Ecosystems short of breath: hypoxia consequences for aquatic life

Hypoxia (oxygen depletion) impacts all life from the tiniest microorganism to the largest fish. Once 'dead zones' develop lacking higher life, recovery may take years or even decades – with strong implications for ecosystem goods and services. Hypoxia-related changes in microbial and chemical processes invoke the release of toxic substances and greenhouse gases that may add to ecosystem deterioration and global warming. Hypoxia effects are specific to ecosystems and thorough investigations are needed to identify the processes involved.

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.

Fish kill at the northwestern Black Sea shelf during summer hypoxia in 2010. Photograph courtesy of Adrian Teaca.

Alarming oxygen levels

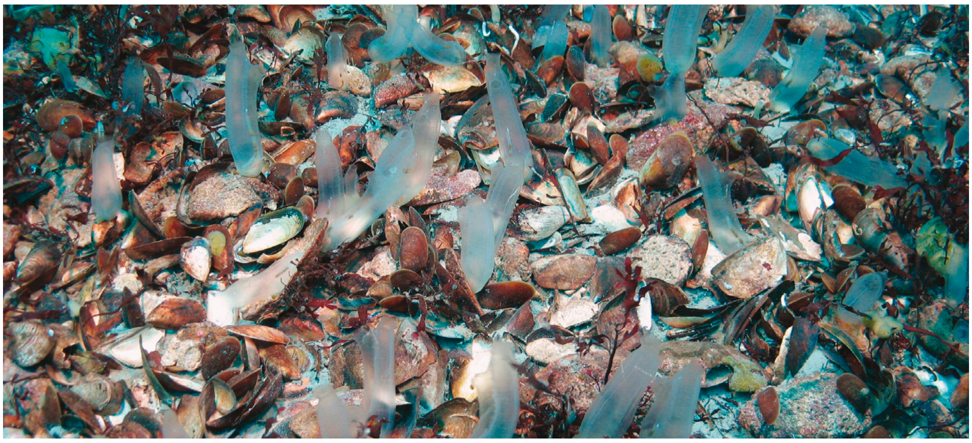
Hypoxia occurrence in seas and inland waters increases due to climate change and other human-induced pressures. When oxygen levels drop, animals relocate, show reduction in growth and reproduction, or die. The response depends on species and hypoxia severity and spatial extent. The paleontological record reveals an extreme example: in a warm period 250 million years ago oxygen levels dropped drastically and more than 90% of the marine species got extinct. Fish kills are the most obvious signs for 'dead zones'. Hypoxia also acts on microbial and chemical processes at the seafloor resulting in the release of toxic substances, nutrients and greenhouse gases. In coastal areas excess nutrients add to plankton growth and subsequent hypoxia. In 'oxygen minimum zones' microbial processes may turn nitrogen compounds into climate-relevant gases. To fully address the consequences of hypoxia, it is important to observe much more than just oxygen concentrations.

hypoxia occurrence	episodic	periodic	seasonal	persistent
ecosystem changes	small, recovery in days to months	moderate, recovery in months to years	severe, recovery takes years	severe, recovery needs decades
	animals survive or recolonize without community shifts	shift towards smaller animals, reduction in biodiversity	partial recolonization between hypoxic periods, severe biodiversity loss	no higher life left, endemic species extinct
		restricted sediment reworking reduces denitrification and adds to eutrophication	additional eutrophication by phosphate released from reduced sediments	accumulation of reduced compounds in sediments impedes recovery. methane release adds to global warming and formation of new hypoxia events
highest trophic level ultimate fate of eco system productivity	large motile animals (fish, crabs...)	large and small sessile animals (e.g., worms)	small animals and microbes	microbes and organic matter burial
signs of ecosystem decline	subtle	nothing obvious („black spots“)	fish catches may start to decline	collapsing fish catches and mass mortality

Patterns of ecosystem decline: from occasional hypoxia to permanently anoxic dead zones

The long way back: slow recovery of benthic communities

Once a flourishing ecosystem with rich fishing grounds, the broad northwestern Black Sea shelf turned into the world's largest 'dead zone' after 1960, when vast inputs of nutrients and wastewaters resulted in area-wide oxygen depletion. Conditions only improved when fertilizer and industrial wastewater efflux dropped in the 1990s after the political changes in the riparian states. Investigations of the project HYPOX reveal that the ecosystem is still not restored. Opportunistic and sometimes invasive species still occupy ecological niches of long-lived and slow-growing organisms. Characteristic habitats like mussel beds did hardly reestablish. A major challenge for future monitoring is to identify declining oxygen levels at an early stage to allow for countermeasures before essential ecosystem functions are lost.



Filter feeder communities at the northwestern Black Sea shelf. In many areas the semitransparent fast growing ascidians still dominate over slow growing mussels that died off due to hypoxia. Photograph courtesy of Tim Stevens.

Oxygen rules seafloor processes

High nutrient levels in western Baltic waters sustain an intense production of microalgae. When the algal biomass is degraded at the seafloor, bottom water oxygen is consumed and nutrients are recycled back the water column – further enhancing productivity and the risk of bottom water hypoxia. At the long term monitoring site 'BOKNIS ECK' hypoxic conditions develop in summer and wipe out the bottom fauna. Next, the strong greenhouse gas methane is produced in the oxygen deficient sediments. Methane seeps from the seafloor, carrying high amounts of nutrients back to the water column and potentially adding to global warming. Summer hypoxia thus creates conditions favorable for even stronger oxygen depletion. Further efforts are needed to investigate if such feedback loops also exist in other areas that similarly suffer from summer hypoxia.

Further reading

Dale A. et al (2011): Rates and regulation of nitrogen cycling in seasonally hypoxic sediments during winter (Boknis Eck, SW Baltic Sea): sensitivity to environmental variables. Estuarine, Coastal and Shelf Science 95: 14-28 (www.sciencedirect.com/science/article/pii/S0272771411001739)

Langmead, O. et al. (2009) Recovery or decline of the northwestern Black Sea: A societal choice revealed by socio-ecological modelling. Ecological Modelling 220: 2927–2939 (www.sciencedirect.com/science/article/pii/S0304380008004420)

Levin, L. A. et al. (2009) Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences 6: 2063-2098 (www.biogeosciences.net/6/2063)

Middelburg, J. J. and Levin, L. A. (2009) Coastal hypoxia and sediment biogeochemistry. Biogeosciences 6: 1273-1293 (www.biogeosciences.net/6/1273)

Hypoxia research in the Northern Adriatic by the University of Vienna: www.marine-hypoxia.com

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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, Andrew Dale, Jana Friedrich, Sergey Konovalov, Antje Boetius

Layout: Sabine Lüdeling, www.medieningenieure.de