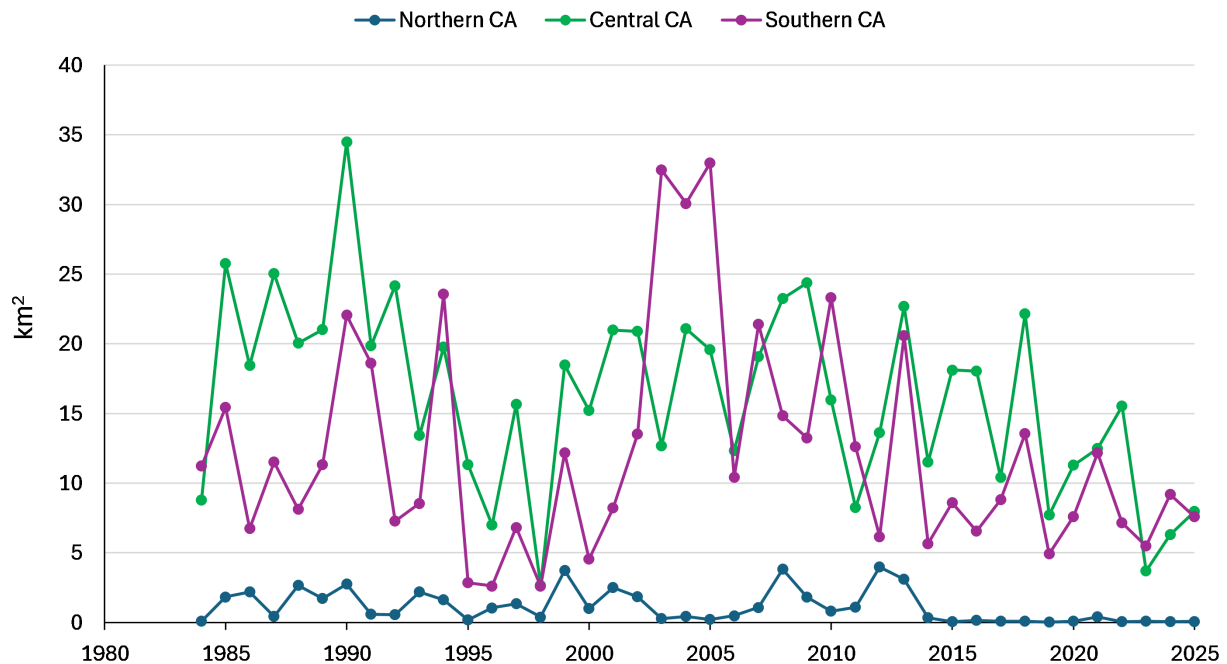


3.7 Kelp Populations

Kelp provides ecosystem services including critical habitats for marine life and valuable fisheries that support coastal economies, shoreline protection, and carbon storage. While kelp forests naturally fluctuate in response to changing ocean conditions, kelp are known for being resilient. This changed during the unprecedented 2014-2016 marine heatwave, when unusually warm ocean conditions, sea star wasting disease, and a rapid expansion in sea urchin populations combined contributed to widespread kelp loss. Climate change is expected to increase the frequency and intensity of marine heatwaves, increasing the likelihood of these types of ecosystem disturbances. Northern California's bull kelp canopy area declined by 95% and has yet to recover.

Figure 3.7.1. Annual Maximum Kelp Area.



This figure shows the annual maximum area (km²) covered by kelp for Northern, Central, and Southern California regions. Bull kelp was the dominant species in forests of the Northern region, while giant kelp dominates the Central and Southern regions. Source: Bell et al. (2026)

What does the indicator show?

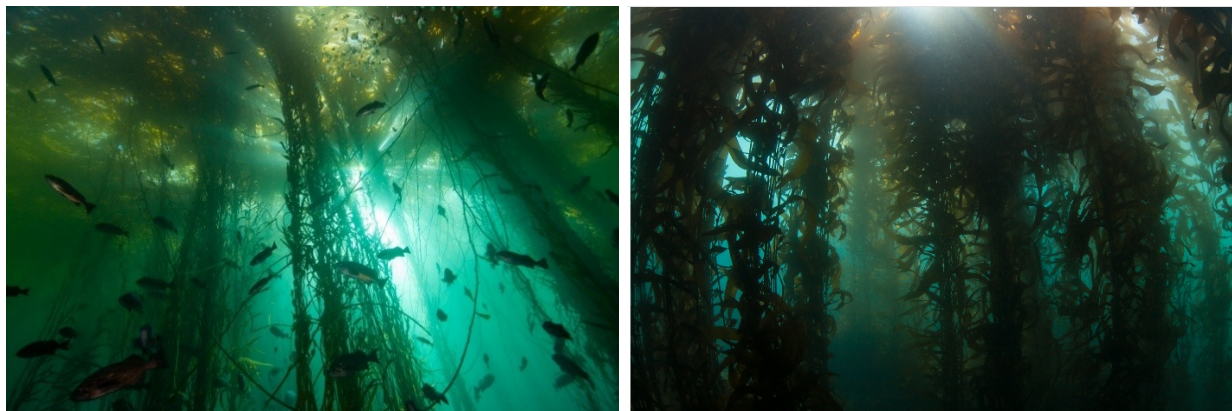
Kelp is a large brown alga that grows in dense stands reaching the surface, creating kelp forests in cold, shallow coastal waters. Satellite imagery dating back to 1984 shows



variability but overall resilience in kelp canopy areas across the state prior to the unprecedented Northeast Pacific marine heatwave that began in 2014 and persisted through 2016. The heatwave coincided with and was further intensified by the 2015-2016 El Niño, resulting in prolonged periods of unusually warm ocean conditions (**Figure 3.7.1**; Bell et al., 2020; California Ocean Protection Council, 2021; Reed et al., 2011). The marine heatwave had variable effects on kelp in each of California's major geographic regions: Northern California (California/Oregon border to San Francisco Bay), Central California (San Francisco Bay to Point Conception), and Southern California (Point Conception to the California/Mexico border, including the Channel Islands) (see map of regions in **Figure 3.7.2**). Bull kelp is an annual species and the dominant kelp in Northern California. Northern California represents the southern extent of this species' range and is where the bull kelp forests experienced a greater than 95% loss in canopy from 2013 to 2014 (Rogers-Bennett and Catton, 2019; Bell et al., 2026). Giant kelp is a perennial species and the primary kelp species in Central and Southern California. These regions encompass the center and northern extent of the species' range. Giant kelp forests in central California have exhibited patchy declines prior to 2014, with low years in the late 1990's and again in recent years (2020-2025). The marine heatwave generally had minimal effects on giant kelp forests in Southern California. However, in recent years (2020-2025), giant kelp canopy areas have been below average, similar to cases observed in central California (Cavanaugh et al., 2019; California Ocean Protection Council, 2021).



Figure 3.7.2. Bull Kelp and Giant Kelp.



The photos show vibrant kelp forests along the coast of California: bull kelp on the left and giant kelp on the right. Kelp forests provide critical ecosystem services such as harboring endangered or commercially important species, sequestering carbon, preventing shoreline erosion, and oxygen production. Left photo by Chad King/Monterey Bay National Marine Sanctuary/NOAA; right photo by Velvetfish/istock

Why is this indicator important?

Kelp forests are among the most productive and biodiverse ecosystems on the planet. In combination with their proximity to the shore, the productivity and biodiversity of these ecosystems generate a wide range of ecosystem services including supporting (e.g., primary production, habitat), regulating (e.g., water flow, coastal erosion), provisioning (e.g., commercial and recreational fisheries), and cultural (e.g., recreational, artisanal) service (Malone et al., 2022). Kelp forests help mitigate ocean acidification by utilizing large amounts of dissolved carbon dioxide (CO₂) from seawater during photosynthesis, creating local, less-acidic refuge that protect shellfish and other marine life. Globally they are estimated to fix as much as twice the carbon fixed in Canada's boreal forests (Duarte et al., 2022).

Both giant kelp (*Macrocystis pyrifera*), which dominates in southern and central California, and bull kelp (*Nereocystis luetkeana*), which dominates in northern California, are foundation species that provide a variety of ecological functions. Kelp forests form complex three-dimensional habitats and host a diverse wide array of invertebrates, fishes, marine mammals, and birds. Kelp is an important food source for



herbivores and detritivores and underpins nearshore food webs (California Ocean Protection Council, 2021). Additionally, kelp plays an important role in coastal nutrient cycling, offshore provisioning of deep kelp falls (Britton-Simmons et al., 2009), and may help to mitigate ocean acidification at local scales (Steneck et al., 2002; Springer et al., 2010; Carr and Reed, 2016; Miller et al., 2018; Nielsen et al., 2018; Hirsh et al., 2020; Lamy et al., 2020) while having limited potential to buffer shorelines against waves during storms (Elsmore et al., 2024).

Declines in kelp populations are a key indicator of climate-driven changes affecting California's coastal marine ecosystems. Because kelp responds rapidly to changes in ocean temperature, nutrient availability, and marine heatwaves, long-term changes in kelp canopy reflect the cumulative effects of warming oceans and associated ecological disturbances, such as disease outbreaks and shifts in predator-prey interactions (see the *Coastal Ocean Temperatures* chapter for more information on nearshore warming along the coast). Other species also show the impacts of warming such as the nudibranch (a shell-less sea snail) found in California called *Phidiana hiltoni* that has expanded its range north along the California coast in response to warming ocean conditions (OEHHA, 2018). Population declines in other nudibranch species have occurred at Duxbury Reef, located north of San Francisco, where particularly high densities of *P. hiltoni* have been observed (Goddard et al., 2011). These declines appear to have resulted from *P. hiltoni* preying on other nudibranchs and competing for common prey species. The range shift of these predatory species may be disrupting food webs and altering community composition at sites along the California coast where its populations are dense.

Kelp is also critical to the well-being of California's coastal residents and the state's coastal economy. California's indigenous peoples, who have inhabited and stewarded the coast for millennia, continue to rely on kelp forest ecosystems for food, medicine, and ceremony. Kelp supports a variety of commercially and recreationally important fisheries, including recreational red abalone (*Haliotis rufescens*), commercial red sea urchin (*Mesocentrotus franciscanus*), and groundfish, including rockfishes (*Sebastes* spp.) (California Ocean Protection Council, 2021). Kelp is an important food source and habitat for many of these species. Following the decline of the bull kelp forest in



northern California, red abalone populations experienced widespread starvation and declines in abundance, contributing to the closure of California's recreational red abalone fishery in 2018, which had generated more than \$44M USD for the local economy (Reid et al., 2016). Commercial red sea urchin divers were also similarly affected as urchins had reduced marketable roe production due to the loss of kelp food resources, resulting in federal disaster relief declarations.

What factors influence this indicator?

Factors such as ocean temperature, nutrient availability, pollution, disturbances from large waves, and grazing from sea urchins strongly influence kelp growth and persistence. Cool, nutrient-rich waters typically promote strong kelp recruitment and rapid growth, while warm, nutrient-poor conditions can reduce productivity and increase mortality (García-Reyes et al., 2022). Physical disturbances such as large waves and storms can remove kelp from the seafloor, and intense grazing by sea urchins can transform kelp forests into persistent “urchin barrens”. The limited recovery of kelp across much of northern California has been linked to a widespread ecosystem transition toward urchin barrens (NOAA, 2020; Rogers-Bennett and Catton, 2019).

Between 2013 and 2014, more than 95% of bull kelp along northern California's coastline disappeared, accompanied by a surge in kelp-eating purple sea urchins (*Strongylocentrotus purpuratus*) and densities continue to remain high. Significant kelp declines also occurred along portions of the central and Southern California coast, including the Monterey Peninsula. Purple sea urchins proliferated in response to the loss of their natural predators, the sunflower sea star (*Pycnopodia helianthoides*), due to a sea star wasting disease (Gravem et al., 2021) linked to a bacterium (Prentice et al., 2025). Anomalously warm ocean temperatures were associated with greater morbidity of sunflower stars from this disease (Harvell et al., 2019) but the onset of the disease occurred prior to ocean warming.

At the same time, the 2014-2016 marine heatwave created unusually warm, nutrient-poor conditions (García-Reyes et al., 2014) that stressed kelp populations (McPherson et al., 2021; Rogers-Bennett and Catton, 2019). Together, the marine heatwave, sea star wasting disease, and increased sea urchin grazing shifted large areas of the



ecosystem from kelp forests to persistent sea urchin barrens, limiting recovery even after ocean temperatures moderated. Notably, kelp in marine protected areas (managed regions where fishing and other types of human disturbances are limited) off the California coast initially rebounded more quickly than other kelp after the 2014-2016 marine heatwave. This rebound effect was most pronounced in Southern California, likely because predators may have kept sea urchin populations in check, reducing grazing pressure on kelp. In Southern California, populations of grazing sea urchins may be regulated by predatory fish and California spiny lobster (*Panulirus interruptus*) that are rare elsewhere in California (Ortiz-Villa et al., 2025). In Central California, the southern sea otter (*Enhydra lutris*) is an important sea urchin predator (Smith et al. 2021) also not found elsewhere in California following the historic fur trade—sea otters have been absent from most of the Pacific Coast for more than 100 years, since their near extinction following the maritime fur trade in the 1700s and 1800s (US FWS, 2026).

Figure 3.7.3. Kelp Forest and an Urchin Barren in California.



The photo on the left shows a vibrant California kelp forest. The photo on the right shows an urchin barren caused by urchins overgrazing on kelp and consequently, converting the kelp

forests into sea urchin barrens. Credit: Left photo by Monterey Bay National Marine Sanctuary Foundation. Right photo by David Witting (NOAA). Source: [SeaGrant California](#).

Technical considerations

Data characteristics

The proportional cover of emergent kelp canopy (i.e., the amount of kelp canopy that is directly floating at the surface of the ocean, hereafter referred to as kelp canopy area) was estimated with Landsat satellite imagery from 1984 to the present. Atmospherically corrected 30 meters (m) resolution multispectral imagery was used from five Landsat sensors: Landsat 4, Landsat 5, Landsat 7, Landsat 8, and Landsat 9.

Poor-quality observations, including cloud coverage, were identified and removed. For each month, enough imagery was collected so that each pixel in the study area was covered at least five times. Land areas were masked out using a digital elevation model produced by the USGS Coastal National Elevation Database.

Strengths and limitations of the data

Satellite imagery is a powerful tool for monitoring the distribution of canopy-forming kelps and studying the drivers that control their abundances. The Landsat data spans the period from 1984 to the present and covers multiple global regions including the majority of North America's west coast, Argentina, Southern Africa, and Peru, and is incrementally growing to cover kelp habitat worldwide (Bell et al., 2026).

Satellite imagery provides a valuable tool for monitoring the distribution of canopy-forming kelps and studying the drivers that control their abundances. Canopy-forming kelps are distinctive when viewed from above, particularly in the near infrared spectral region, and suitable for remote mapping (Jensen et al., 1980; Deysher, 1993). Satellite platforms such as Landsat and Planet support the monitoring of kelp forests on local to global spatial scales and allow for historical comparison on seasonal to decadal time scales (Bell et al., 2026).

While Landsat data are highly effective in detecting long-term regional trends, local-scale applications might require higher resolution data to detect sparse and/or fringing kelp patches (Cavanaugh et al., 2026; Hamilton et al., 2020). For example, areas very



close to shore or offshore rocks (typically within one Landsat pixel; ~30 m) or areas that are exposed during low tide will be removed by the land-masking procedure and thus the kelp canopy area within these pixels will not be measured. Additionally, areas with sparse kelp canopy may not be detected by the classifier. For example, Hamilton et al. (2020) performed a miss rate analysis for bull kelp canopies in Oregon and found that pixels with less than 10% canopy cover were often missed, while pixels with greater than 15% canopy cover were rarely missed. Local-scale analyses that require a census of all fringing/sparse canopies or a determination of kelp species should investigate other imaging methods that provide high spatial resolution imagery, such as aerial overflights or unoccupied aerial vehicles (i.e., drones). These methods may also be able to provide data acquired at specific tidal states that may be useful to some research applications (Bell et al., 2026). Overall, the long time series of satellite imagery of kelp canopy provides a robust tool for assessing the health of California's kelp and their associated kelp forest ecosystem. As such, this metric serves as an invaluable indicator of ocean health during a period of unprecedented change.

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References

Bell T, Cavanaugh K, and Siegel D (2026). SBC LTER: Time series of quarterly NetCDF files of kelp biomass in the canopy from Landsat 5, 7 and 8, since 1984 (ongoing) ver 23. Environmental Data Initiative. <https://doi.org/10.6073/pasta/2c1218b7ebe6967da52000adf02f6a8b>.

Bell TW, Allen JG, Cavanaugh KC and Siegel DA (2020). Three decades of variability in California's giant kelp forests from the Landsat satellites. *Remote Sensing of Environment* **238**:110811.



Britton-Simmons KH, Foley G and Okamoto D. (2009). Spatial subsidy in the subtidal zone: utilization of drift algae by a deep subtidal sea urchin. *Aquatic Biology* **5**: 233-243.

California Ocean Protection Council (2021). *California Ocean Protection Council Interim Action Plan for Protecting and Restoring California's Kelp Forests*. Contributors: Michael Esgro (California Ocean Protection Council) and James Ray (California Department of Fish and Wildlife)

Carr MH and Reed DC (2016). Chapter 17: Shallow Rocky Reefs and Kelp Forests. Pages 311-336. In: H. Mooney and E. Zavaleta (eds) *Ecosystems of California*. Berkeley: University of California Press.

Cavanaugh KC, Cavanaugh KC, Berberian LA, Ortiz-Villa EM, Callahan MC and Leung M (2026). High-resolution planet Dove data identify local drivers of kelp canopy persistence. *Communications Earth & Environment* (7): 137.

Cavanaugh KC, Reed DC, Bell TW, Castorani MC and Beas-Luna R (2019). Spatial variability in the resistance and resilience of giant kelp in southern and Baja California to a multiyear heatwave. *Frontiers in Marine Science* **6**:413.

Dayton PK, Tegner MJ, Parnell PE and Edwards PB (1992). Temporal and spatial patterns of disturbance and recovery in a kelp forest community. *Ecological Monographs* **62**(3):421-445.

Deysher LE (1993). Evaluation of remote sensing techniques for monitoring giant kelp populations. *Hydrobiologia* **261**: 307–312.

Duarte CM, Gattuso JP, Hancke K, Gundersen H, Filbee-Dexter K, et al. (2022). Global estimates of the extent and production of macroalgal forests. *Global Ecology and Biogeography* **31**(7):1422-1439.

Elsmore K, Nickols KJ, Miller LP, Ford T, Denny MW and Gaylord B (2024). Wave damping by giant kelp, *Macrocystis pyrifera*. *Annals of Botany* **133**(1): 29-40.

García-Reyes M, Largier JL and Sydeman WJ (2014). Synoptic-scale upwelling indices and predictions of phyto-and zooplankton populations. *Progress in Oceanography* **120**: 177-188.

García-Reyes M, Thompson SA, Rogers-Bennett L and Sydeman WJ (2022). Winter oceanographic conditions predict summer bull kelp canopy cover in northern California. *PloS one* **17**(5): e0267737.

Goddard JHR, Gosliner TM and Pearse JS (2011, updated 2017). Impacts associated with the recent range shift of the aeolid nudibranch *Phidiana hiltoni* (Mollusca: Opisthobranchia) in California. *Marine Biology* **158**: 1095–1109.

Gravem SA, Heady WN, Saccomanno VR, Alvstad KF, Gehman ALM, et al. (2021). *Pycnopodia helianthoides*. *IUCN Red List of Threatened Species* 2021.

Hamilton SL, Bell TW, Watson JR, Grorud-Colvert KA and Menge BA (2020). Remote sensing: generation of long-term kelp bed data sets for evaluation of impacts of climatic variation. *Ecology* **101**, e03031.

Harvell CD, Montecino-Latorre D, Caldwell JM, Burt JM, Bosley K, et al. (2019). Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (*Pycnopodia helianthoides*). *Science Advances* **5**(1):eaau7042.

Hirsh HK, Nickols KJ, Takeshita Y, Traiger SB, Mucciarone DA, et al. (2020). Drivers of biogeochemical variability in a central California kelp forest: Implications for local amelioration of ocean acidification. *Journal of Geophysical Research: Oceans* e2020JC016320.



Jensen JR, Estes JE, and Tinney L (1980). Remote sensing techniques for kelp surveys. *Photogrammetric Engineering and Remote Sensing* **46**: 743–755.

Krumhansl KA, Okamoto DK, Rassweiler A, Novak M, Bolton JJ, et al. (2016). Global patterns of kelp forest change over the past half-century. *Proceedings of the National Academy of Sciences* **113**(48):13785-13790.

Lamy T, Koenigs C, Holbrook SJ, Miller RJ, Stier AC and Reed DC (2020). Foundation species promote community stability by increasing diversity in a giant kelp forest. *Ecology* **101**(5):e02987.

Malone DP, Davis K, Lonhart SI, Parsons-Field A, Caselle JE, Carr MH (2022). Large-scale, multidecade monitoring data from kelp forest ecosystems in California and Oregon (USA). *Ecology* **103**(5): e3630.

McPherson ML, Finger DJ, Houskeeper HF, Bell TW, Carr MH, et al. (2021). Large-scale shift in the structure of a kelp forest ecosystem co-occurs with an epizootic and marine heatwave. *Communications Biology* **4**(1): 298.

Miller RJ, Lafferty KD, Lamy T, Kui L, Rassweiler A and Reed DC (2018). Giant kelp, *Macrocystis pyrifera*, increases faunal diversity through physical engineering. *Proceedings of the Royal Society B: Biological Sciences* **285**(1874): 20172571.

Nielsen K, Stachowicz J, Carter H, Boyer K, Bracken M, et al. (2018). Emerging understanding of the potential role of seagrass and kelp 16 Interim Action Plan for Protecting and Restoring California's Kelp Forests as an ocean acidification management tool in California. Oakland: California Ocean Science Trust.

NOAA (2020). Prepared by the Northwest Straits Commission, NOAA's National Marine Fisheries Service, Puget Sound Restoration Fund, Washington State Department of Natural Resources, and Marine Agronomics.

Ober H (2025). UCLA Newsroom. <https://newsroom.ucla.edu/releases/marine-protected-areas-protect-help-climate-change>. Retrieved January 2026.

OEHHA (2018). "Nudibranch Range Shifts". In: *Indicators of Climate Change in California Technical Report, Third Edition*, California Environmental Protection Agency, Office of Environmental Health Hazard Assessment.

Ortiz-Villa EM, Rassweiler A, Caselle JE, Cavanaugh KC, Arafeh-Dalmau N, et al. (2025). Marine protected areas enhance climate resilience to severe marine heatwaves for kelp forests. *Journal of Applied Ecology* **62**(9):2439-2453.

Prentice MB, Crandall GA, Chan AM, Davis KM, Hershberger PK, et al. (2025). *Vibrio pectenicida* strain FHCF-3 is a causative agent of sea star wasting disease. *Nature Ecology & Evolution* **9**(9):1739-1751.

Reed DC, Rassweiler A, Carr MH, Cavanaugh KC, Malone DP and Siegel DA (2011). Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. *Ecology* **92**(11): 2108-2116.

Reid J, Rogers-Bennett L, Vasquez F, Pace M, Catton CA, et al. (2016). The economic value of the recreational red abalone fishery in northern California. *California Fish and Game* **102**: 119-130.

Rogers-Bennett L and Catton CA (2019). Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. *Scientific Reports* **9**(1):1-9.



Selgrath JC, Carlton JT, Pearse J, Thomas T and Micheli F (2024). Setting deeper baselines: kelp forest dynamics in California over multiple centuries. *Regional Environmental Change* **24**(3):104.

Smith JG, Tomoleoni J, Staedler M, Lyon S, Fuji J and Tinker MT (2021). Behavioral responses across a mosaic of ecosystem states restructure a sea otter–urchin trophic cascade. *Proceedings of the National Academy of Sciences*, **118**(11): e2012493118.

Springer YP, Hays CG, Carr MH and Mackey MR (2010). Toward ecosystem-based management of marine macroalgae—The bull kelp, *Nereocystis luetkeana*. *Oceanography and Marine Biology* **48**:1.

Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA, Tegner MJ. 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environmental Conservation* 436-459.

US FWS (2026). [Exploring Potential Sea Otter Introduction](#). Retrieved June 3, 2026.

