources, driving bigger boats to drag longer lines.

Engagement at many levels, from fishermen and concerned citizens to state and federal governments, is involved in improving the sustainability of California's commercial and recreational fishing operations—both to ensure their economic viability and to reduce impacts to nontarget wildlife species. A complex combination of inland and ocean habitat degradation has resulted in the near collapse of California's commercial salmon fishery, and the California Department of Fish and Wildlife ordered its complete closure from 2008 to 2010. Severe restrictions are in place on both commercial and recreational rockfish fisheries, which have depleted these slow-growing, long-lived species. Vessels involved in crab fishing are now limited to 500 traps each in the hope of reducing overharvest and trap loss—previously, when the number of traps allowed was unlimited, an arms race had developed. Lost crab traps become marine debris, and their drifting ropes and buoys are known to kill marine mammals and sea turtles (an occurrence called ghost fishing). Longlines, bottom trawls, and drift gillnets are indiscriminate types of fishing gear that snare large numbers of nontarget species (known as bycatch). Most longlines are currently banned off the coast of California and, to protect sensitive habitats and species, bottom trawls and drift gillnets are restricted. California's drift gillnet fishery deploys floating nets a mile long into the California Current Ecosystem and is under scrutiny by conservationists for its high bycatch of ocean sunfish (*Mola mola*), endangered sperm whales, dolphins, white sharks, and leatherback sea turtles. As the population of California, and the world, continues to grow, and the demand for fish increases, the pressure to balance the demand for seafood with the harmful realities caused by its harvest will continue to increase.

California State Marine Protected Areas and National Marine Sanctuaries

With so many threats to the offshore environment, many have recognized the need for marine protected areas; and while large-scale environmental damage such as oil spills may still impact these areas in the future, the established network of marine reserves is vital to sustaining the California Current Ecosystem.

Marine protected areas are marine or estuarine waters set aside primarily to protect or conserve marine life and its associated habitat. Marine protected areas have varying levels of protections and allowed uses, from "no-take" zones to those that allow some forms of fishing. They conserve biological diversity and protect a variety of marine habitats, communities, and ecosystems for their intrinsic value, while improving marine resources for human use. When sensitive ocean and coastal habitat is protected, marine life flourishes and, in turn, a healthier system is created overall. Long-term monitoring in no-take areas established in the Channel Islands proves that marine protected areas, by protecting ecosystems and not just individual species, allow economically important sport fish to thrive. Marine protected areas also provide opportunities to learn from and enjoy marine areas that are subject to reduced human disturbance. California's coastal network of marine protected areas, which was completed in 2012, protects over 800 square miles, or 16 percent, of California's ocean. Nine percent of California's ocean falls within no-take state marine reserves.

Preserving California's ocean identity, heritage, and economy for future generations was at the heart of the process to designate the marine protected areas. They were designed by local stakeholders to achieve goals set forth in California's Marine Life Protection Act, passed by the Legislature in 1999. The Marine Life Protection Act directed the California Department of Fish and Wildlife to redesign its system of marine protected areas to increase the system's coherence and its effectiveness at protecting the state's marine life, habitats, and ecosystems. The process brought together scientists, fishermen, conservationists, business owners, residents, and officials from the Department of Fish and Wildlife to create a long-term plan to restore and protect California's most unique and threatened marine environments. California residents can now enjoy these special areas for swimming, kayaking, diving, snorkeling, and tide pooling, and can join local citizen science efforts to monitor these areas.

Currently, there are four national marine sanctuaries in California, totaling 12,145 square miles of protected ocean (fig. 21). From south to north, they are the Channel Islands (1,470 square miles), Monterey Bay (6,094), Greater Farallones (3,295), and Cordell Bank (1,286) National Marine Sanctuaries. Within the Channel Islands National Marine Sanctuary, 318 square miles are protected as no-take zones. Outside such zones, the national marine sanctuaries are mixed-use areas where fishing is unrestricted—but it is prohibited to produce or explore for oil and gas; produce or explore for other minerals; deposit or discharge material; and, outside the national marine sanctuary, deposit or discharge material that may injure resources within the sanctuary.

Additional federal and state regulations that strengthen protections in the California

Figure 21. View of the Channel Islands National Marine Sanctuary from Santa Barbara Island.

Current Ecosystem include the Endangered Species Act and Marine Mammal Protection Act, as well as California Department of Fish and Wildlife rules. The Endangered Species Act protects threatened and endangered species from any "take," including many populations of salmon, such as the Central Coast coho; many seabirds, such as the marbled murrelet (*Brachyramphus marmoratus*); all sea turtle species; and marine mammals such as the Guadalupe fur seal. Under the Endangered Species Act, to "take" is defined as to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." The Marine Mammal Protection Act prohibits the intentional or unintentional killing of any marine mammal. The Act outlines defined processes to bring about swift and legally binding changes to any activities that are calculated to exceed the allowable "potential biological removal" of any given marine mammal species. The Department of Fish and Wildlife protects the viability of many fish and marine invertebrate populations with requirements regarding recreational and commercial fishing licenses, fishing gear types, and both seasonal and area closures. Federal agencies such as the U.S. Fish and Wildlife Service and National Park Service are also responsible for marine protected areas in California, including the Farallon Islands National Wildlife Refuge—which hosts the largest colony of endangered ashy storm petrels (*Oceanodroma homochroa*) in the world—and the Channel Islands National Park, which supports over thirty threatened and endangered species and includes some of the oldest no-take marine protected areas in California.

Conservation Case Study: Modifying Shipping Lanes to Avoid Whale Strikes

A blue whale swims in the Santa Barbara Channel near a container ship. ***Source:*** **Cascadia Research.**

An example of effective management of the California Current Ecosystem's diverse resources and stakeholder needs took place within the Gulf of the Farallones, Cordell Bank, and Channel Islands National Marine Sanctuaries, established hotspots for whales. Approximately 20 tankers, container ships, or barges enter and exit San Francisco Bay through the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries every day, at an average speed of 17 knots, to reach ports via designated shipping lanes. As a result of this vessel traffic, there were 30 documented whale strikes within these national marine sanctuaries from 1988 to 2011, but many more are not documented or occur outside sanctuary boundaries. For blue whales, the annual mortality caused by ship strikes exceeded 3.1, the level defined by the National Marine Fisheries Service as the species' "potential biological removal"—that is, the amount of human-induced mortality that a species can withstand without negative impacts on its population.

A joint working group of stakeholders and agencies mapped the fine-scale patterns of whale habitat use across seasons and compared these with shipping vessel traffic patterns to identify areas of greatest risk to whales. Three recommendations to reduce whale strikes were identified, which also take into account carbon emissions and economic impacts on the shipping industry:

- Shipping lanes should be modified so that traffic is routed as directly as possible over the highly productive continental shelf.
- A system of dynamic management areas should be implemented, whereby ships would either choose alternate shipping lanes or reduce speeds when whales are present in high concentrations.
- A real-time network should be established for whale sighting and monitoring to support the dynamic management areas.

A citizen science mobile phone application that now feeds into this system allows whale watchers and recreational boaters to assist state and federal agencies in reporting whale sightings. These efforts demonstrate how science and management can interact to identify ways to minimize anthropogenic impacts on marine ecosystems while maintaining sustainable human uses.

Things You Can Do—Protecting the Future of the California Current Ecosystem

All Californians can take part in ensuring a healthy marine ecosystem off the coast of the Golden State. At each national marine sanctuary, volunteers serve on advisory councils that respond to and address concerns. The state welcomes public involvement at meetings of the Ocean Protection Council, California Fish and Game Commission, and California Coastal Commission. Local and regional governments, which are constantly faced with coastal development and pollution issues, benefit from the active input of caring, knowledgeable naturalists.

Individual, everyday actions can have a big cumulative effect on the ocean, in California and across the globe. Our individual and family carbon footprints are directly connected to excess atmospheric carbon loading, which is responsible for warmer ocean temperatures, sea level rise, ange include a shift north for tide pool species that were once confined to the Southern d increased ocean acidification. In California, the measurable effects of climate chanCalifornia Bight, as well as reduced reproductive abilities among oysters due to ocean acidification. Reducing carbon emissions by riding a bike or walking to the beach instead of driving helps the ocean!

Reducing ocean plastic pollution starts with reducing the purchase and use of disposable plastic items we encounter every day at home, in stores, and in restaurants. While consumers can use their purchasing power, experts agree that laws to restrict, reduce, or eliminate plastic beverage bottles, plastic bags, and polystyrene foam containers will have the greatest impact.

Seafood consumption fuels the arms race for fishery resources, driving bigger boats to drag longer lines and deeper nets to extract whatever marketable species remain in abundance. Choosing locally caught or sustainably branded seafood can ease some of the pressure that commercial fishing exerts on marine ecosystems.

Connecting with California's wild ocean can take some effort, but the rewards make the effort worthwhile. Being in, or near, the ocean makes most people feel happier and healthier! Whether you gaze offshore from the shoreline of one of many coastal promontories, surf the waves, go out in a boat to be surrounded by the ocean, or enjoy the underwater environment during a recreational or community-science scuba dive, your experiences and observations can bring you closer to understanding the complex and beautiful life forms that exist in the ocean off the coast of California.

Additional Reading

50 Ways to Save the Ocean, by David Helvarg; 208 pages. ISBN: 978-1-93-072266-8.

Coastal Fish Identification: California to Alaska, by Paul Humann; 292 pages. ISBN: 978-1-87-834843-2.

Field Guide to Birds of the Northern California Coast, by Rich Stallcup and Jules Evens; 366 pages. ISBN: 978-0-52-027617-8.

Field Guide to Marine Mammals of the Pacific Coast: Baja, California, Oregon, Washington, British Columbia, by Sarah G. Allen and Joe Mortenson; 584 pages. ISBN: 978-0-52-026545-5.

Introduction to Birds of the Southern California Coast, by Joan Easton Lentz; 329 pages. ISBN: 978-0-52-024321-7.

Sea Change: A Message of the Oceans, by Sylvia Earle; 361 pages. ISBN: 978-0-44-991065-8.

Sharks, Rays, and Chimaeras of California, by David A. Ebert; 297 pages. ISBN: 978-0-52-023484-0.

Explore!

The National Marine Sanctuary System, sanctuaries.noaa.gov/about/westcoast.html, is a wonderful way to experience the ocean in California. Connect with opportunities for guided naturalist walks along the coast, family-friendly ocean exhibits, and citizen science projects through the regional offices of California's four national marine sanctuaries.

MPA Watch, mpawatch.org/, is a community science monitoring program that trains volunteers to observe and collect data about use of coastal and marine resources inside and outside marine protected areas. Volunteers

Girl Scouts from Tijuana and San Diego collect community science data for the Marine Protected Area (MPA) Watch program. *Source:* Wildcoast/Costasalvaje.

use standardized protocols to collect relevant, scientifically rigorous, and broadly accessible data to inform the management, enforcement, and science of California's marine protected areas, and to track how the public uses coastal areas. By involving local communities in this monitoring of marine protected areas, MPA Watch programs inspire and empower stewardship and educate the public about California's ocean ecosystems.

Reef Check California, https://www.reefcheck.org/country/usa-california, aims to build a network of informed and involved community members who support the sustainable use and conservation of our nearshore marine resources. The organization trains volunteer scuba divers to carry out surveys of nearshore reefs and gather data on the status of key indicator species. Trainings are offered annually in the spring and summer.

The California Coastal Commission, coastal.ca.gov, protects, conserves, restores, and enhances the environmental and human-based resources of the California coast and ocean for environmentally sustainable and prudent use by current and future generations. Visit the commission's website for information on proposed coastal and ocean management policies, public hearings, and the annual Coastal Cleanup Day.

Explore the latest research, find in-depth educational materials, and even get data sets to explore at the **Long Term Ecological Research** (LTER) page on the California Current website, lternet.edu/site/california-current-ecosystem-lter.

Visit the **California Department of Fish and Wildlife's** website, dfg.ca.gov/marine/mpa/guidebooks.asp, for maps of all the marine protected areas and to identify underwater parks in your area.

Native California tribes stewarded nearshore marine resources for thousands of years. The Tolowa Dee-Ni' Nation in far Northern California is leading intertribal efforts to conduct marine monitoring and conservation planning. You can learn more about modern and traditional management by the Ventura-based Wishtoyo Chumash Foundation, wishtoyo.org, through their marine and environmental science programs. The California Indian Environmental Alliance is developing a Tribal Marine Stewards Network, and the Marine Traditional Knowledge Ethnographic Database allows tribes to own and share their data.

The Bay Foundation (TBF), santamonicabay.org—also known as the Santa Monica Bay Restoration Foundation—was founded in 1990 to restore and enhance Santa Monica Bay and local coastal waters. TBF undertakes projects that clean up our waterways, create green spaces in urban areas, and restore natural habitats both on land and under water. TBF is part of the U.S. EPA's Santa Monica Bay National Estuary Program, https://www.epa.gov/nep, which also includes two other programs in California at Morro and San Francisco Bays.

Wildcoast/Costasalvaje, wildcoast.org, conserves coastal and marine ecosystems and addresses climate change through natural solutions. Many of its programs span the United States-Mexico Border around the Tijuana River, facilitating international learning and cooperation to achieve ocean conservation.

There are several nearshore and offshore **national parks in California**, nps.gov/state/ca/index.htm, that offer beach, island, and underwater experiences. They include Cabrillo National Monument, Santa Monica Mountains National Recreation Area, Channel Islands National Park, Golden Gate National Park, and Point Reyes National Seashore.

The coastal **state parks**, parks.ca.gov/ParkIndex, are too numerous to list, but some highlights include Bolsa Chica

Big Sur coastline.

State Beach, Asilomar, and a series of parks along the Big Sur coast.

California has some of the premier **aquariums and marine museums** in the world, including the Aquarium of the Bay in San Francisco, aquariumofthebay.org/; Monterey Bay Aquarium, montereybayaquarium.org/; Aquarium of the Pacific, aquariumofpacific.org/; the Cabrillo Marine Aquarium, cabrillomarineaquarium.org/; and the Birch Aquarium in San Diego, aquarium.ucsd.edu/.

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Figure 4 is redrawn from: Strub, P. T., and C. James. 2000. Altimeter-derived variability of surface velocities in the California Current Ecosystem: 2. Seasonal circulation and eddy statistics. Deep-Sea Research Part II: Topical Studies in Oceanography 47(5–6):831–870. https://doi.org/10.1016/S0967-0645(99)00129-0.

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