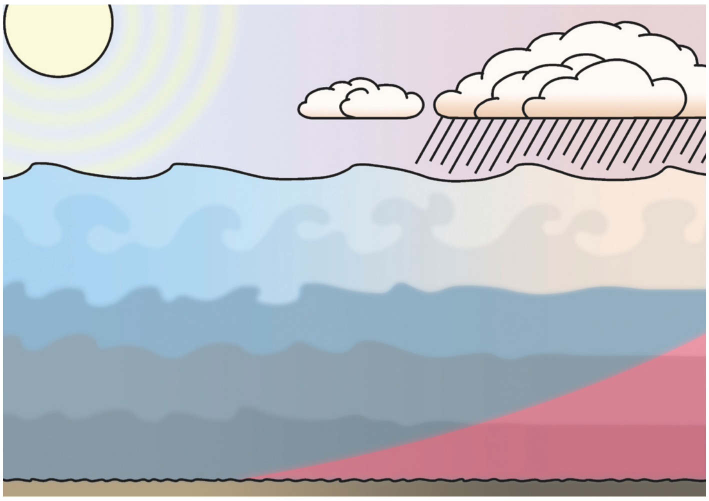
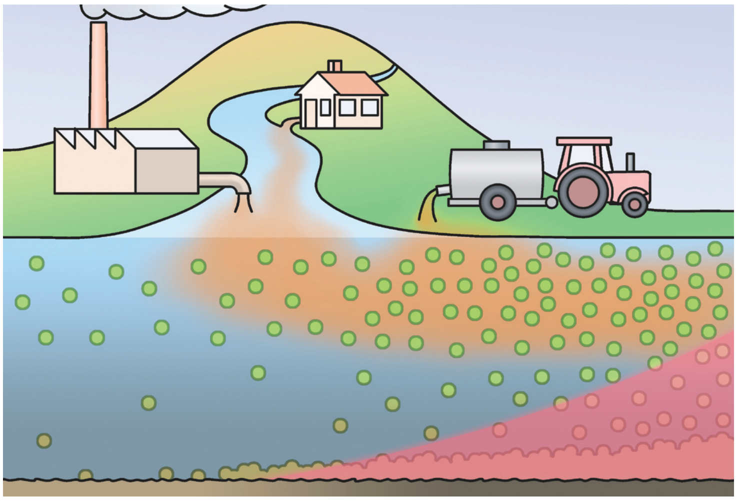
Declining oxygen in water bodies of an overcrowded and warming world

Climate change and nutrient runoff from agriculture and wastewaters lead to decreasing oxygen levels in water bodies worldwide. This is due to a combination of physical, chemical, and biological processes including complex interactions between organisms and self-enhancing feedback loops. Hypoxia (oxygen depletion) has vast consequences for aquatic ecosystems. Long-term oxygen monitoring efforts are needed to assess trends in hypoxia development, and to identify the drivers and mechanisms involved. This information is indispensible for decisions on appropriate countermeasures.



Warming and increased precipitation associated with climate change intensify stratification and restrict mixing. Reduced downward mixing of oxygen may lead to hypoxia (pinkish area) in many aquatic ecosystems.



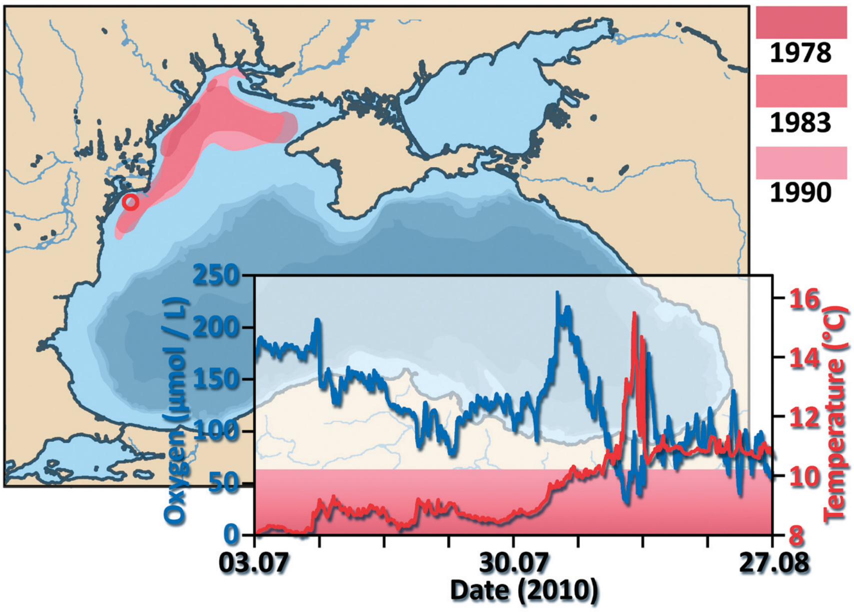
Fertilizer and wastewater runoff enhances primary production in surface layers and organic matter export to deeper layers. This creates oxygen demand and potentially hypoxic conditions at depth (figures: Felix Janssen).

Oxygen deserves attention: too little oxygen even more

Oxygen is on the decline in aquatic ecosystems worldwide and is expected to decrease further, mainly due to anthropogenic pressures. Oxygen depletion ('hypoxia') has substantial consequences for life, its biodiversity and hence ecosystem goods and services. The EU project 'HYPOX' (www.hypox.net) developed novel oxygen monitoring strategies to identify ecosystems at risk and to support decisions on effective countermeasures. This series of 'Hypoxia Briefs' provide information on hypoxia causes and consequences and findings from three years of intense hypoxia research in European waters.

Less supply and stronger demand: anthropogenic pressures causing deoxygenation of aquatic systems

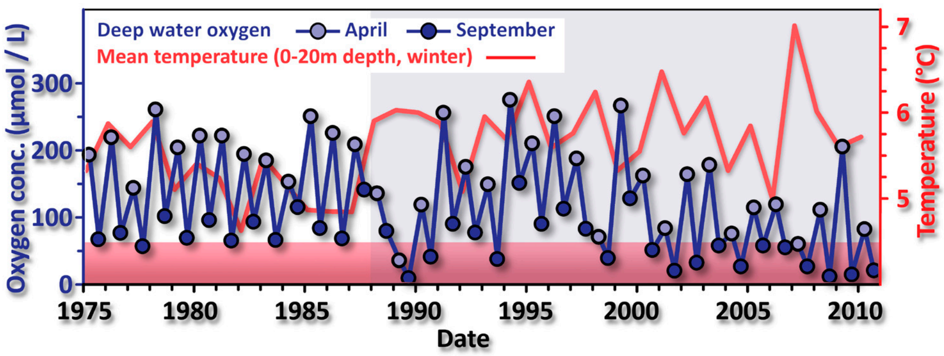
Climate change results in warming of surface waters and reduces their capacity to take up atmospheric oxygen. Warming – and in many places increased precipitation – intensifies stratification and reduces oxygen transport to deeper waters. In coastal and inland waters, eutrophication (nutrient input from waste waters and agriculture) adds to the problem. Growth of microalgae is stimulated just like crop growing in fertilized farmlands. Eventually the excess algal biomass sinks through the water column creating a strong oxygen demand at the seafloor. Once oxygen gets depleted animals die off and a vicious cycle sets in. Nutrients, locked in the sediments in the presence of oxygen are returned to the water column where they stimulate further algal growth. Methane and nitrous oxide, greenhouse gases produced by microorganisms at low oxygen conditions, further promote climate change. The situation is not expected to improve: Global warming is predicted to decrease oceanic oxygen concentrations by several percent over the next century and ever-growing human populations are likely to increase nutrient runoff and the formation of 'dead zones'.



Expansion of hypoxic areas (pinkish) on the Black Sea northwestern shelf in the 1970s to 1990s (map after Zaitsev, Yu, Mamaev V. (1997) Marine Biological Diversity in the Black Sea. UN Publications, New York). The graph shows oxygen and temperature in the bottom water at the 'Portita' site (red circle in map). Summer hypoxia (pinkish zone in the plot) may still occur although conditions largely improved since the 1990s (Jana Friedrich, unpublished data).

After 20 years of reduced nutrient input: Summer hypoxia at the Romanian Black sea shelf

The north western Black Sea shelf provides a unique example for the mitigation of coastal hypoxia through reduced nutrient input. Since the 1990s, when economies of former Black sea Soviet countries collapsed and nutrient inputs decreased substantially, oxygen concentrations in shelf waters generally recovered. However, continuous bottom water oxygen recordings carried out for the first time within the project HYPOX revealed that hypoxia still occurs at warm summer temperatures and unfavorable hydrographic conditions. At the same time a strong release of nutrients from the seafloor was found, showing memory effects that counteract recovery. Monitoring efforts are indispensable to follow improvements and to assess remaining risks for deterioration.



Abrupt warming of the upper layer of Lake Zurich in the late 1980s restricted lake winter overturning and oxygen replenishment from 1988 to present (blue gray area). As a result, hypoxic conditions (pinkish area) regularly occurred at the end of summer at the bottom of the lake, particularly after 1999. Data courtesy of Wasserversorgung Zürich.

Climate variability driving oxygen depletion in deep Lake Zurich (Switzerland)

The City of Zurich's long term monitoring program allowed HYPOX scientists to investigate the impact of climate variability on deep-water oxygen conditions in Lake Zurich. Throughout the 1970s and 1980s the water column overturned most winters, ventilating lake Zurich down to the bottom. An abrupt increase in air and water temperatures in the end of the 1980s strengthened the lake's stratification and reduced the frequency of overturning. Consequently, deep water hypoxia was commonly observed in the last twenty years, confirming that global warming can turn ecosystems hypoxic. Nutrient availability in Lake Zurich cannot explain the observed patters as it decreased since the 1970s. Long-term observations are needed to separate climate and nutrient driven hypoxia also for other systems and to identify appropriate mitigation strategies.

EUROPEAN COMMISSION
European Research Area

SEVENTH FRAMEWORK PROGRAMME

Further reading

Díaz, R. J., Rosenberg, R. (2008) Spreading Dead Zones and Consequences for Marine Ecosystems. Science 321: 926-929 (www.sciencemag.org/content/321/5891/926.full.pdf)

Keeling R.F. et al. (2010) Ocean deoxygenation in a warming world, Ann. Rev. Mar. Sci., 2: 199–229 (www.annualreviews.org/doi/abs/10.1146/annurev.marine.010908.163855)

Kemp, W. M. et al. (2009) Temporal responses of coastal hypoxia to nutrient loading and physical controls. Biogeosciences 6: 2985-3008 (www.biogeosciences.net/6/2985)

Mee, L. D. et al. (2005) Restoring the Black Sea in Times of Uncertainty. Oceanography 18: 100-111 (www.tos.org/oceanography/archive/18-2_mee.pdf)

Stramma, L. et al (2010) Ocean oxygen minima expansions and their biological impacts. Deep Sea Research I 57: 587-595. (www.sciencedirect.com/science/article/pii/S0967063710000294)

World Hypoxic and Eutrophic Coastal Areas by WRI (World Resources institute):
http://www.wri.org/map/world-hypoxic-and-eutrophic-coastal-areas
http://www.wri.org/project/eutrophication/about

Contact

Antje Boetius (HYPOX coordinator),
HGF-MPG Group for Deep Sea Ecology and Technology, Alfred Wegener Institute for Polar and Marine Research,
Bremerhaven, Germany,
Antje.Boetius@awi.de

Project: HYPOX, EU-FP7 #226213,
www.hypox.net

Authors: Felix Janssen, David Livingstone, Jana Friedrich, Ryan North,
Sergey Konovalov, Antje Boetius

Layout: Sabine Lüdeling,
www.medieningenieure.de