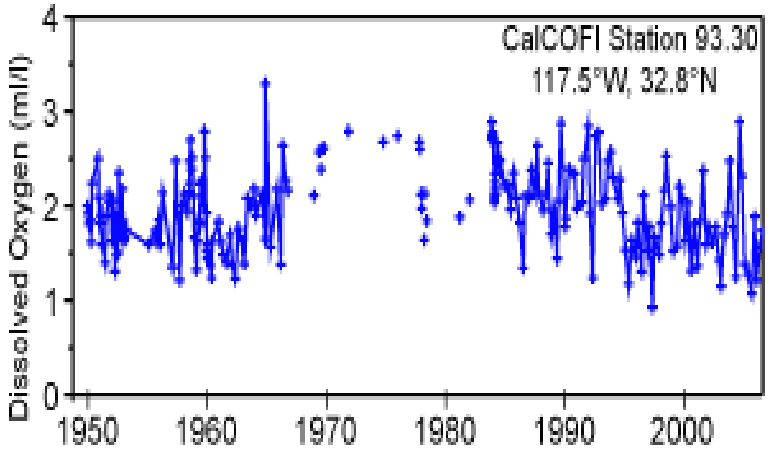
OXYGEN CONCENTRATIONS IN THE CALIFORNIA CURRENT (NO UPDATE)

TYPE II INDICATOR

Dissolved oxygen (DO) concentrations in the ocean provide an indication of physical and biological processes occurring in the marine environment, and their impacts on marine ecosystems. Climate change models predict a decline in mid-level concentrations of DO under global warming scenarios.

Declining DO levels in ocean waters, and the associated changes in the depth and extent of oxygen-deficient zones, can lead to significant and complex ecological changes in marine ecosystems. In addition to the direct adverse effects of lower oxygen concentrations (hypoxia), shallower oxygen-deficient zones can also lead to a compression of favorable habitat for certain marine species and an expansion of favorable habitat for other species. 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).

Dissolved oxygen levels off the coast of San Diego (at 200 m depth)

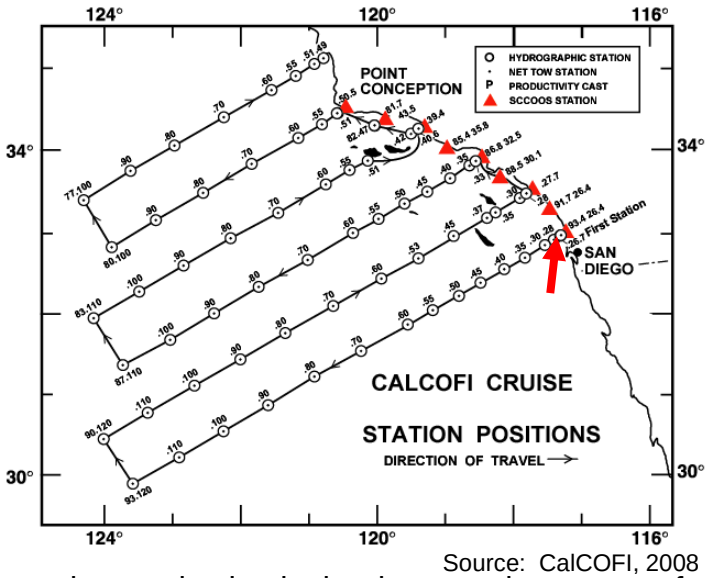


Source: Bograd et al., 2008

Note: The unconnected points denote a period of limited sampling during 1968 to 1983; the connected points denote regular scheduled surveys.

Measurements of dissolved oxygen concentrations in ocean waters off southern California have revealed a strong and persistent decline since the mid-1980s. As a result, the oxygen-deficient zone (waters having low dissolved oxygen concentrations at depths of about 100 – 1,000 meters) in this area has expanded closer to the surface. The graph on the right presents levels of dissolved oxygen at a location off the coast of San Diego, in the Southern California Bight (Station 93.30—see red arrow on the map, next page). The data are from sampling and monitoring conducted by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. At this station, the depth of the oxygen-deficient zone is 90 meters shallower (i.e., moving into the oxygen-rich surface waters) in 2006 than in 1984. This station reveals the significant influence of the California Undercurrent, which transports waters of tropical origin into the Bight. (The Southern California Bight is the 400 miles of recessed coastline from Point Conception in Santa Barbara County, California, to Cabo Colnett, just south of Ensenada, Mexico) (SCCWRP, 2008).

Large declines in DO between 1984 and 2006 have been observed. The decrease was generally less than 10 percent at 50 to 100 meters deep, but ranged from 10 to 30 percent at 200 to 300 meters. These declines are consistent with observations from several regions of the western and eastern subarctic North Pacific. It should be noted that the DO concentrations in the Bight in recent years are similar to those seen in the late 1950s (McClatchie et al., 2010). The declines in DO predicted by climate models are mostly attributed to enhanced thermal stratification near the surface due to warming, and a resultant reduction in the downward transport of oxygen from well-oxygenated surface waters into the ocean interior (Keeling and Garcia, 2002). Significant surface-intensified warming has been observed in the southern California Current System, with a subsequent increase in thermal stratification and large declines in DO levels. Although it has only been documented in the Bight, it is suspected that it has occurred throughout the California Current. These changes are consistent with a hypothesized reduction in vertical oxygen transport.



Source: CalCOFI, 2008

In addition, the Southern California Bight is impacted seasonally by the California Undercurrent, making it an important location to monitor changes in source waters (i.e., water masses carried into the area by ocean currents) to the southern California Current. The declining oxygen concentrations seen in this region imply a change in the properties of the source waters, although the precise mechanisms of the decline are not known. The declines observed off California are consistent with an observed expansion of the oxygen deficient zone in the tropical oceans (Stramma et al., 2008).

It should be noted that the observed DO levels 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 of the water being measured. While both factors are important, quantification of their relative influences is not feasible at this time.

References:

Barry JP, Baxter CH, Sagarin RD and Gilman SE (1995). Climate-related, long-term faunal changes in a California rocky intertidal community. *Science* **267**(5198): 672-675. http://www.sciencemag.org/content/267/5198/672.abstract

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. http://dx.doi.org/10.1029/2008GL034185

CalCOFI (2008): California Cooperative Oceanic Fisheries Investigations. "Program Info." Retrieved July 13 2012, http://www.calcofi.org/newhome/info/program_info.htm.

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. http://www.globec.org/index.php?act=downloads&view=cat&cid=11

Goericke R, Venrick E, Koslow T, Sydeman WJ, Schwing FB, Bograd SJ, et al. (2007). *The State of the California Current, 2006–2007: Regional and Local Processes Dominate*. Calif. Coop. Oceanic Fish. Invest. Rep. **48**: 33-66. http://calcofi.org/publications/calcofireports/v48/Vol_48_State_Of_California_Current.pdf

IPCC (2007e). *Summary for Policymakers.* In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

Joos F, Plattner G-K, Stocker TF, Körtzinger A and Wallace DWR (2003). Trends in marine dissolved oxygen: Implications for ocean circulation changes and the carbon budget. *Eos, Transactions, American Geophysical Union* **84**(21): 197-204. http://dx.doi.org/10.1029/2003EO210001

Keeling RF and Garcia HE (2002). The change in oceanic O_2 inventory associated with recent global warming. *Proceedings of the National Academy of Sciences* **99**(12): 7848-7853. http://www.pnas.org/content/99/12/7848.abstract

Levitus S, Antonov JI, Wang J, Delworth TL, Dixon KW and Broccoli AJ (2001). Anthropogenic warming of Earth's climate system. *Science* **292**(5515): 267-270. http://www.ncbi.nlm.nih.gov/pubmed/11303098

Mantua NJ, Hare SR, Zhang Y, Wallace JM and Francis RC (1997). A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* **78**(6): 1069-1079. http://dx.doi.org/10.1175/1520-0477(1997)078<1069:APICOW>2.0.CO;2

McClatchie S, Goericke R, Cosgrove R, Auad G and Vetter R (2010). Oxygen in the Southern California Bight: Multidecadal trends and implications for demersal fisheries. *Geophysical Research Letters* **37**(19): L19602. http://dx.doi.org/10.1029/2010GL044497

SCCWRP (2008): Southern California Coastal Water Research Project. "Research Area: Bight Regional Monitoring." http://www.sccwrp.org/view.php?id=95.

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

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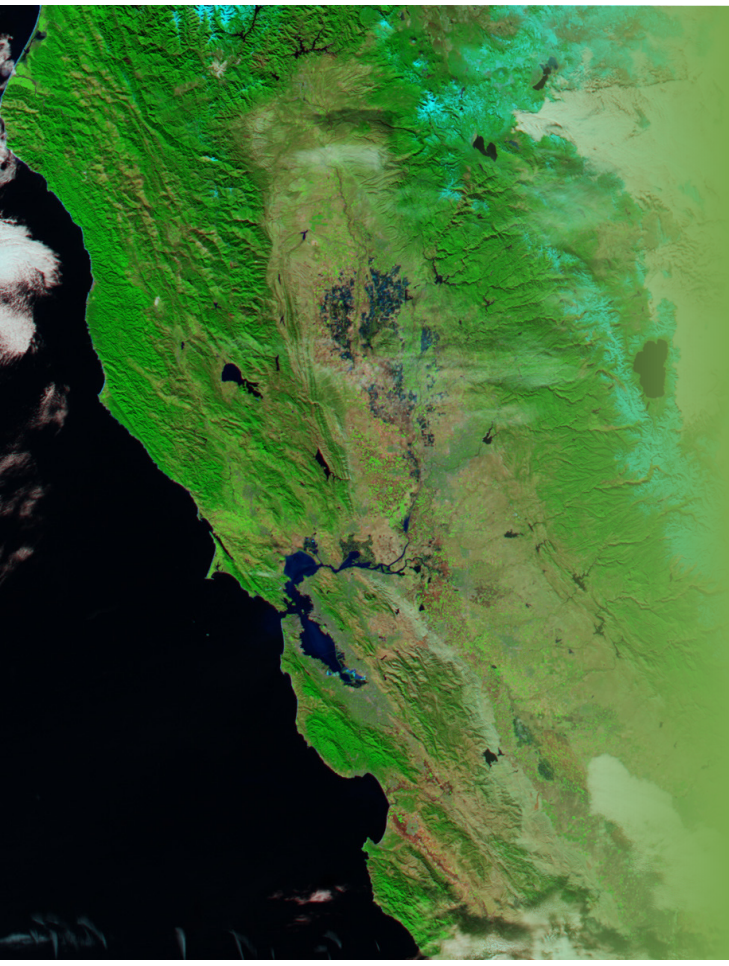
August 2013









Indicators of Climate Change in California

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INDICATORS OF CLIMATE CHANGE IN CALIFORNIA

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ACKNOWLEDGEMENT:
OEHHA is grateful to the Cal/EPA Office of the Secretary,
and to the staff and researchers (listed on the next page)
who contributed their ideas, data, findings and other information
for inclusion in this report.

Cover design: California Air Resources Board

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