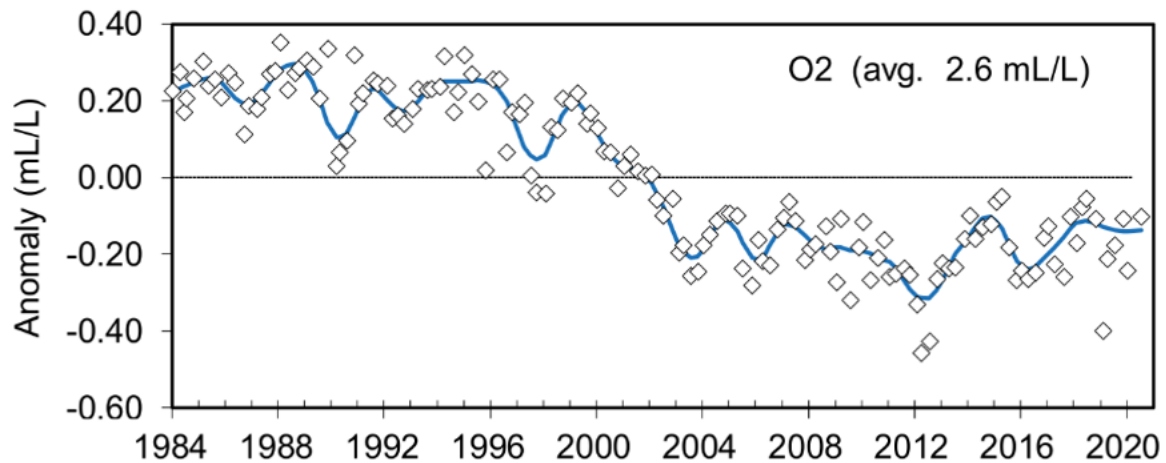


3.2 Dissolved Oxygen in Coastal Waters

Dissolved oxygen concentrations are declining in ocean waters off Southern California, in part due to increasing coastal water temperatures.

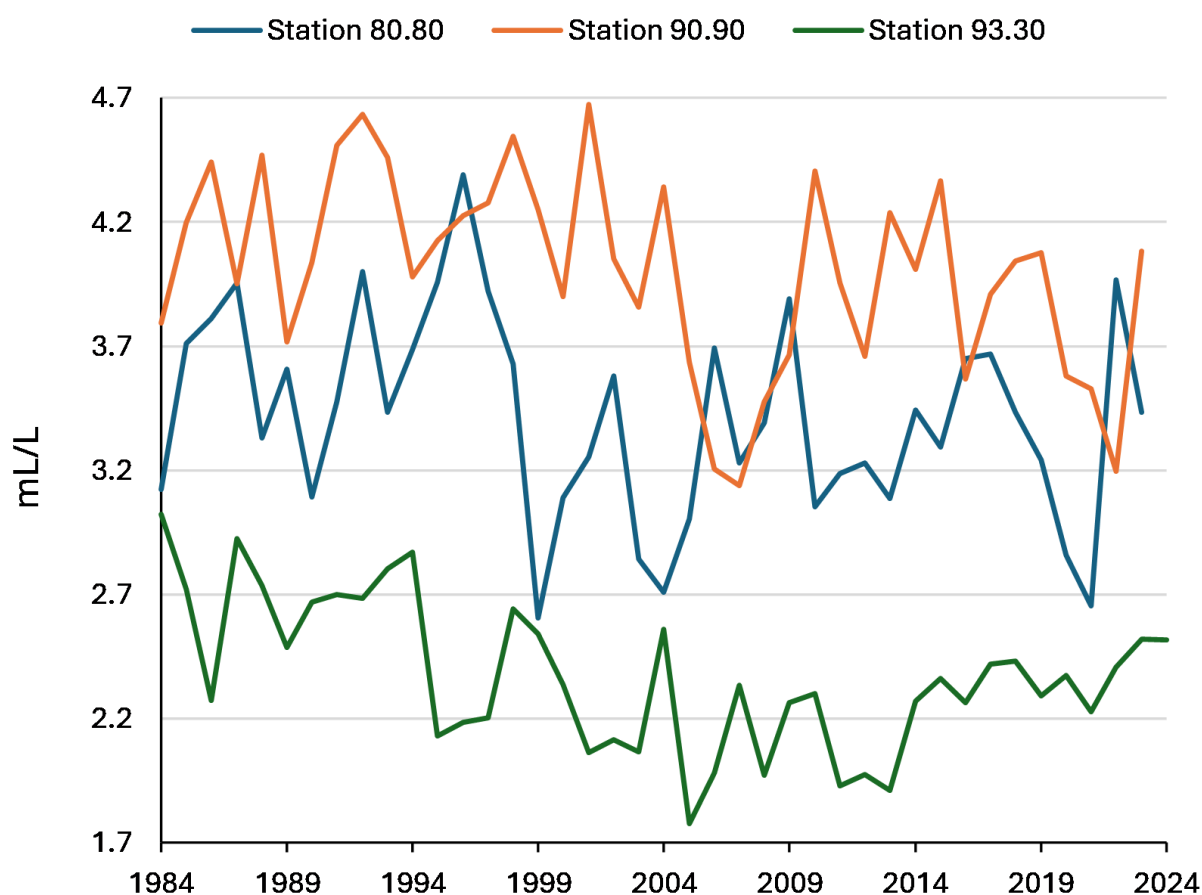
Figure 3.2.1. Dissolved Oxygen (DO) Concentration Anomalies.



In the above graph, each diamond represents the annual DO anomaly from 1984-2020, calculated as the difference between the average DO concentrations measured across 66 CalCOFI monitoring stations and the long-term mean concentration (2.6 milliliters of dissolved oxygen per liter of seawater (mL/L)) (abbreviated “O2”) derived from the baseline period 1984 to 2013. The solid blue line represents the trend in annual averages. Measurements were taken on the $\sigma_\theta=26.4$ kilograms per cubic meter (kg/m^3) isopycnal, corresponding to seawater at a density of 1026.4 kg/m^3 . Source: Weber et al. (2021) Supplementary Figure 6



Figure 3.2.2. Annual Average Dissolved Oxygen Concentrations.



The graph shows DO levels (mL/L) at three monitoring stations along the southern California coast from 1984 to 2025 at a depth of 150 meters (m); data gaps between 1950 and 1980 preclude calculations of annual averages for that time period. Source: California Current Integrated Ecosystem Assessment (CCIEA, 2026)

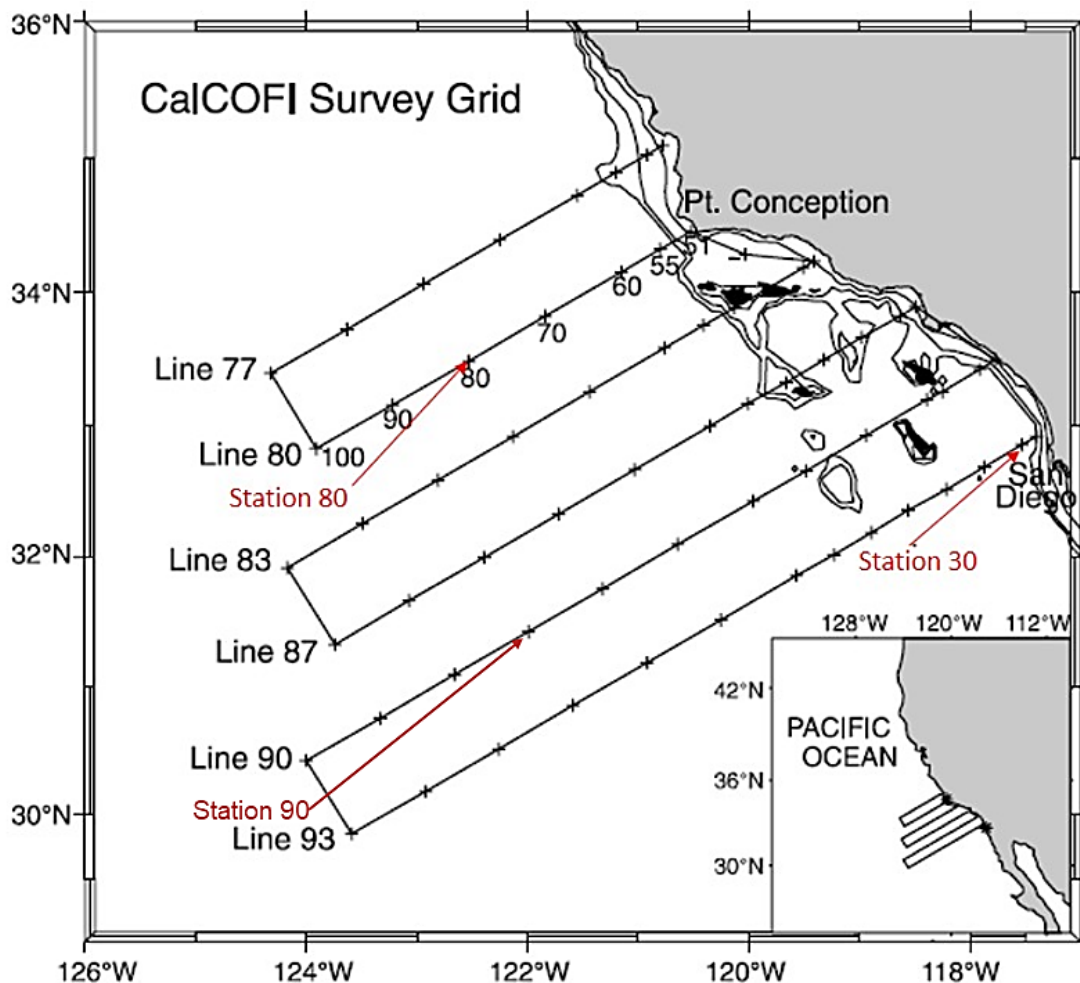
What does this indicator show?

Instrumental measurements of dissolved oxygen (DO) concentrations point to increasing deoxygenation of coastal waters within the subsurface waters of the California Current System (CCS) in recent decades ([Figure 3.2.1](#); Bograd et al., 2019; Evans et al., 2020; Smith Jr et al., 2022; Weber et al., 2021). These trends align with predictions that warming will increase hypoxia frequency in the CCS (Shi et al., 2023).



The CCS extends from British Columbia, Canada to Baja California, Mexico. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) has been taking measurements of DO periodically off southern California from San Diego to Point Conception since 1950, and consistently at a grid of stations four times per year since 1984 (see [Figure 3.2.3](#) for locations). [Figure 3.2.1](#) is based on measurements from the 66 core stations in the CalCOFI survey area. [Figure 3.2.2](#) presents data collected at 150 m at three stations: Line 80, Station 80 (referred to as “80.80”); Line 90, Station 90 (“90.90”); and Line 93, Station 30 (“93.30”) ([Figure 3.2.3](#)).

Figure 3.2.3. Sampling Locations.



Modified from Bograd et al. (2008)



Throughout the CalCOFI survey area, at depths corresponding to the σ_{θ} -26.4 isopycnal – the depth at which seawater density is 1026.4 kg/m^3 – DO concentrations decreased significantly between the mid-1990s and the mid-2000s (**Figure 3.2.1**; Bjorkstedt et al., 2012, as cited in Thompson et al., 2019). Following this decline, DO concentrations have been relatively stable, but below the long-term average since 2000 (Weber et al., 2021). Overall, DO concentrations in this region (to at least 500 m depth) are now generally lower than those observed in the 1950s to 1960s (Bograd et al., 2008, 2015, 2019).

93.30 is representative of the influence of the northward-flowing California Undercurrent, which is a major supplier of deeper source waters (200 to 500 m) to the region and has a large influence on oxygen content for much of the survey area. At 80.80, offshore of Point Conception and within the core of the near-surface, southward-flowing California Current, DO concentrations have also declined sharply since the mid-1990's but have been generally increasing at 150-300 m in recent years. DO levels at 90.90 have generally decreased since 2000.

Why is this indicator important?

Declining DO levels are a significant environmental concern in coastal waters. Recent studies indicate that there is a measurable decline in DO content, exacerbated by various climatic and ecological factors. Declining DO concentrations in ocean waters and the associated changes in the depth and extent of low oxygen zones can lead to significant and complex ecological changes in marine ecosystems, including wide-ranging impacts on diversity, abundance, and trophic structure of communities (Levin et al., 2009; Somero et al., 2015; Stramma et al., 2010). Changing ocean chemistry, in combination with temperature changes, may lead to even greater and more diverse impacts on coastal marine ecosystems (Somero et al., 2015).

Offshore California waters contain an Oxygen Minimum Zone (OMZ), a layer of depleted oxygen concentrations that occurs at depths of approximately 600 to 1100 meters. The OMZ is expanding both vertically, moving closer towards the ocean surface (Bograd et al., 2008), and horizontally (Somero et al., 2015). The declines in oxygenation observed off the California coast are consistent with an observed



expansion of the low-oxygen zones elsewhere around the world, including in parts of the tropical Pacific and Atlantic Oceans (Breitburg et al., 2018; Stramma et al., 2008).

The expansion of oxygen-deficient zones can lead to a compression of favorable habitat for certain marine species and an expansion of favorable habitat for others. For example, following the 1997-98 El Niño event, the Humboldt squid (*Dosidicus gigas*) — which thrives in low-oxygen environments — expanded its range northward from Baja California to southeast Alaska, a shift that may have been affected by changes in the extent of oxygen-deficient zones (Gilly and Markaida, 2007). Studies have indicated that low-oxygen waters can reach nearshore coastal habitats via upwelling, with potential impacts on these habitats (Chan et al., 2019).

Oxygen plays a role in the cycling of nutrients such as nitrogen, phosphorus and iron. As a result, changes in oxygen levels can influence nutrient budgets, biological productivity and carbon fixation. In oxygen-depleted waters, anaerobic microbial processes can produce chemicals such as hydrogen sulfide, which is toxic to other organisms, and methane, a potent greenhouse gas (Breitburg et al., 2018).

What factors influence this indicator?

DO levels reflect a complex interplay between physical and biological drivers in the marine environment, including currents, upwelling, air-sea exchange, and biological productivity, respiration and decomposition. Warmer waters hold less oxygen, as the gas becomes less soluble, and surface warming produces stratification that reduces the overturning circulation essential in ocean ventilation processes. Warming also accelerates the rate of oxygen consumption by marine organisms (Breitburg et al., 2018; Somero et al., 2015). In addition to these processes, DO is influenced by high surface productivity, regional circulation of the North Pacific Ocean, and anthropogenic nutrient inputs to the coastal ocean, as discussed below.

Upwelling is a wind-driven physical process wherein deep, nutrient rich waters move upward into the shallow surface ocean. There is evidence that upwelling has increased in some locations along the California coast due to anthropogenic impacts (Bustos et al., 2024; García-Reyes and Largier, 2010; Quilfen et al., 2021). Upwelling brings nutrient rich waters to the surface, where it drives surface ocean productivity



(photosynthesis). The amount of surface water productivity affects DO concentrations because as biological material sinks downward from the surface ocean and decays, oxygen is utilized in the decay and decomposition process. Thus, DO concentrations decrease in the subsurface below regions of high biological productivity. Climate models indicate future changes in coastal upwelling within eastern boundary upwelling systems such as the CCS (Sydeman et al., 2014; Bograd et al., 2023). The projected changes in the CCS suggest a weak increase in coastal upwelling north of $\sim 40^{\circ}\text{N}$ but little change or even decreasing intensity further south, in the Southern California Bight (SCB), the curved section of coastline extending from Point Conception to northern Baja California (Rykaczewski et al., 2015). The impacts of these upwelling changes on subsurface oxygen will depend both on the intensity of wind forcing as well as changes in ocean stratification.

DO concentrations are also controlled by regional and global oceanographic processes. Waters undersaturated in oxygen off the coast of central California appear seasonally in spring, summer, and winter and vary in intensity (Ren et al., 2025). The SCB – the 400 miles of coastline from Point Conception in Santa Barbara County to Cabo Colnett, south of Ensenada, Mexico -- is impacted seasonally by the northward-flowing California Undercurrent, which likely impacts the trends seen at CalCOFI Station 93.30. Much of the SCB is included in the CalCOFI survey region. Declining oxygen concentrations in this region imply a change in the properties of equatorial source waters (Bograd et al., 2015, 2019). Equatorial waters transported via the California Undercurrent account for an estimated 81% of the deoxygenation trend in the CalCOFI region since 1993 (Evans et al., 2020).

Along the California coast, local nutrient inputs from human activities (e.g., agriculture, wastewater discharge) can also reduce DO concentrations in coastal waters. Fertilizers and nutrient enrichment from wastewater promote algal growth. As this material sinks and decays, it can create localized areas of low oxygen. Management of coastal pollution is an important aspect of minimizing changes in oxygen concentrations on a regional scale.



Scientists estimate that about 15% of global oxygen decline between 1970 and 1990 can be explained by ocean warming and the remainder by increased stratification. In coastal areas, especially nutrient-enriched waters, warming is predicted to exacerbate oxygen depletion (Breitburg et al., 2018). In its Sixth Assessment, the Intergovernmental Panel on Climate Change concluded that oxygen levels have declined in many upper ocean regions since the mid-20th century, and that deoxygenation will continue to increase in the 21st century (IPCC, 2021).

Technical considerations

Data characteristics

This indicator is based on data from the CalCOFI program. Established in 1949, CalCOFI conducts quarterly cruises (18 to 28 days long) to measure the physical and chemical properties of the CCS and census populations of organisms from phytoplankton to avifauna. Data collected at depths down to 500 meters include temperature, salinity, oxygen, phosphate, silicate, nitrate and nitrite, chlorophyll, phytoplankton and zooplankton biodiversity and biomass (CalCOFI, 2021).

DO measurements for CalCOFI Line 93.3, Station 30.0 (offshore of San Diego) and Line 80, Station 80 (within the offshore California Current core) were downloaded from the [CalCOFI website](#). Quarterly averages were derived from oxygen concentrations reported for that calendar quarter. Since sampling did occur between 1950 and 1980, there are data gaps during this period.

Strengths and limitations of the data

Long-term datasets describing DO conditions along the California coast are limited, particularly in areas north of San Francisco. One analysis suggests that 20-30 years of data are needed to robustly detect long-term declines in DO above natural variability (Henson et al., 2016). All the CalCOFI datasets meet this criterion, thus CalCOFI currently represents the best resource for distinguishing long-term trends in DO from natural variability. However, CalCOFI has limited sampling availability in nearshore/coastal habitats, highlighting a need for additional coastal monitoring sites to characterize DO conditions in these areas.



These observations are also limited by sites where oxygen concentration measurements are currently monitored along the coast and do not reflect oxygen declines that may be occurring across the entire CCS. As described above, the observed DO concentrations could be influenced by both local thermodynamic and biological processes, and remote, large-scale changes. The oxygen concentrations can vary with the depth, temperature and time of year DO levels are measured.

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