Deoxygenation—coming to a water body near you

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"When you can't breathe, nothing else matters."—slogan of The American Lung Association

The world's waters are losing oxygen, and we should be very concerned.

In 2017, Denise Breitburg, Lisa Levin, and I wrote a guest editorial for this column about ocean deoxygenation—the loss of dissolved oxygen in our oceans, estuaries, and coastal zones. At the time, deoxygenation was little known among many scientists, let alone the general public or policy makers, except as related to eutrophication. We pointed out that although many low oxygen events are tied to sewage pollution and agricultural runoff, deoxygenation is increasingly recognized as a climate-driven problem, affecting even waters without excess nutrients.

2017 was the year when we learned that the oceans had lost ~2% of their oxygen inventory since 1960. Then in 2018, scientists led by Denise and Lisa published a groundbreaking synthesis of what we then knew about coastal "dead zones" and oxygen minimum zones (OMZs), those vast regions of the open ocean where oxygen depletion occurs naturally, which are expanding due to the physics of warming on ocean circulation and ventilation. And in 2019, the IUCN published a summary volume on ocean deoxygenation, which was featured at that year's UN Climate Change Conference (COP25). These works were supported by a UNESCO–Intergovernmental Oceanographic Commission working group, the Global Ocean Oxygen Network (GO_2NE), whose mission is to promote awareness, stimulate research, and provide advice to policy makers on all aspects of ocean deoxygenation.

GO_2NE has indeed been successful, and much has been learned since 2017. For example:

- A well-calibrated modeling exercise by Andreas Oschlies showed that even if all CO_2 emissions were halted starting in 2020, the global ocean was "committed" to a fourfold increase in deoxygenation—due to warming-induced changes in circulation—that will persist for centuries. Unfortunately, CO_2 releases have not ceased, but rather continue to rise.
- Once thought to be damaged only by warming, many coral reefs were found by Andrew Altieri and others to also experience harmful deoxygenation events, with some corals bleaching from lack of oxygen, and with changes in community structure due to differential resilience.
- In the fisheries realm, there is increased evidence that tunas, sharks, and billfishes avoid hypoxia by moving into shallower water, making them more vulnerable to fishing. And although it is often difficult to separate the effects of climate change from fishing effort, Baltic Sea cod provide a cautionary tale. The fisheries have been closed since 2019, and yet the population has failed to recover. The fish are smaller, reproduce at age 1 instead of 3 or 4, are heavily infested with liver parasites, and are generally undernourished. These intertwined effects are exacerbated by hypoxia, which lowers metabolic rates and reduces immune responses.
- The marked increase in studies on hypoxia from local to ecosystem scales has underscored the complexity of its impacts on ecosystem services, as well as improved our understanding of multiple stressors and their interactions (eg warming, hypoxia, and acidification, all driven by greenhouse-gas emissions).

Currently, efforts are underway to produce an open-access and community-driven Global Ocean Oxygen Database and Atlas (GO_2DAT), to make the growing volume of coastal and open ocean data accessible for displays and analyses. This will be part of the Global Ocean Oxygen Decade, a program within the UN Ocean Decade, and should help us with a better understanding of where problem areas are happening.

But deoxygenation is not limited to oceans: inland water bodies are also losing oxygen, due to a combination of warming, elevated organic matter loading from increased precipitation, longer seasonal stratification, and the attendant impacts of human population growth. In a survey of nearly 400 temperate lakes and reservoirs between 1980 and 2017, Stephen Jane and colleagues reported that surface waters lost >5%, and hypolimnions >18%, of their oxygen. Even rivers are deoxygenating, despite their flowing nature; Penn State's Wei Zhi and colleagues discovered that 70% of 580 rivers surveyed lost oxygen.

Colleagues of mine working in the Adirondack Mountains of New York are concerned about oxygen-related threats to coldwater fishes. Thermal refugia in Adirondack lakes are shrinking as hypoxic/anoxic periods extend longer into the fall. And in New York's Hudson River estuary, 28 years of high-resolution, continuous monitoring in a National Estuarine Research Reserve site show that the Hudson is deoxygenating, with a whopping 32% decline in the month of July—a month when oxygen demands, which increase with increasing temperatures, are at their highest.

Now established in the climate lexicon, deoxygenation is included in the latest IPCC reports, and has also recently been proposed as a tenth "planetary boundary." As ecologists, policy makers, and resource managers, we should recognize deoxygenation as an increasing environmental constraint. Continuing research and monitoring on how deoxygenation interacts with other stressors is key. From an ecosystem health/services perspective, we must work to increase resiliency of aquatic systems through restoration and conservation, adjust aquaculture and fisheries management to account for ecosystem changes, and—above all—support efforts to kick the fossil-fuel habit.