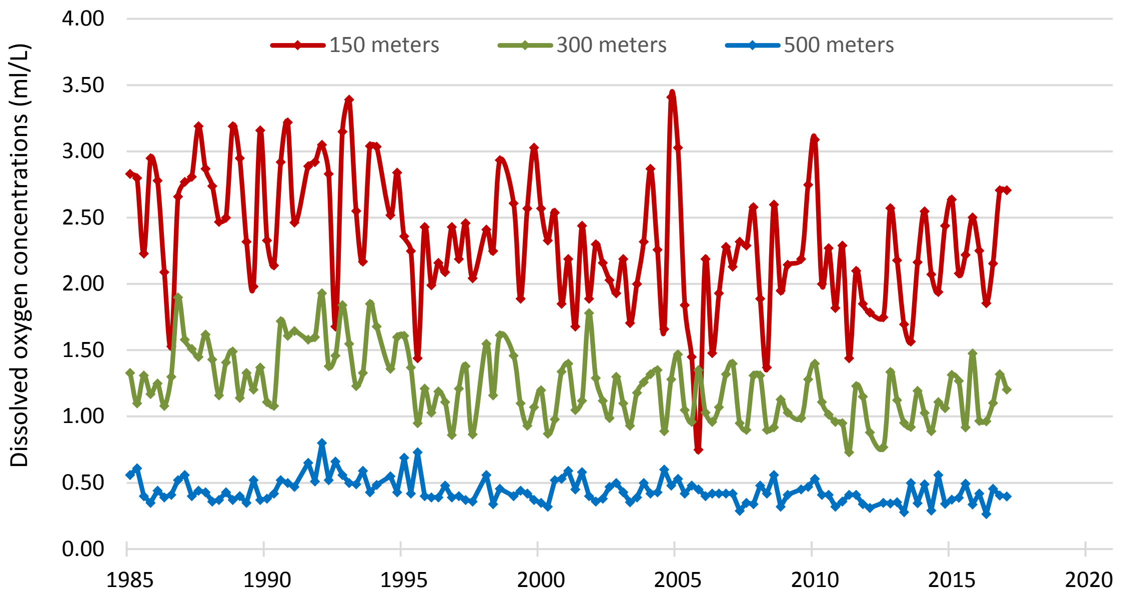
Dissolved Oxygen in Coastal Waters

Dissolved oxygen concentrations are declining in ocean waters off southern California.

Figure 1. Dissolved oxygen concentrations at three water depths, 1985-2017* off the San Diego coast (CalCOFI station 93.3 30)



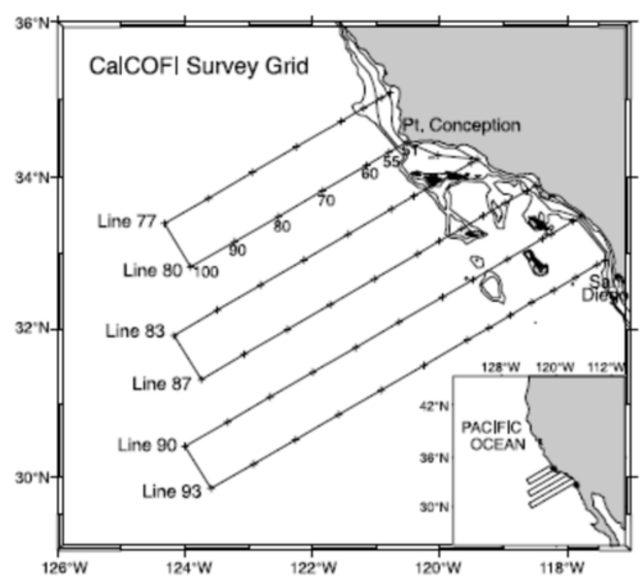
Source: CalCOFI, 2017

* *Values shown are quarterly averages of oxygen concentrations measured at this location.*

What does this indicator show?

Instrumental measurements of dissolved oxygen (DO) concentrations point to decreasing oxygenation of coastal waters within the California Current. As shown in Figure 1, DO concentrations at three water depths offshore of San Diego indicate overall mean decreases as well as significant low-oxygen events since the mid-1990’s. The measurements were taken by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) as the location “Line 93.3, station 30” shown in Figure 2. This location is where the influence of the California Undercurrent is typically observed. This current is a

Figure 2. Map showing location of Line 93



Source: Bograd et al., 2008

major supplier of source waters to the region and has a large influence on oxygen content for much of the survey area. Declines in DO over time have been observed throughout the CalCOFI survey region (to at least 500 m depth) (Bograd et al., 2008).

Why is this indicator important?

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 (e.g., Levin et al., 2009; Stramma et al., 2010; Somero et al., 2015). Changing ocean chemistry, in concert with changes in temperature, may lead to even greater and more diverse impacts on coastal marine ecosystems (e.g., Somero et al., 2015).

Globally since 1950, more than 500 coastal sites have been reported to have experienced hypoxic conditions (waters with low or depleted oxygen concentrations, <1.4 mL/L, or 2 mg/L). Fewer than 10 percent of these were known to have hypoxia before then (Breitburg et al., 2018). Separate from these episodic hypoxic events, coastal California is characterized by the presence of a zone of depleted oxygen concentrations (Oxygen Minimum Zone, or OMZ) at depths from 600 to 1100 meters. The OMZ near California is expanding both vertically (moving upward towards the ocean surface (e.g., Bograd et al., 2008) and horizontally (Somero et al., 2015). The declines in oxygenation observed off California are consistent with an observed expansion of the low oxygen zones elsewhere around the world (Stramma et al., 2008; Breitburg et al., 2018).

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 other species. For example, during the last decade, the Humboldt squid (*Dosidicus gigas*) — which thrives in low-oxygen environments — has 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). Recent studies have indicated that low-oxygen waters can reach nearshore coastal habitats via upwelling; impacts on coastal habitats have not yet been observed (e.g., Booth et al., 2012; Frieder et al., 2012).

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. 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 (e.g., Somero et al., 2015; Breitburg et al, 2018). 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 (García-Reyes and Largier, 2010; Wang et al., 2015; see also discussion in *Coastal ocean temperature* indicator). 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.

DO concentrations are also controlled by regional and global oceanographic processes. For example, the Southern California Bight is impacted seasonally by the northward flowing California Undercurrent. The Southern California Bight is the 400 miles of coastline from Point Conception in Santa Barbara County to Cabo Colnett, south of Ensenada, Mexico. Much of the Bight is included in the CalCOFI survey region. Declining oxygen concentrations in this region imply a change in the properties of these equatorial source waters, although the precise mechanisms of the decline are unknown (Bograd et al., 2015).

Local nutrient inputs from human practices (e.g., agriculture, wastewater discharge) can also decrease oxygen 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 local scale.

Scientists estimate that about 15 percent 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). Climate change models predict a decline in concentrations of DO under future scenarios, based primarily on decreased oxygen solubility in seawater with warming ocean temperatures.

Technical considerations:

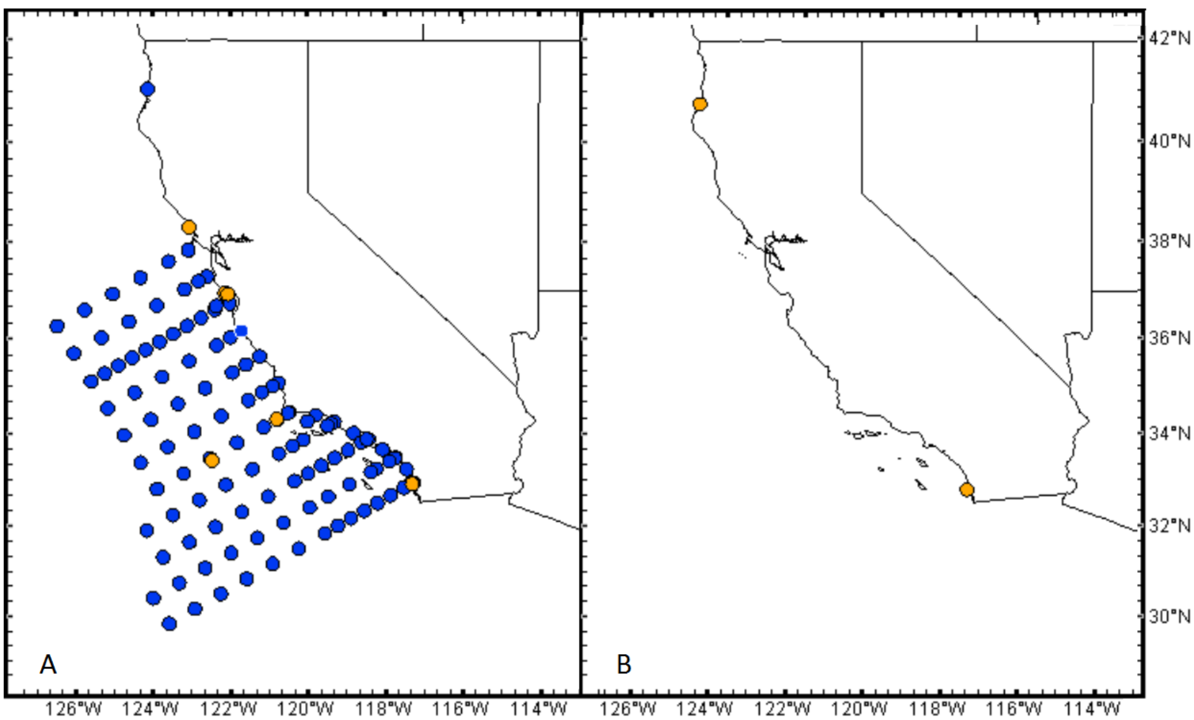
<u>Data Characteristics</u>

This indicator is based on data from the CalCOFI program. As noted above and illustrated in Figures 1 and 2, DO measurements were taken between the surface and depths of up to 500 meters at CALCOFI Line 93.3 Station 30.0, offshore of San Diego from 1951 to 2016. Data were downloaded from the CalCOFI website at http://calcofi.org/data.html. Quarterly averages were derived from oxygen concentrations reported for that calendar quarter. While sampling did occur between

1950 and1980, there are data gaps during this period (notably between 1952-1955, and 1966-1976).

The locations and lengths of collection periods of publicly available DO datasets for California are shown in Figure 3. DO is currently measured and monitored within California at 124 sites. Most data are collected south of San Francisco Bay, with only two collection sites north of Bodega Bay. The vast majority of the central and south coast data (>90%) are from offshore stations monitored by the CalCOFI Program. The majority of the datasets that are 10 years or longer (97 percent) are from the CalCOFI Program. There are no datasets longer than 50 years. The CalCOFI data collection presents a significant opportunity to detect the signature of climate change in DO concentrations along the California coast.

Figure 3. Publicly available datasets on California dissolved oxygen (DO)



Panel (A) shows the DO datasets that are ongoing. Panel (B) shows the DO datasets that have terminated or may not be ongoing.

The colors of the dots refer to dataset length: Blue: 10+years; Orange: 0-9 years.

Source: UC Davis Bodega Marine Laboratory, 2016

Strengths and Limitations of the Data

Very few datasets describe DO conditions north of San Francisco and/or in coastal regions. 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 of the CalCOFI datasets meet this criterion, thus CalCOFI currently represents our best resource for distinguishing long-term trends in DO from natural variability. CalCOFI has limited sampling availability in nearshore/coastal habitats, so establishing additional coastal monitoring sites may be critical for characterizing DO conditions in these areas.

These observations are 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 California Current System. As described above, the observed DO concentrations could be influenced by both local thermodynamic or biological processes, as well as 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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2013 report provided by S. Bograd, NOAA.
2018 updates provided by UC Davis team: Myhre, Hill, Rivest, Gaylord, Sanford, Largier

References:

Bograd SJ, Castro CG, Di Lorenzo E, Palacios DM, Bailey H, Gilly W, et al. (2008). Oxygen declines and the shoaling of the hypoxic boundary in the California current. *Geophysical Research Letters* **35**(12): L12607.

Bograd SJ, Buil MP, Di Lorenzo E, Castro CG, Schroeder ID, et al. (2015). Changes in source waters to the Southern California Bight. *Deep-Sea Research Part II: Topical Studies in Oceanography* **112**:42-52.

Booth JAT, McPhee-Shaw EE, Chua P, Kingsley E, Denny M, Philips R, Bograd SJ, Zeidberg LD and Gilly WF (2012). Natural intrusions of hypoxic, low pH water into nearshore marine environments on the Californian coast. *Continental Shelf Research* 45:108-115.

Breitburg D, Levin LA, Oschlies A, Gregoire M, Chavez FP, et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science* **359** (6371).

CalCOFI (2017): California Cooperative Oceanic Fisheries Investigations: Hydrographic Data – 1949 to Latest Update. Retrieved December 29, 2017 from http://calcofi.org/data.html

Frieder CA, Nam SH, Martz TR and Levin LA (2012). High temporal and spatial variability of dissolved oxygen and pH in a nearshore California kelp forest. *Biogeosciences* **9**: 3917-3930.

García-Reyes M and Largier J (2010). Observations of increased wind-driven coastal upwelling off Central California. *Journal of Geophysical Research* **115**(C4).

Gilly W and Markaida U (2007). Perspectives on Dosidicus gigas in a changing world. Olson R and Young J (Eds.). The role of squid in open ocean ecosystems. Report of a GLOBEC-CLIOTOP/PFRP workshop, 16-17 November 2006, Honolulu, Hawaii, USA. GLOBEC. Report 24: vi, 81-90.

Henson SH, Beaulieu C, Lampitt R (2016). Observing climate change trends in ocean biogeochemistry: when and where. *Global Change Biology* **22**:1561-1571.

Levin LA, Ekau W, Gooday AJ, Jorissen F, Middelburg JJ, Naqvi SWA, et al. (2009). Effects of natural and human-induced hypoxia on coastal benthos. *Biogeosciences* **6**(10): 2063-2098.

Rhein M, Rintoul SR, Aoki S, Campos E, Chambers D, et al. (2013): Observations: Ocean. *In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, et al. (Eds.)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Somero GN, Beers JM, Chan F, Hill TM, Klinger T and Litvin SY (2015). What changes in the carbonate system, oxygen, and temperature portend for the northeastern Pacific Ocean: A physiological perspective. *BioScience* **66**(1): 14-26.

Stramma L, Johnson GC, Sprintall J and Mohrholz V (2008). Expanding oxygen minimum zones in the tropical oceans. *Science* **320**(5876): 655-658.

Stramma L, Schmidtko S, Levin L and Johnson GC (2010). Ocean oxygen minima expansions and their biological impacts. *Deep Sea Research Part I: Oceanographic Research Papers* **57**(4):587–595.

UC Davis Bodega Marine Laboratory (2016). Map showing location of stationary monitoring sites for dissolved oxygen off California.

Wang D, Gouhier TC, Menge BA and Ganguly AR. (2015). Intensification and spatial homogenization of coastal upwelling under climate change. *Nature* **518**: 390-394.