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The Ocean is Losing its Breath

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Introduction

Decreased oxygen concentrations in the ocean, as a result of climate change and other anthropogenic stressors, e.g. nutrient input due to inefficient fertilizer use, was discussed in the latest IPCC report (2014). However, so far this emerging threat for the ocean is not fully acknowledged by policymakers and stakeholders at the global level. Systematic deoxygenation of the ocean will have widespread consequences. O_2 plays a direct role in the biogeochemical cycling of carbon, nitrogen, and many other biogeochemically important elements (P, Fe, Mn, etc.). O_2 is also fundamental for all aerobic life, including organisms living in the dark ocean interior. Deoxygenation (reduced oxygen concentration) mostly affects the marine environment at the local level, nevertheless economic and socio-economic impacts will impair the human society at the regional and global level.

Scientific background

The ocean is a major actor in mediating the global oxygen cycling. At least 50 % of the oxygen we breathe originates from the ocean, but at the same time the ocean experiences a continuous loss of oxygen in its water column and sediments.

Hypoxic to anoxic and even sulfidic conditions have already been reported for various aquatic systems, from lakes, estuaries and coastal areas to off-shore regions of the ocean, where oxygen supply does not compensate for its consumption in various redox processes, including respiration of organic matter (IPCC 2014). Thresholds for hypoxia vary greatly between marine taxa, with fish and crustaceans tending to be the most sensitive (Vaquer-Sunyer&Duarte 2008). A typical threshold for hypoxia is approximately 60 µmol kg^{-1} (Gray et al. 2002); zones with lower O_2 are defined as "dead zones" for many higher animals.

In the coastal ocean, oxygen minimum zones (OMZs) have spread exponentially since the 1960s and have been reported for more than 400 systems (e.g. Baltic, Black, Kattegat Sea, Gulf of Mexico, East China Sea) (Stramma et al. 2008a, Stramma et al. 2008b, Stramma et al. 2010). OMZ are areas where subthermocline dissolved oxygen levels are<3.5 ml l^{-1} (< 150 mol kg^{-1}; Prince & Goodyear 2006) In these shallow areas, where the bottom is occupied by ecologically and economically valuable benthic communities, hypoxic/anoxic conditions cause catastrophic biological losses, acidification, secondary pollution, nitrogen and phosphorus surplus (eutrophication). In the open ocean, eastern boundary upwelling systems (EBUSs) are characterized by high primary and export production that, in combination with weak ventilation, cause oxygen depletion and the development of OMZs in sub-surface waters.

OMZs play critical roles in atmospheric chemistry and climate through emission of active trace gases and affect nearly all aspects of ecosystem structure and function in the water and on the sea floor. The potential expansion of OMZs will have large effects on fisheries species through habitat compression, altered food webs, and modified species interactions, including with fishermen. Within a few decades ocean deoxygenation will increasingly stress marine and aquatic ecosystems in a way that is currently overlooked on the global scale, and is largely only considered locally. The expansion of hypoxic and anoxic zones will affect the biogeochemical and ecological status and functioning of marine and freshwater ecosystems, as well as the delivery of services. As the ocean loses its breath locally the global ecosystem service of providing an environment to live in is hampered.

Climate model projections predict continued and intensified ocean deoxygenation into the future (e.g. Matear et al., 2000; Bopp et al., 2002; Oschlies et al., 2008). Hindcasting of these models is supported by the geological record, which illustrates expansive ocean anoxic events that follow climate excursions.

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Strategies for the future

Deoxygenation is the only threat of such critical importance to marine ecosystems that accelerated so drastically in such a short timeframe. Future scenarios for this in the global oceans will largely depend on a combination of factors related to global environmental change and land-use, including a growing human population, especially along the coasts; agricultural practices; and nutrient loadings. Under a business as-usual-scenario, the amount of reactive nitrogen entering the ocean is projected to grow by 50 percent by 2050 (Noone et al. 2012), leading to the increased frequency, intensity and duration of coastal hypoxia. Integrated action is urgently required to prevent and remediate hypoxia.

Its global extent and threat to human health and marine ecosystem services are just beginning to be appreciated, and much remains unknown regarding its social and economic consequences. Virtually all of the information we do have is from North America and Europe. We know very little about conditions in the most populated parts of the planet or oceanic islands. A global network would facilitate and improve the cooperation for ocean oxygen monitoring and identify the gaps for further research. Subsequently new collaborations in research activities will fill the current gaps of knowledge, to revise model calculations and standardize applied methods, to enhance the utility for the economic sector (e.g. fisheries, tourism), and to evaluate impacts on non-market ecosystem services (carbon sequestration, nutrient cycling, biodiversity, food web support).

The good news is that it is possible to recover oxygen levels even in the deadest of dead zones. To do so will require dramatic increases in fertilizer-use efficiency, and therefore institutional capacities for managing nutrient levels need to be strengthened at the local, national, regional and global levels. New public-private partnerships are also needed across key sectors to stimulate innovation in nutrient reduction and reuse technology. In any case as deoxygenation, warming of the ocean and ocean acidification are all mainly driven and enforced by increased atmospheric CO_2, which enters the marine water column, the only effective solution to mitigate global environmental change is curbing carbon emissions.

Hypoxia, a multiple stressor challenge, ocean warming, ocean acidification & eutrophication

All regions of the ocean will be impacted by multiple stressors. Especially the biological response is assumed to exhibit a strong variation and complexity. The reduction in local pollutants can potentially reduce the impact of global stressors. But in order to manage our ocean sustainable the impact of multiple stressors has to be considered while calculating and predicting our future marine environment.

While the chemical and physical changes associated with ocean warming, acidification and deoxygenation occur globally, the imprint of these global stressors will have a strong regional and local nature. The coalescence of the different global stressors in certain regions is already creating a number of 'hotspots', e.g. the Eastern Boundary Upwelling Regions, the Arctic Ocean and the Southern Ocean. In addition to these regional 'hotspots', certain marine ecosystems are highly vulnerable to multiple stressors, e.g. coral reefs. Other examples show that top predators in the marine food web of the Eastern Tropical Pacific, also important for the economic development of certain regions, were shown to be impaired by deoxygenation, ocean acidification and temperature increase.

The different levels of response cause the necessity to assess the impacts of multiple stressors measurements have to be conducted at different levels, too, at the physiological/biogeochemical, the organism, and the ecosystem level.
Following the science also policy has to act to manage the marine resources in light of multiple stressors. Cross-scale governance systems for marine resources need to be developed or implemented. A change of societal behavior should result in reducing local threats, while at the same time a precautionary approach to multiple stressors should be adopted at the global scale.

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