DOSI
DEEP-OCEAN STEWARDSHIP INITIATIVE

POLICYBRIEF
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Ocean Deoxygenation: A Hidden Threat to Biodiversity beyond national jurisdiction

Oxygen is critical to ocean health, but climate change is causing the loss of oxygen in the open ocean; this is called "Ocean Deoxygenation". Ocean deoxygenation can adversely impact biodiversity, including by reducing the quality and quantity of appropriate habitat, reducing growth rate, increasing disease susceptibility and interfering with reproduction. Consequently, deoxygenation re-shapes the diversity, composition, abundance, and distribution of marine microbes and animals. Ocean deoxygenation should be factored into the development of legal and policy measures for biodiversity beyond national jurisdiction, including building science capacity, technology transfer, and incorporating ecosystem-based and precautionary approaches to decision-making, especially for area-based management tools and environmental impact assessments.

Why and where is Ocean Deoxygenation Occurring?

All marine animals need oxygen to survive; ocean life depends on oxygen just as much as animals, including humans, do on land. Climate change is causing the loss of oxygen (deoxygenation) in deep and open ocean areas beyond national jurisdiction.

Why is ocean deoxygenation occurring?

- The ocean is taking up heat from the atmosphere, making the water warmer.
- Warmer water holds less oxygen and is less well mixed.
- Animals and microbes also consume more oxygen when water is warmer.
- Closer to shore, where some open water species spend part of their life, excess nutrients from land (agriculture, sewage, fossil fuel combustion) cause coastal eutrophication that contributes to oxygen loss. But even in these areas, ocean warming exacerbates oxygen decline.

How much oxygen has been lost, and how is this measured?

Scientists measure oxygen from ships, moorings, landers, gliders, and, more recently, on > 250 Argo floats (*Figure 1*).

Fig 1 Selected platforms that carry sensors capable of oxygen observations (source: courtesy of Deep Ocean Observing Strategy Science Implementation Guide).

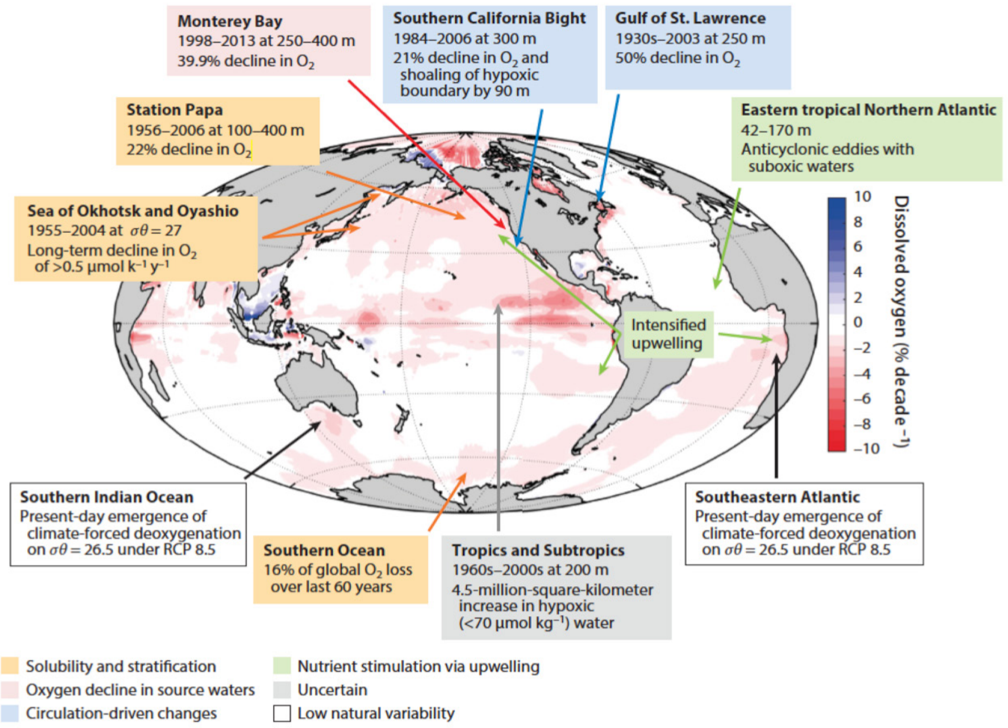

Fig 2 *Percentage change in dissolved oxygen per decade since 1960, with areas subject to different drivers of oxygen loss highlighted in boxes with different colors. Abbreviations: σθ, density surface; RCP, representative concentration pathway (source: Levin, 2018; base map adapted from Schmidtko et al., 2017).*

The ocean has lost about 2% (or over 150 billion tons) of its oxygen over the last 50 years, but not uniformly (*Figure 2*). Since the 1960s over 4.5 million km^2 of the ocean has become increasingly deprived of oxygen (hypoxic) at 200m water depth, over broad swaths of the tropical and subtropical oceans and NE Pacific. All emissions scenarios, through the year 2100, project additional oxygen loss at all water depths (*Figure 3*).

Where is the open ocean losing oxygen?

Naturally occurring oxygen minimum zones (100-1000m water depth) are expanding (*Figure 4*). Oxygen loss is greatest in the Northeast Pacific, Southern Ocean, and Indian Ocean. Intensified upwelling (which brings up nutrients from deep water) and strengthened deep currents both contribute to oxygen loss on the eastern sides of oceans.

→ CONSEQUENCES:

Deoxygenation reduces the quality and quantity of habitat available to marine species. Even very small declines in oxygen can greatly affect biodiversity, where they cross animal oxygen thresholds, such as in oxygen minimum zones. Some animals can move away from low oxygen areas into better-oxygenated waters, but that doesn't mean they aren't affected. **These animals are losing otherwise suitable habitat and being compressed into remaining areas** (*Figure 4*). Fisheries species (especially large, active species such as billfishes and tuna) will be affected, as will areas potentially available for aquaculture production. Meanwhile fish and crustaceans moving upward as oxygen minimum zones expand can become more vulnerable to fishing.

Species that cannot move away from low oxygen areas may experience **mass mortalities** under oxygen shortages (hypoxia), as has already been seen in some coral reefs. **Low oxygen strongly reduces biodiversity**; only the most hypoxia-tolerant species survive (*Figure 5*). Ocean deoxygenation **re-shapes the composition, diversity, abundance, and distribution of marine microbes and animals**. Ultimately, this causes **changes to food web structure. Fish body size and fisheries catches may decline**. Chronic exposure to insufficient oxygen also **increases disease susceptibility, interferes with reproduction, and reduces growth rates**.

Climate-induced ocean deoxygenation has become increasingly evident locally, regionally, and globally. Many biogeochemical feedbacks link to oxygen loss and contribute to even further oxygen decline. Ocean deoxygenation may cause **increase production of greenhouse gasses**, including carbon dioxide

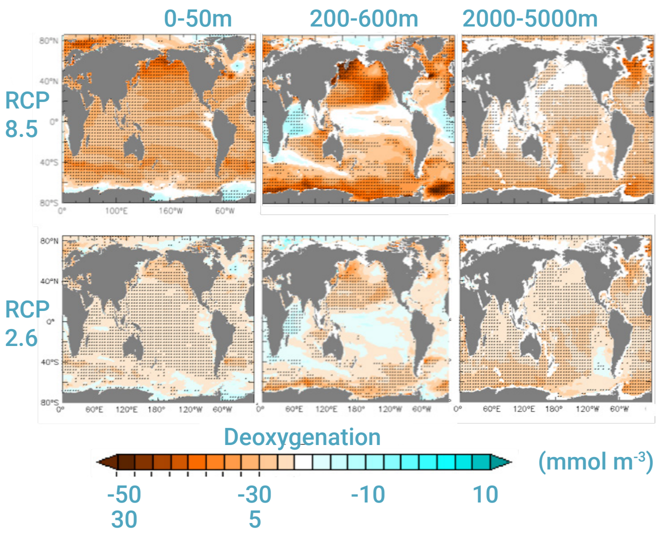

Fig 3 *Projected changes in oxygen content of the open ocean at different water depths under two CO_2 emissions scenarios. RCP 8.5 is business as usual; RCP 2.6 is a highly reduced emissions scenario. (source: Breitburg et al., 2018 via L. Bopp).*

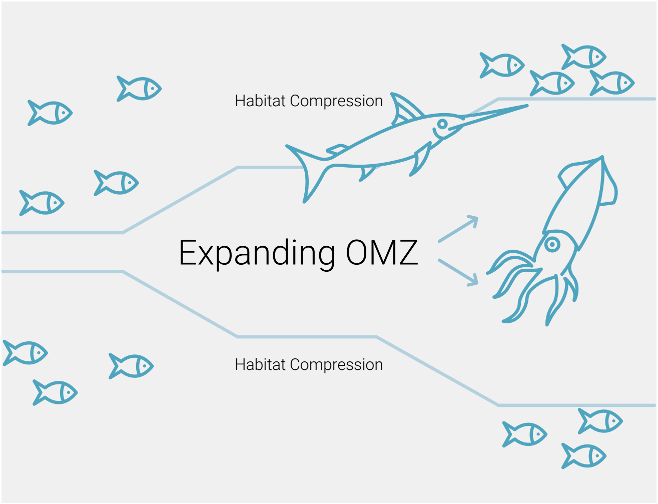

Fig 4 *Schematic showing expansion of naturally occurring oxygen minimum zones as a result of climate change, and resulting habitat compression. Sensitive species (represented here by fish) avoid oxygen-depleted waters that remain available to species that are tolerant of low oxygen (e.g., some squid species).*

(CO_2), nitrous oxide (N_2O) and methane (CH_4); release of these gases to the atmosphere could induce more warming and more oxygen consumption. Loss of biologically-useful nitrogen through denitrification (and a similar process called anammox) results in **diminishing primary production** in the ocean, another potential negative consequence. Many experts project a less productive future ocean with a lower capacity to sequester anthropogenic CO_2 from the atmosphere, hence decreasing the regulating role of the world's ocean.

SOLUTIONS:

There are a range of policy measures that can be adopted to address ocean deoxygenation (Figure 6). **The causes of ocean deoxygenation should be tackled through international efforts to:**

(i) reduce the greenhouse gas and particulate (black carbon) emissions that cause atmospheric and ocean warming; and

(ii) reduce nutrient inputs to the ocean that exacerbate oxygen loss.

In addition, the impacts of ocean deoxygenation could be better addressed by policy measures that encourage and enable the international community to:

a. **recognize that ocean deoxygenation interacts with warming and ocean acidification** and impacts marine biodiversity;

b. **alleviate direct anthropogenic stressors** (e.g.; pollution, overfishing, invasive species, habitat loss, trawling or mining disturbance) that threaten resilience and increase vulnerability of marine ecosystems to deoxygenation;

c. adopt **spatial planning and management strategies** that identify deoxygenation vulnerabilities and protect species and habitats;

d. recognize deoxygenation as an additional stressor when assessing potential **environmental impacts** of projects as well as potential new plans, policies, activities or technologies at local and regional scales;

e. **build oxygen observing capacity** and expand ocean oxygen observations to improve mechanistic understanding and provide early warning systems, including by seeking to unify research collaboration across (i) coasts and the open ocean (ii) biology, geochemistry and physics, (iii) on warming, acidification and deoxygenation and (iv) across academic, industry, government and regulatory sectors; and

f. promote **global awareness and the exchange of information** about ocean deoxygenation, for example through the IOC-UNESCO's Global Ocean Oxygen Network (GO$_2$NE).

The development of a new international legally binding instrument for the conservation and sustainable use of marine biodiversity of areas beyond national jurisdiction under the UN Convention on the Law of the Sea (BBNJ agreement) could advance such measures to recognize and address the impacts of ocean deoxygenation, particularly through provisions for capacity building and technology transfer, as well as area-based management tools, consideration of cumulative impacts, and incorporating precautionary and ecosystem-based approaches in decision-making.

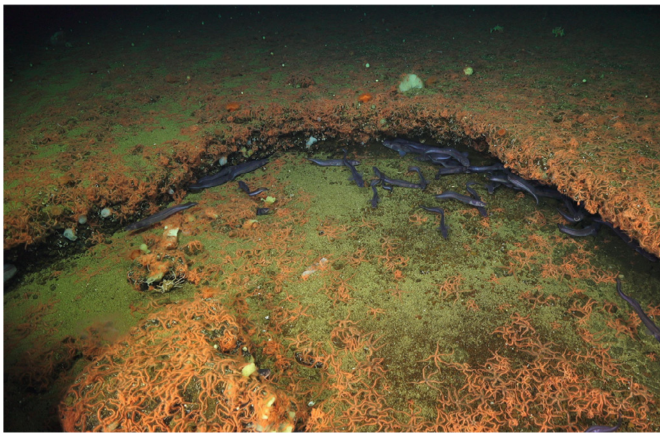

Fig 5 *Low diversity ecosystem in the oxygen minimum zone on a seamount off Costa Rica with high dominance by orange brittle stars (source: courtesy of Schmidt Ocean Institute).*

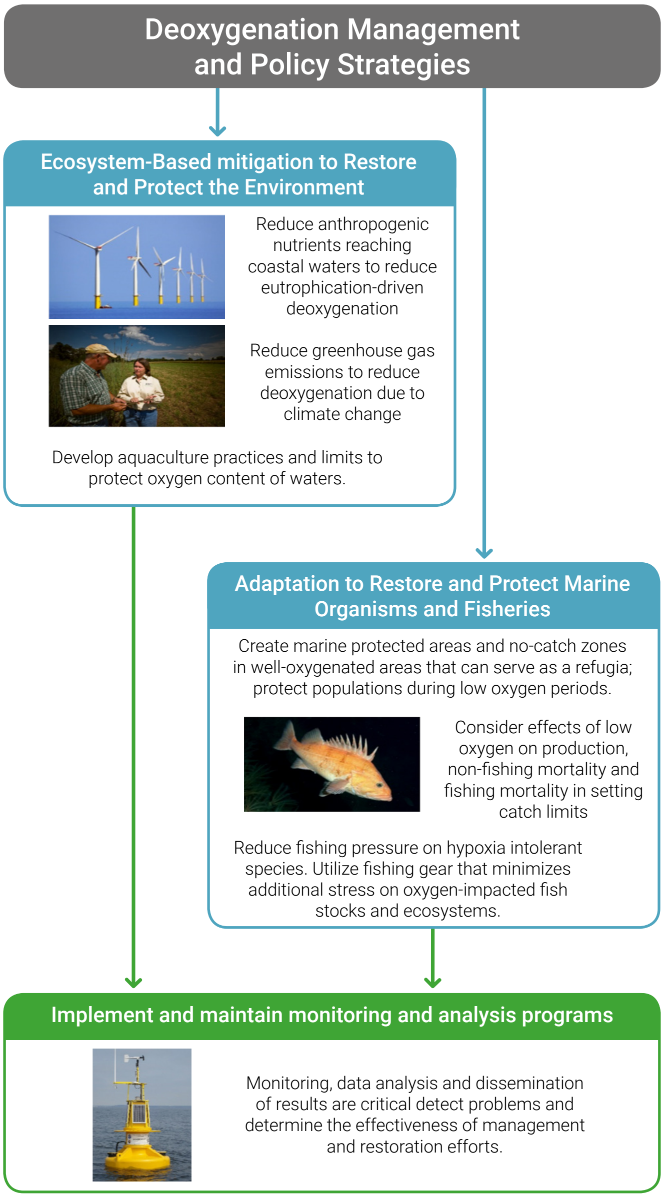

Fig 6 *Management and policy strategies to address ocean deoxygenation (source: Breitburg et al., 2018)*

References & further reading:

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ABOUT DOSI

The Deep-Ocean Stewardship Initiative seeks to integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

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