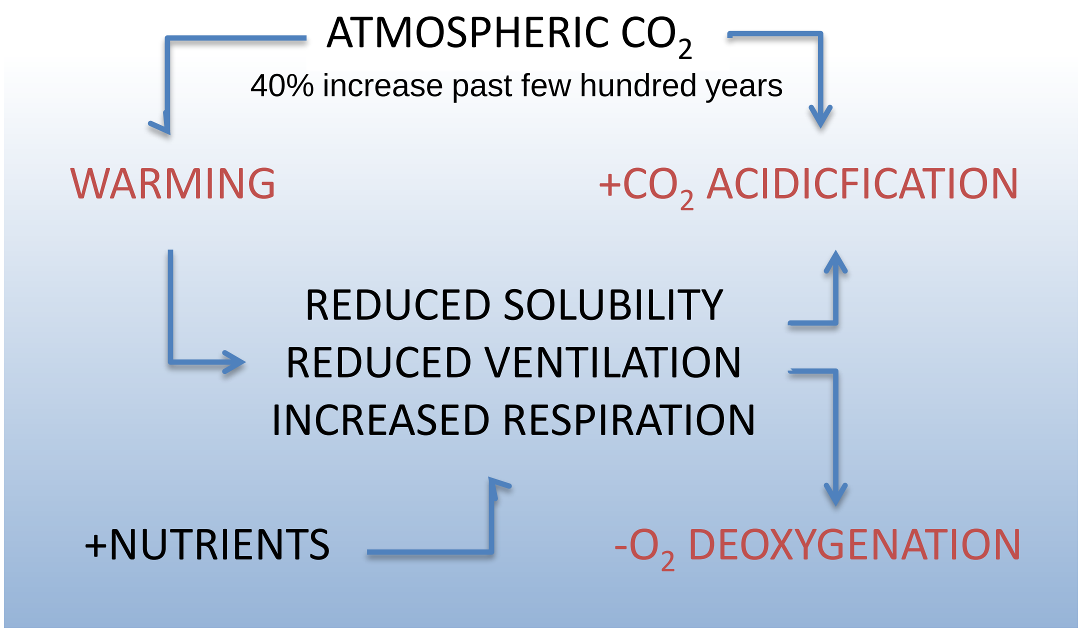
ARE OUR OCEANS CHANGING IN RESPONSE TO CLIMATE CHANGE

DEOXYGENATION OF SOUTH AFRICA'S OCEAN

GRANT C PITCHER

Workshop on Identifying and Coordinating Research as an Adaptation to Climate Change in the South African Marine Fisheries and Marine Aquaculture Sectors

Global warming and eutrophication may both contribute toward deoxygenation.



Global warming, acidification and deoxygenation are linked.

Increase in atmospheric CO_2 resulted in net flux of CO_2 into the oceans causing a sustained decline in pH.

Global warming and warming of the oceans influences O_2 concentrations in the ocean by [1] reduce the solubility of O_2 in water, [2] reduce ventilation [through increased stratification], and [3] increase respiration rates. Nutrients increase total respiration in water bodies by increasing the total biomass of organisms.

Keeling et al. 2010. Ocean deoxygenation in a warming world. *Annual Review of Marine Science* 2: 199-229.

Ocean models predict a decline in global ocean O_2 of 1-7% by 2100.

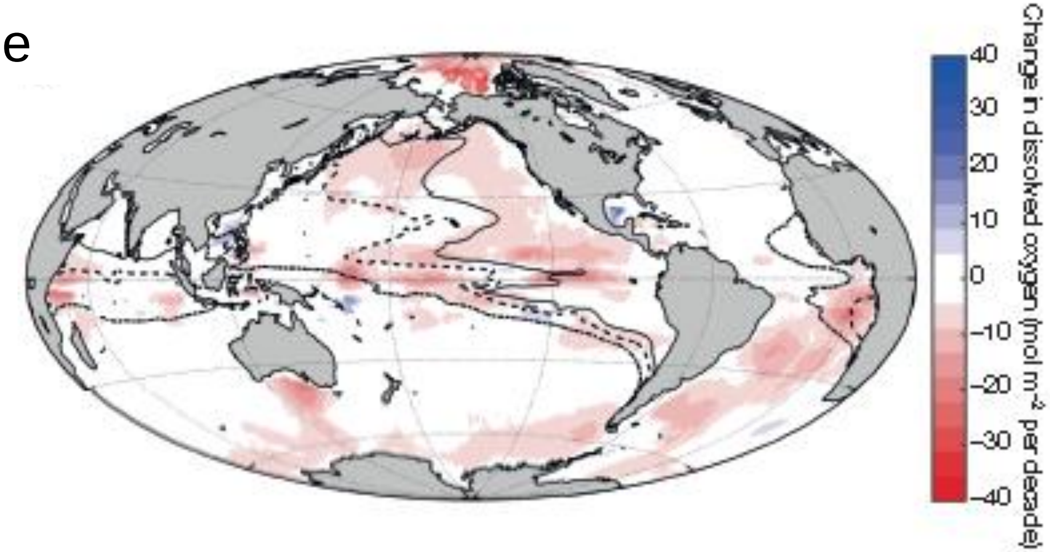
Model predictions of average ocean O_2 decreases by 2100

Study	Model	Forcing	O_2 decrease (μmol kg^{-1})[a]	Solubility contribution (%)
Sarmiento et al. (1998)	GFDL		7[b]	
Matear et al. (2000)	CSIRO	IS92A	7	18
Plattner et al. (2001, 2002)	Bern 2D	SRES A1	12	35
Bopp et al. (2002)	OPAICE-LMD5	SRES A2 CO_2 only	4	25
	HAMOCC-3			
Matear & Hirst (2003)	CSIRO		9	26
Schmittner et al. (2008)	UVic	SRES A2	9	
Oschlies et al. (2008)	UVic	SRES A2	9	
	UVic-variable C/N	SRES A2	12	
Frölicher et al. (2009)	NCAR CSM1.4-CCCM	SRES A2	4	50
		SRES B1	3	

Schmidtko et al. 2017. Decline in global oceanic oxygen content during the past five decades. *Nature* 542: 335-339.

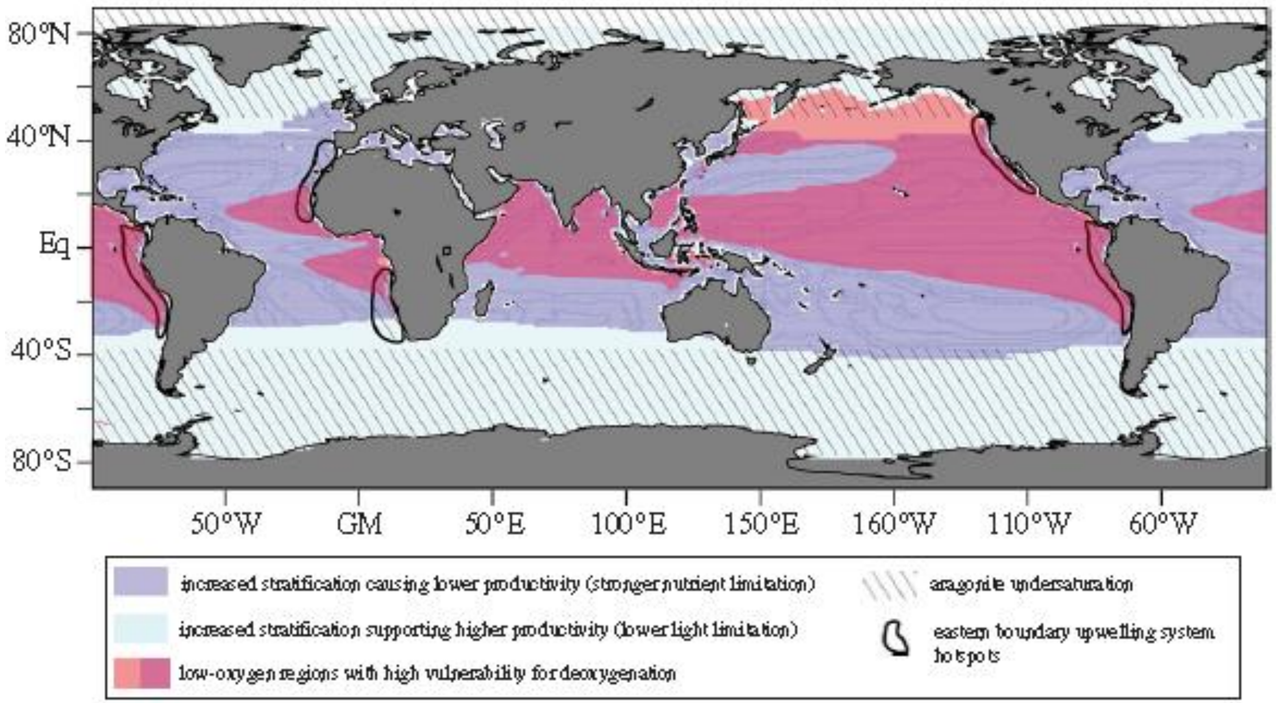
Analysis of historical data shows that the world's ocean has lost 2% of its O_2 since 1960.

Change in dissolved O_2 per decade



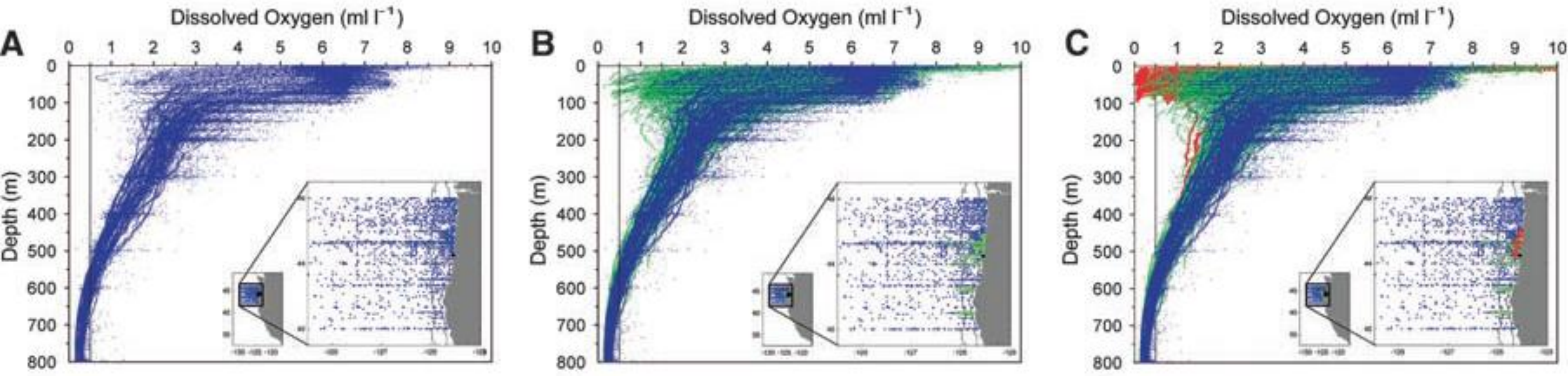
Gruber N. 2011. Warming up, turning sour, losing breath: ocean biogeochemistry under global change. *Philosophical Transactions of the Royal Society* 369: 1980–1996

Identified EBUS as hotspots for change with the stressors of rising temperatures, ocean acidification and ocean deoxygenation acting not only in isolation but simultaneously, and even in part synergistically.

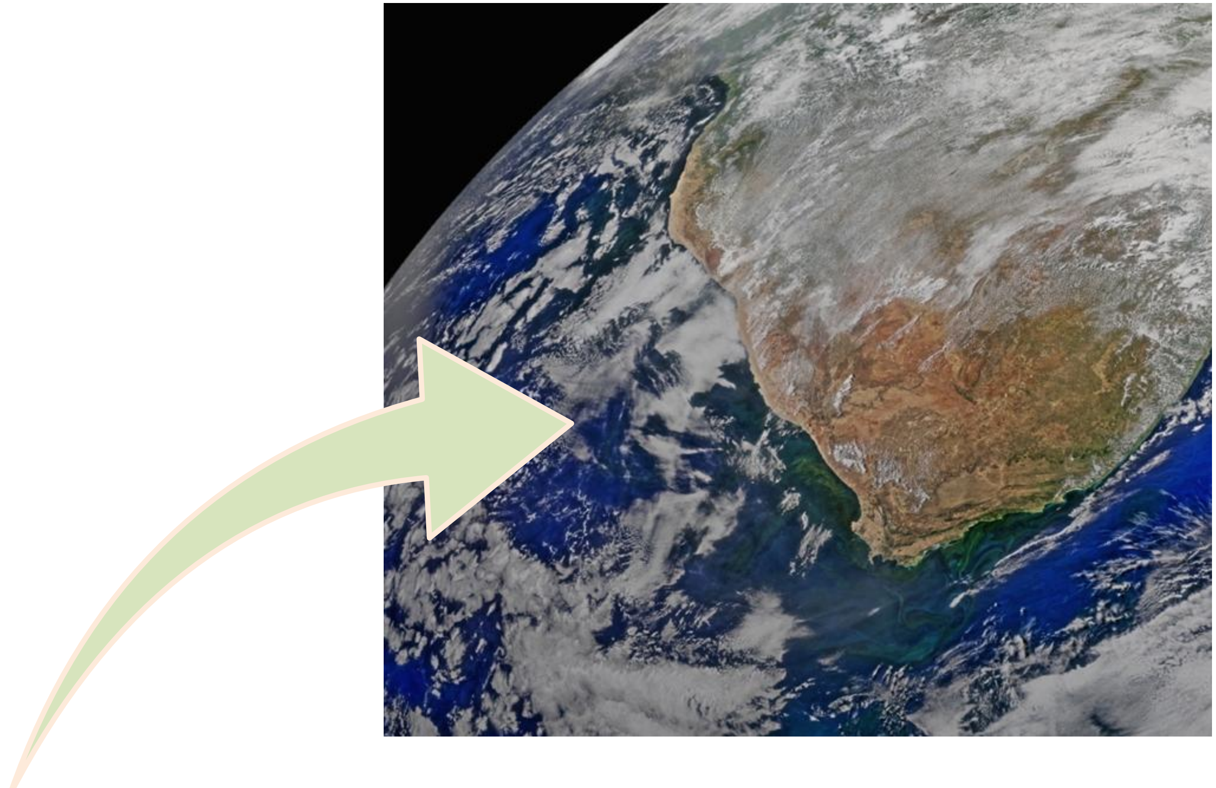


Chan et al. 2008. Emergence of anoxia in the California Current large marine ecosystem. *Science* 319: 920

Recent intensification of inner-shelf hypoxia and anoxia has been reported in the California Current large marine ecosystem and is considered to reflect a basin-wide reduction in dissolved O_2 linked to global change.

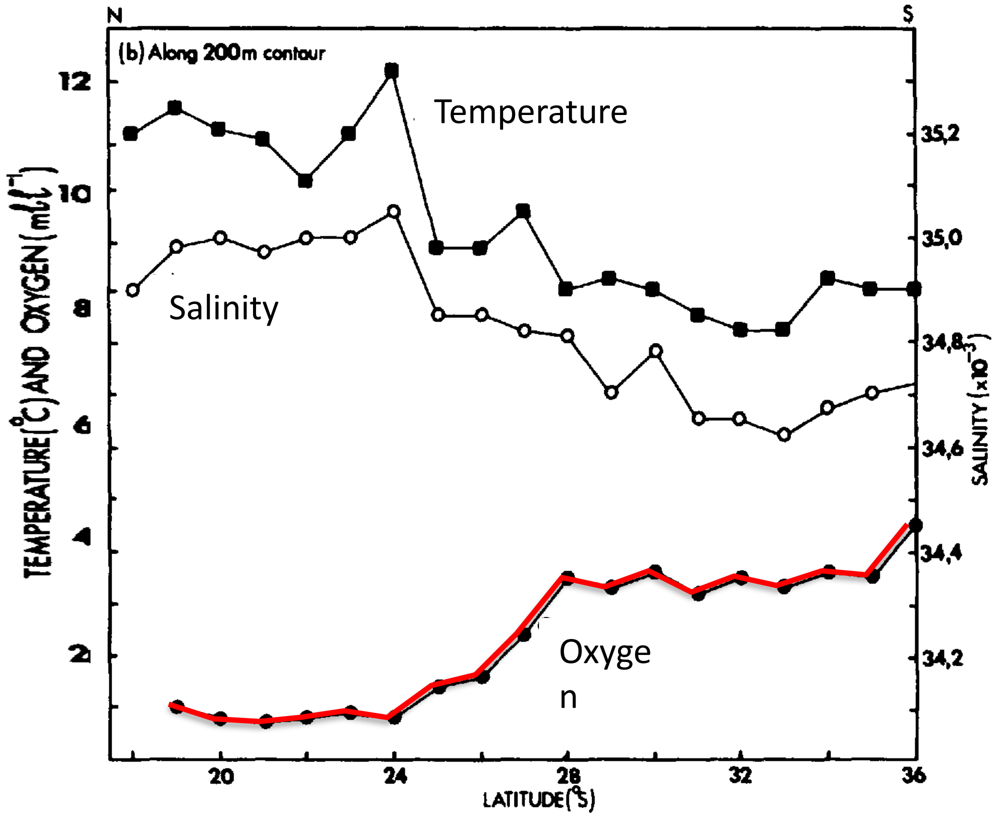


Dissolved O_2 profiles during the upwelling season in the upper 800 m of the continental shelf and slope of Oregon.
(A):1950 to 1999 (n = 3101 hydrocasts, blue).
(B): (A) with additional data for 2000 to 2005 (n = 834 hydrocasts, green).
(C): (A) and (B) plus data for 2006 (n = 220 hydrocasts, red).



For the Benguela Current System, low O_2 in the northern Benguela is more severe and widespread than that in the southern Benguela.

Dingle & Nelson. 1993. Sea-bottom temperature, salinity and dissolved oxygen on the continental margin off south-western Africa. *South African Journal of Marine Science* 13: 33-49



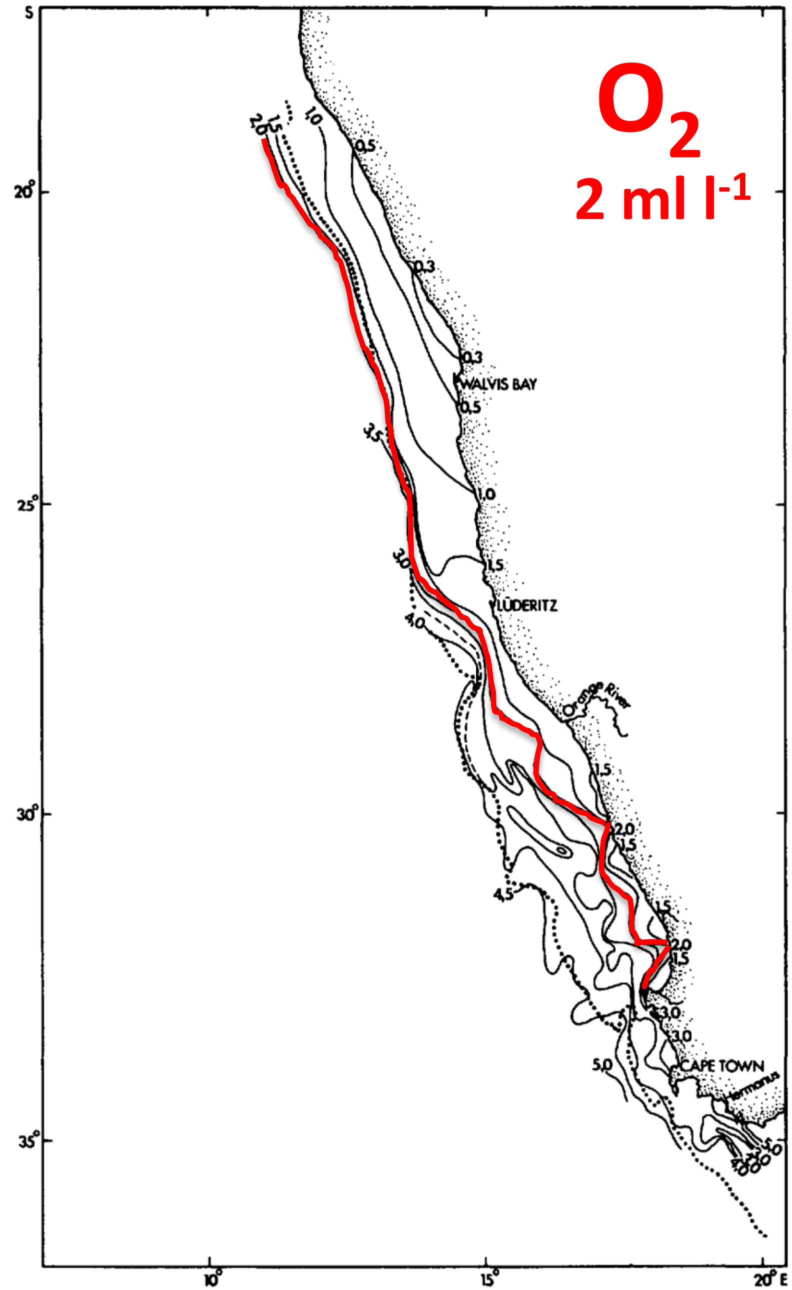
Along-shelf temperature, salinity and O_2 show a progressive increase in O_2 along the 200 m isobath south of the major upwelling cell at Lüderitz.

Dingle & Nelson. 1993. Sea-bottom temperature, salinity and dissolved oxygen on the continental margin off south-western Africa. *South African Journal of Marine Science* 13: 33-49

Average bottom dissolved O_2 over the continental margin off south-western Africa.

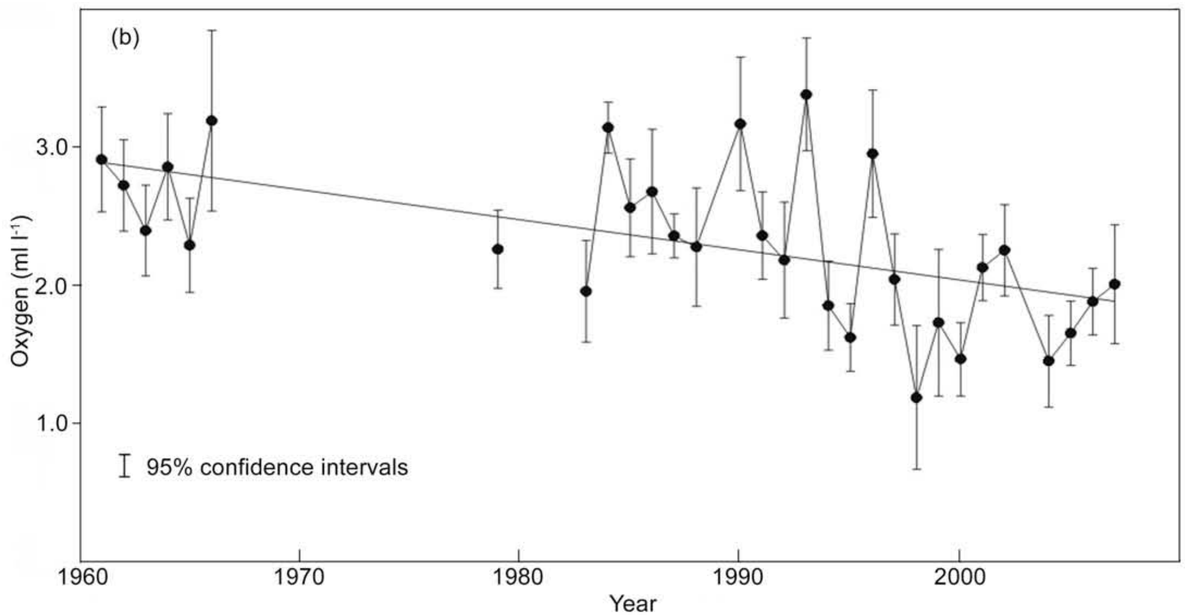
In the southern Benguela O_2 depletion tends to be localized and generally confined to depths of <150 m on the Namaqua shelf.

O_2 concentrations have been shown to be lowest in St Helena Bay [the largest and most productive embayment on the South African coast].



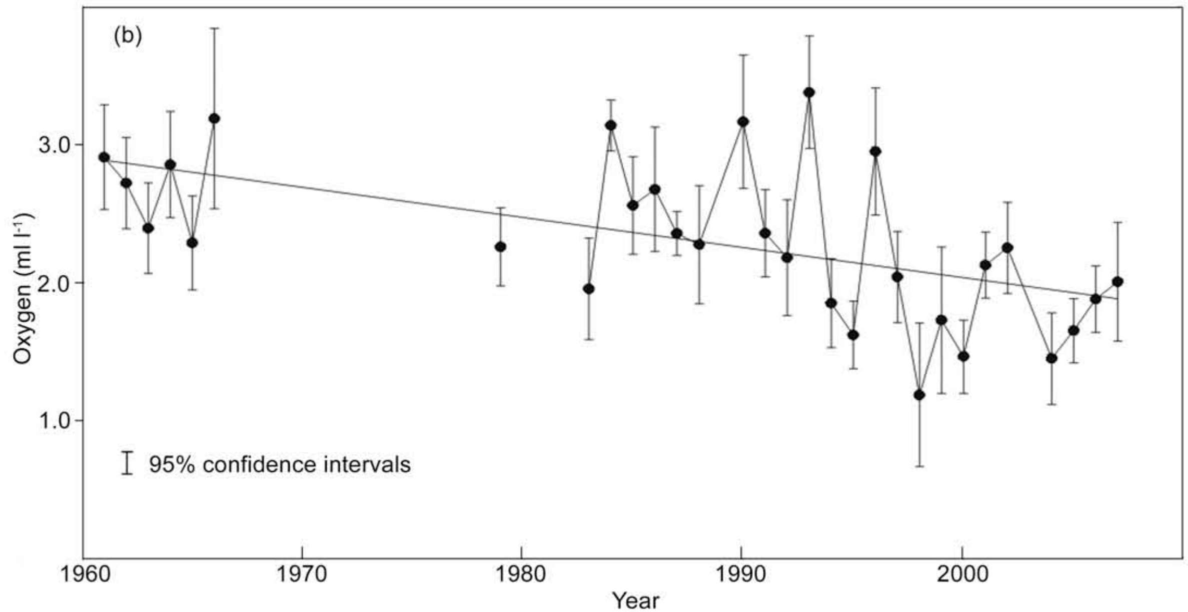
Environmental monitoring [including measures of O_2] has been carried out in the St Helena Bay region since the 1950s and there have been several attempts to evaluate these data in the assessment of long-term change in the southern Benguela.

Hutchings et al. 2009. The Benguela Current: An ecosystem of four components. Progress in Oceanography 83: 15–32



Analyzed all data collected within a demarcated area of St Helena Bay and provided evidence of a 35% long-term decline in O_2 concentrations in sub-thermocline waters since 1961 [1 ml l^{-1}].

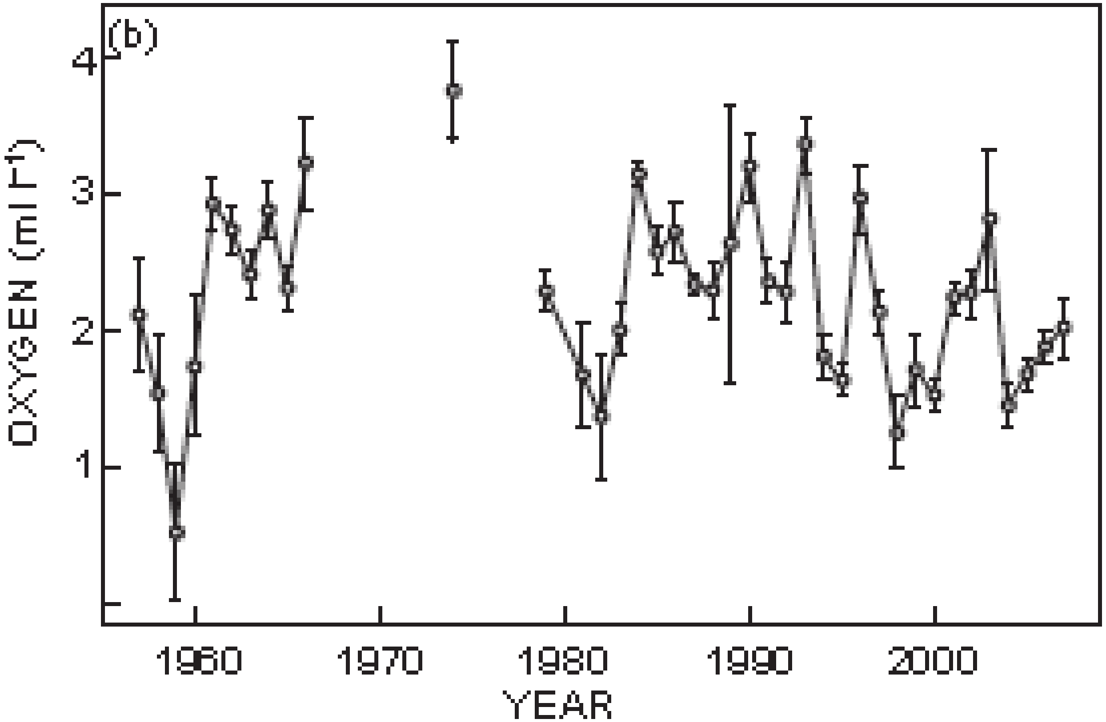
Decline in oxygenated waters was considered to have had a deleterious effects on rock lobster.



Interpretation of this historical data set was compromised by:

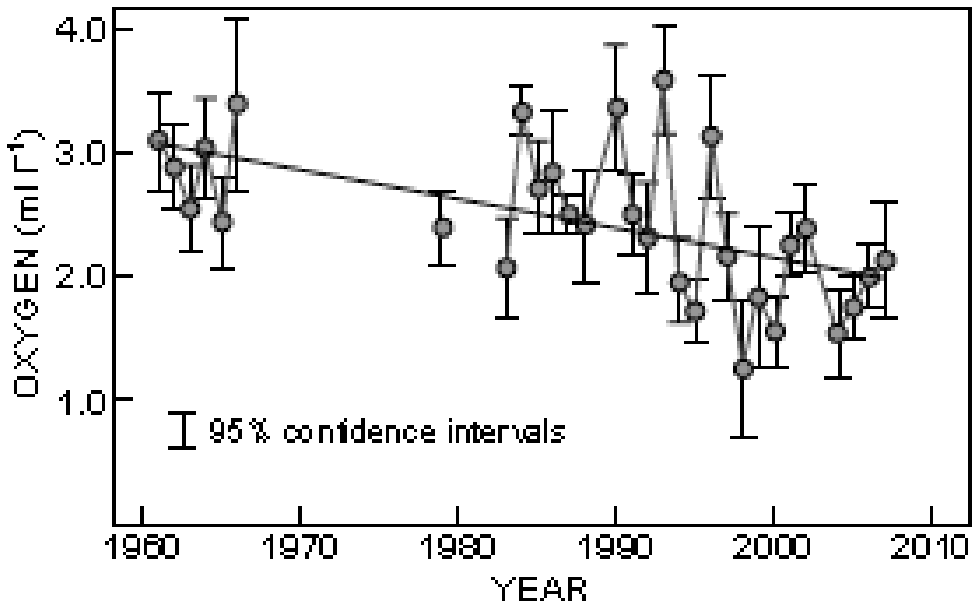
[1] data collection [within demarcated area] over the past 50/60 years was not methodical but was subject to temporal and spatial bias;
[2] data prior to 1961 had been excluded from this analysis.

Hutchings et al. 2012. St Helena Bay (southern Benguela) then and now: muted climate signals, large human impact. *African Journal of Marine Science* 34: 559-583



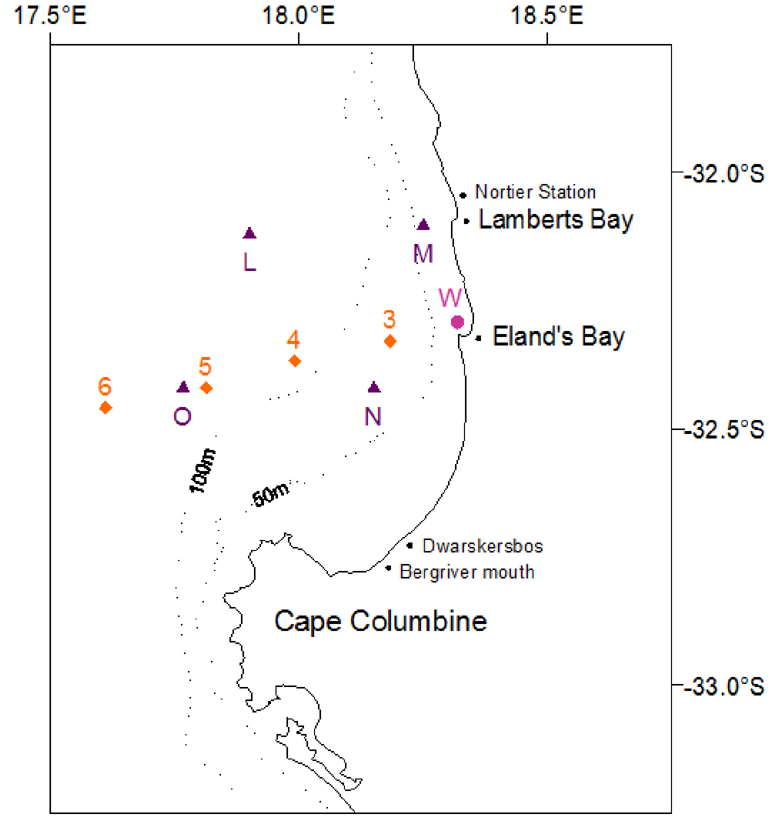
Presented entire time series of bottom O_2 concentrations from 1957 claiming decadal-scale variability with an increase from 1957 to 1975, followed by a long erratic decrease [updated from J. Currie, UCT, unpublished].

Moloney et al. 2013. Reviewing evidence of marine ecosystem change off South Africa. *African Journal of Marine Science* 35: 427-448.



Again claimed a significant decreasing trend in O_2 in St Helena (Hutchings et al. 2009, 2012) at a rate of approximately 20 µl l^{-1} y^{-1}.

Pitcher et al. 2014. Dynamics of oxygen depletion in the nearshore of a coastal embayment of the southern Benguela upwelling System. *Journal of Geophysical Research, Oceans* 119: 2183–2200

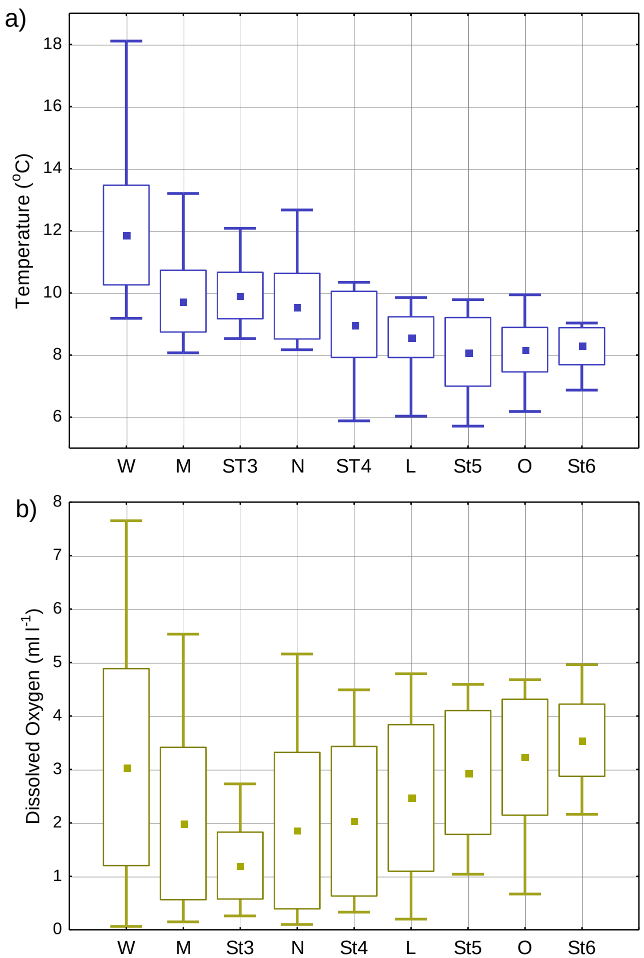


We undertook an assessment of long-term change in bottom O_2 in St Helena Bay by examining two data sets in which data were collected at similar time intervals and from stations in “close” proximity.

The data sets comprised measures of bottom temperature and DO from:
[1] stations W, 3, 4, 5 and 6 collected between 2008 and 2011, and
[2] stations M, N, L and O between 1957 and 1962

[50 years apart].

For the purpose of comparison we combined the two data sets by ordering the stations on the x-axis according to water depth.



Mean bottom temperatures were shown to follow a coherent across-shelf trend [declining with increasing depth, with minimum values outside of the bay].

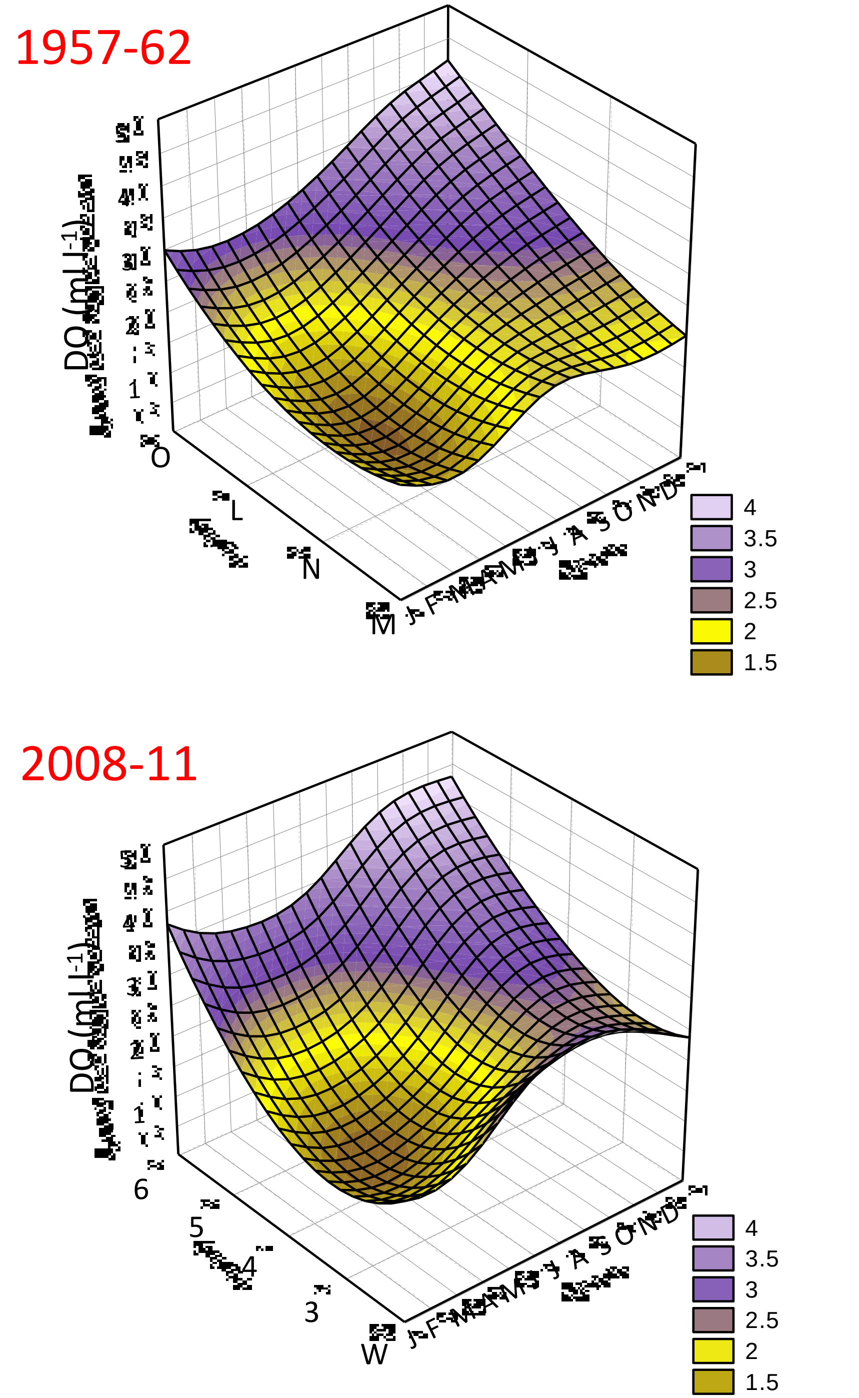
O_2 concentrations as expected were lowest within the bay (at St3, 70m), where they also exhibited low variance.

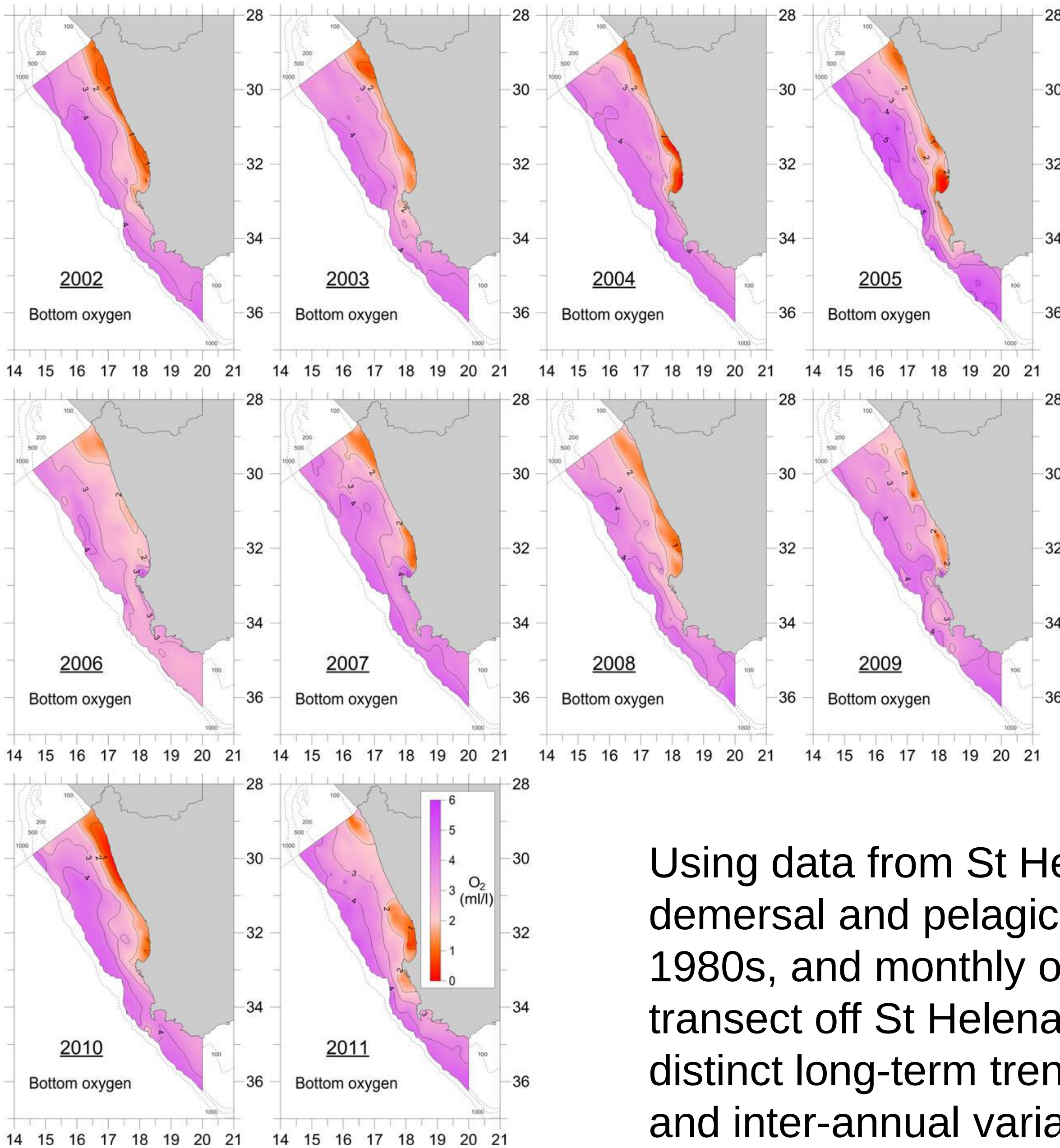
Moving outside the bay O_2 concentrations increased with increasing depth toward the mid-shelf.

The coherence of the recent and historic data in demonstrating these cross-shelf trends suggests the absence of any long-term trend in either temperature or O_2.

Three-dimensional plots of the 2 data sets showing remarkable similarity [both spatially and seasonally] indicating an absence of any long-term trend in bottom O_2.

Any differences are likely to be attributed to the comparison of data from different station positions and depths [e.g., the greater seasonality evident in the recent data is a likely result of the inclusion of data from a shallower depth].





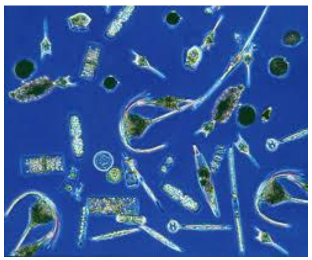
Jarre et al. 2015. Oxygen-depleted bottom waters along the west coast of South Africa, 1950–2011. Fisheries Oceanography 24: 56–73

Using data from St Helena Bay (from 1957), from demersal and pelagic fisheries surveys since the 1980s, and monthly observations from a fixed transect off St Helena Bay from 2000 to 2011, no distinct long-term trends can be discerned. Decadal and inter-annual variability dominate the signals.

A further consideration in the assessment of long-term changes in O_2 is recognition of 2 categories of O_2-deficient waters:

(1) Seasonally recurrent hypoxia confined to bottom waters attributed to high bay productivity and to summer stratification [isolates bottom layer from surface waters].

(2) episodic anoxia through the water column of shallow, nearshore environments attributed to decay of high biomass dinoflagellate blooms, termed red tides.



Elevated surface O_2 concentrations

(2) Anoxia

Sinking of labile organic matter fuels microbial respiration and the consumption of O_2

(1) Hypoxia

Pitcher & Probyn. 2011. Anoxia in southern Benguela during the autumn of 2009 and its linkage to abloom of the dinoflagellate *Ceratium balechii*. *Harmful Algae* 11: 23–32.

Perception of an increase in the impacts of low O_2 on marine resources (e.g., Cockcroft et al (2008) demonstrated a possible link between declining West Coast rock lobster and low O_2).

However these impacts are attributed to episodic events of low O_2 and therefore point to an increase in red tides [rather than declining sub-thermocline O_2 concentrations].

Inadequate long-term records prevent validation of an increase in red tides although St Helena Bay continues to be plagued by mortalities attributed to these events [e.g., mortality of 415 tons of rock lobster in 2015, attributed to blooms of *Prorocentrum triestinum*.

GO$_2$NE Global Ocean Oxygen NEtwork [IOC WG]

TOR include:

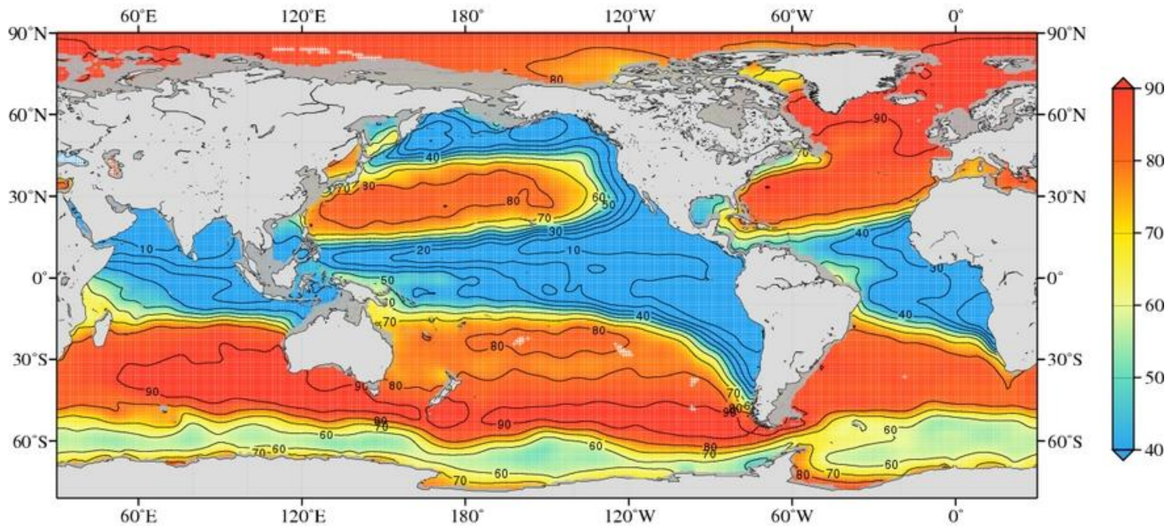
Development O_2 Observing System

To reliably establish the magnitude and severity of long-term O_2 trends against a background of natural variability [sustained accurate measurements].

Also to advance our understanding of relevant processes and to improve our modeling capability.

World Ocean Atlas Climatology

Contour Interval=10



Annual percent oxygen saturation at 300 m. depth (one-degree grid)

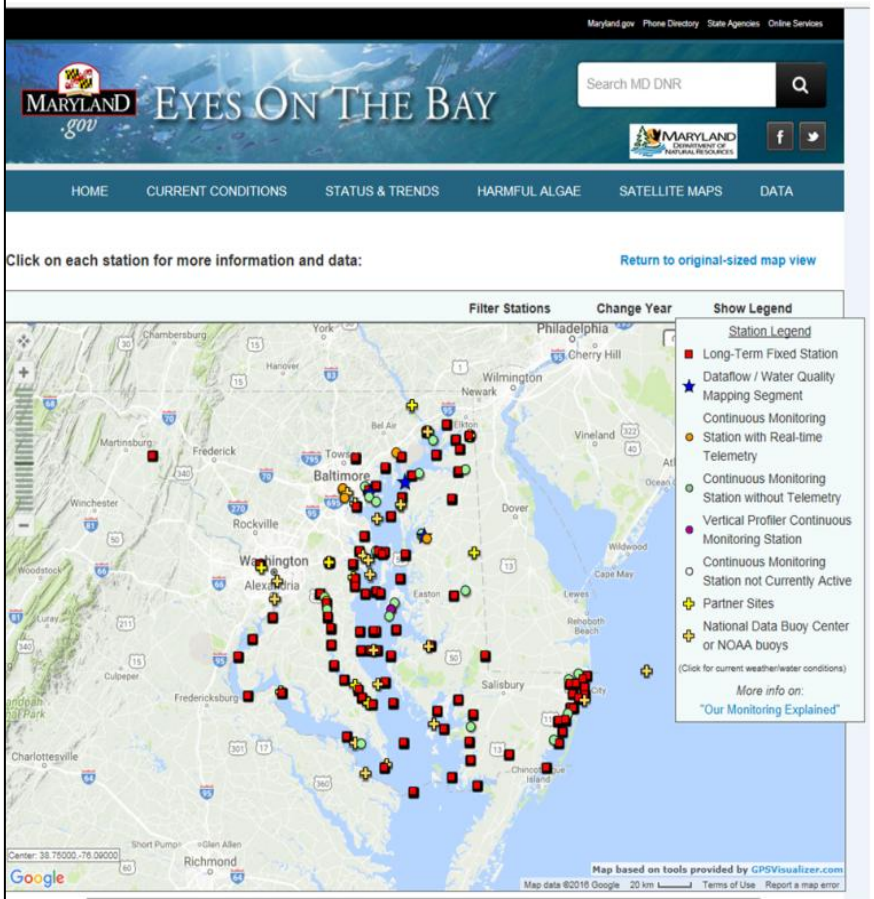


Figure X. Field monitoring, numerical modeling and experiments are all used to identify spatial patterns and trends in oxygen in coastal waters and to develop solutions. On left, public website allows all stakeholders to access data collected at monitoring sites in the Maryland portion of Chesapeake Bay.

Extensive data collection by continuous sensors and shipboard measurements identify patterns and problems

↓

Data made accessible to managers, scientists, and the public

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Experiments and biological monitoring inform oxygen criteria developed to sustain living resources

↓

Models numerical models and statistical analyses identify relationships among land use, nutrients and oxygen concentrations

↓

Management strategies developed to limit nutrient loads to levels that yield oxygen concentrations suitable for living resources

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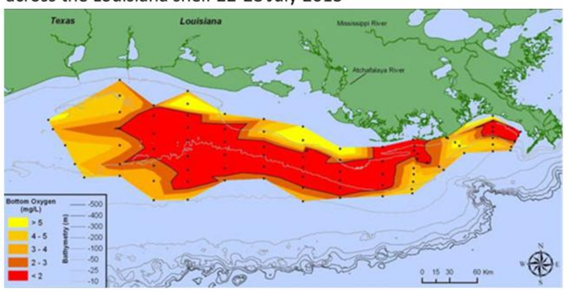
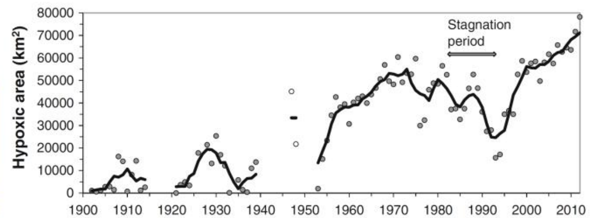
Continued monitoring to ensure oxygen concentrations remain at or above management targets.

Northern Gulf of Mexico: Bottom-water dissolved oxygen across the Louisiana shelf 22-28 July 2013





Baltic Sea: Area of bottom covered by water with <2 mg/L dissolved oxygen from 1900 to 2011 (above) and in 2012 (below: red = <2 mg/L dissolved oxygen, black = 0 mg/L dissolved oxygen)

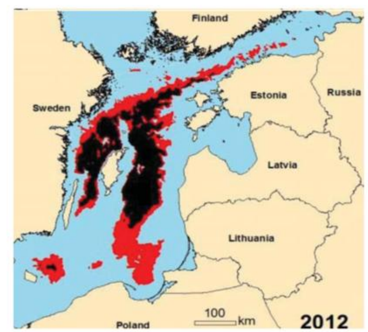


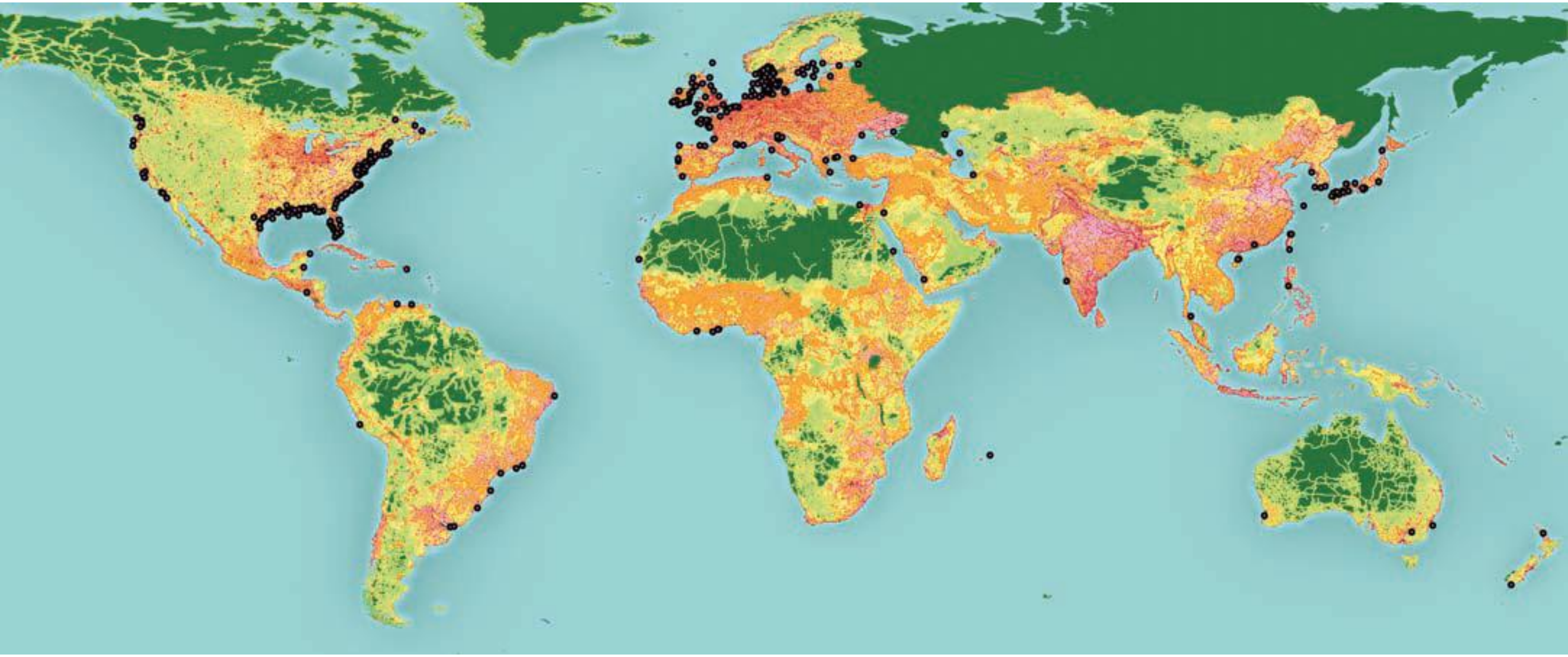
Figure X. The world's two largest coastal water low-oxygen zones persist and may be worsening. The Northern Gulf of Mexico (above) receives nutrients from the Mississippi River – the largest river in North America. As a result, low oxygen waters can cover can cover 15,000 – 18,000 km^2 along the coast of Louisiana during summer. Low oxygen in the Baltic Sea has expanded, and includes areas where bottom water becomes hypoxic seasonally as well as deep basins that remain hypoxic or anoxic for years to decades. In both the Gulf of Mexico and the Baltic watersheds, management actions have been put in place to reduce nutrient loads, but nutrient reductions have not been sufficient to substantially reduce or eliminate low oxygen.
Figure sources. Gulf of Mexico: http://en.es-static.us/upl/2013/08/deadzone-gulfofmexico-2013-580.jpg; Data N.N. Rabalais and R.E. Turner. Baltic: Carstensen et al., 2014.

Anthropogenic influences such as eutrophication are considered important causal factors for this increase, and warming associated with climate change is predicted to further intensify shelf hypoxia and anoxia.
Conley et al [2009]
Rabalais et al [2009]

Eastern boundary upwelling systems are among the most productive large marine ecosystems in the world but are as a result subject to natural shelf hypoxia and anoxia [best known in the Humbolt and Benguela Currents]
Levin et al [2009]

Diaz and Rosenberg [2008] Spreading dead zones and consequences for marine ecosystems. *Science* 321: 926

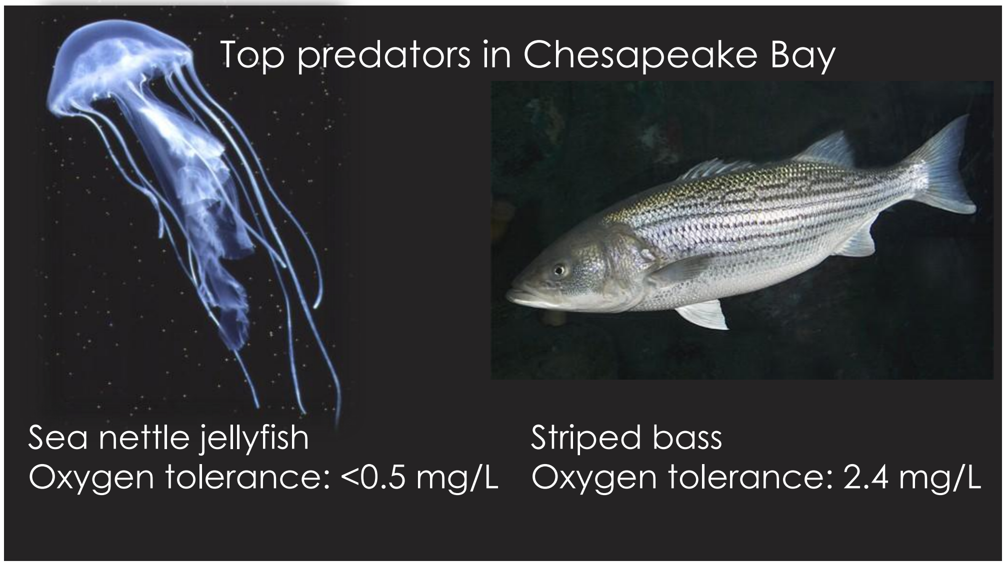
Dead zones in the coastal oceans have spread exponentially since the 1960s attributed to worldwide coastal eutrophication and an increase in primary production.



- **Eutrophication-associated dead zones**

O_2 is critical to the health of our oceans:

- a fundamental requirement for marine life
- it structures aquatic ecosystems



Food webs are disrupted by changes in O_2 concentrations, because different species have vastly different O_2 tolerances;
e.g., in Chesapeake Bay declining O_2 concentrations associated with an increase in jellyfish because they can tolerate lower O_2 concentrations than their competitors and prey.

- fundamental to the biogeochemical cycling of carbon, nitrogen and other key elements.