Global Warming and Coastal Dead Zones

By Donald F. Boesch

Massive, low-oxygen "dead zones" unable to support marine life can be found in coastal waters worldwide. Excessive nutrients, primarily from chemical fertilizers, are mostly to blame. Absent immediate action, climate change will only exacerbate the problem.

During the latter part of the 20th century, many estuaries, bays, continental shelves, and enclosed seas around the world experienced a significant reduction of dissolved oxygen concentrations in bottom waters, creating what are commonly referred to as "dead zones." These are sometimes vast areas where, at least during the warmer part of the year, oxygen concentrations are too low to support fish, crustaceans, and other animals. Eutrophication—the abundant accumulation of nutrients in an ecosystem—is often the cause of these dead zones, termed hypoxia where concentrations of oxygen fall below 2 mg/L, and anoxia where the presence of oxygen is virtually nil.

The Gulf of Mexico dead zone, extending west on the inner Louisiana-Texas continental shelf from the mouth of the Mississippi River, is perhaps the most famous. It has developed virtually every summer since the early 1970s and can cover 22,000 km^2 (Rabalais et al., 2007). The deep hypoxic zone of the Baltic Sea is even larger and has become a year-round, multi-decade feature. Seasonal dead zones are prominent in the Chesapeake Bay, Long Island Sound, many smaller U.S. bay estuaries, and in coastal environments around the world, particularly in Europe and Asia. Some 169 of these hypoxic zones have been documented, and their numbers are increasing (Selman et al., 2008).

Although natural processes can cause and always contribute to the development of hypoxia and anoxia, most of these dead zones have developed or been exacerbated by human activities, particularly the increase in loading of nutrients—nitrogen and phosphorus in various forms—from land to the coastal waters. Phytoplankton—microscopic plants that live in the water—photosynthesize these excess nutrients through a process known as primary production, creating new organic matter along the way. Some of the additional organic matter that is produced settles into bottom waters where it decomposes and consumes oxygen in the process. Coastal waters prone to hypoxia are deep enough to experience density stratification, whereby the mixing between the fresher, warmer surface water and saltier, cooler bottom water is restricted. As the oxygen inventory of the bottom water is consumed, it is not replenished fast enough, even though dissolved oxygen in the surface waters may be supersaturated due to the very high rates of photosynthesis.

Dissolved oxygen concentrations plummet in bottom waters, killing animals or requiring them to flee if they can. Sometimes fish kills result, but typically the lack of corpses belies the impact as many fish, crustaceans, and shellfish are taken by predators as they leave the relative safety of their bottom habitats. Biogeochemical changes enhance the return of nitrogen and phosphorus from the sediments to the water column, refueling the fire of primary production in a vicious cycle (Kemp et al., 2005). As a result, the important ecosystem services these coastal environments provide are compromised.

The more-or-less synchronous development of coastal dead zones around the world was closely linked with increased inputs of nitrogen and phosphorus from human activities, including agriculture, waste discharges, atmospheric deposition of nitrogen resulting from the combustion of fossil fuels, and runoff from urbanizing areas (Boesch, 2002). In particular, the dramatic growth in the use of industrially manufactured nitrogen fertilizer beginning in the 1960s, which provided a needed increase in food production, resulted in increased nutrient runoff from crop lands and intensified animal production and waste generation. Artificial drainage of heavily fertilized crop lands, such as in the Mississippi River basin, and the loss of riparian wetlands also facilitated downstream nutrient discharges (Mitsch et al., 2001; EPA Science Advisory Board, 2007).

There are a number of large, concerted and expensive efforts to reverse eutrophication in coastal waters, including commitments to reduce nitrogen and phosphorus loadings by 50% or more in the Baltic and North seas and the Chesapeake Bay (Boesch, 2002; Kemp et al., 2005). An action plan to reduce the Gulf of Mexico dead zone by two-thirds has not yet adopted a numeric nutrient reduction goal, though a U.S. Environmental Protection Agency Science Advisory Board has recommended that nitrogen and phosphorus loads be reduced by 45%. Depending on the sources within the relevant watershed, reduction of nutrient loads can involve tertiary treatment of municipal wastes (e.g., for Long Island Sound where these are the major sources), air pollution control to reduce

Dr. Donald Boesch is the President of the University of Maryland Center for Environmental Science. He was recently recognized for lifetime leadership in ecological restoration at the National Conference on Ecosystem Restoration.

Table 1. The influence of multiple climate drivers on the extent and severity of coastal hypoxia (adapted from Boesch et al., 2007).			
Climate Driver	Direct Effect	Secondary Effect	Hypoxia
Increased temperature	More evapotransportation	Decreased streamflow	-
		Land-use and cover changes	+/-
	Less snow cover	More nitrogen retention	-
	Warmer coastal water temperature	Stronger stratification	+
		Higher metabolic rates	+
More precipitation	More streamflow	Stronger stratification	+
		More nutrient loading	+
	More extreme rainfall	Greater erosion of soil P	+
Less precipitation	Less streamflow	Weaker stratification	-
		Less nutrient loading	-
Higher sea level	Greater depth/volume	Stronger stratification	+
		Greater bottom water volume	-
		Less hydraulic mixing	+
	Less tidal marsh	Diminished nutrient trapping	+
Weaker summer wind	Less water column mixing	More persistent stratification	+
Stronger summer wind	More water column mixing	Less persistent stratification	-

atmospheric deposition of nitrogen, various agricultural management practices (e.g., in the Chesapeake and Mississippi basins where these sources are large), and restoration of nutrient-trapping wetlands and riparian zones.

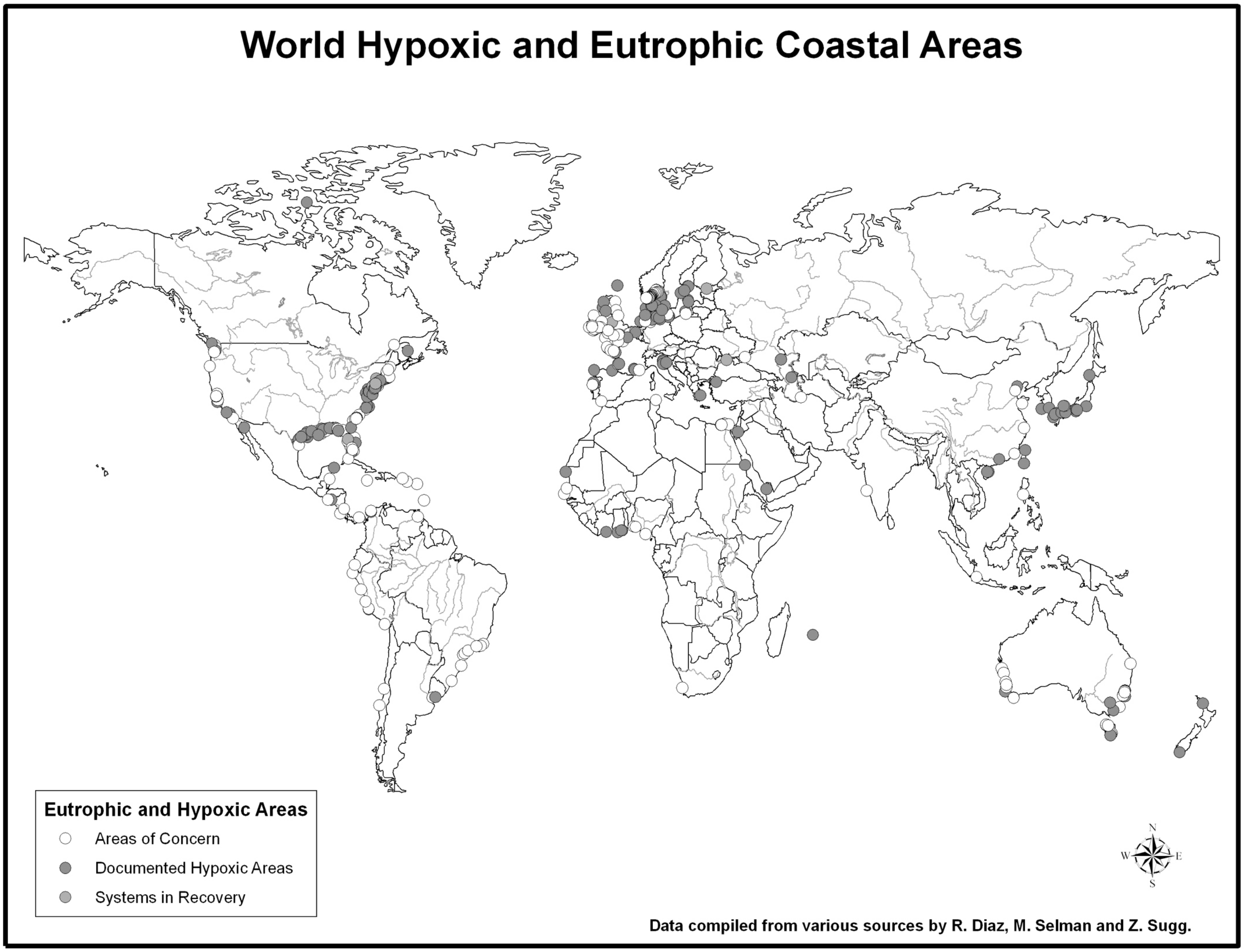
Recent reports have demonstrated that the longer a region suffers from regularly recurrent hypoxia the more difficult it is to restore oxygen conditions and bring the dead zones back to life because the sediments build up organic matter and nutrients (Conley et al., 2007; Turner et al., 2008). These ecosystems have reached a recalcitrant, degraded state, and significant and sustained reduction in nutrient loading may be required for them to cross back over the threshold of recovery (Kemp & Goldman, 2008). Because recovery becomes increasingly more difficult, time is of the essence.

It is likely that global warming will only exacerbate hypoxic conditions. A degraded ecosystem suffering from eutrophication has diminished resilience in its response to changing conditions. Effects of global warming are already being observed on both land and in the ocean and will intensify during this century (IPCC, 2007). Multiple climatic drivers that influence the formation of dead zones will be affected, including increased temperatures, changes in the amount and timing of precipitation, sea level rise, and changes in the frequency and intensity of winds and storms. These will interact in complex ways to exacerbate, or under some conditions alleviate, hypoxia (see Table 1).

In the Baltic Sea, for example, the projected increases in precipitation and runoff and sea surface temperature will likely strengthen the density stratification of this brackish, inland sea, worsening hypoxia in bottom waters (BACC Author Team, 2008). In the United States, global warming is projected to increase river runoff in the Midwest and Northeast while decreasing it in the already arid Southwest (Milly et al., 2005). In the Gulf of Mexico, a 20% increase in Mississippi-Atchafalaya River system discharges will increase the flux of nitrate to the northern gulf and increase density stratification on the inner shelf, thereby increasing the frequency and extent of hypoxia and requiring greater reductions of human nutrient sources to achieve the objectives of the action plan (Justić et al., 2003). In the Chesapeake Bay, in addition to increased winter-spring runoff and warming, accelerated sea-level rise will increase the volume of the bay and the penetration of ocean water, with complex effects on mixing and stratification (Boesch et al., 2008).

Recent reports on how climate change may already be influencing oxygen availability in the ocean, unrelated to nutrient loading from human activities, underscores the sensitivity of ocean life to this great 21st century challenge. Changes in wind patterns have resulted in shifts in ocean currents and deep upwelling, causing hypoxia and mass mortalities in recent years along the inner shelf off the Oregon and Washington coasts (Chan et al., 2008). Deep oxygen minimum zones in tropical oceans have vertically expanded over the last 50 years (Stramma et al., 2008).

Future projections and current warning signs of the effects of global warming should provide a sense of urgency in our efforts to abate coastal eutrophication and resuscitate dead zones. Healthy, resilient ecosystems will still be subject to change, but will allow for better adaptation and management options. Restoring wetlands within the watersheds of these coastal ecosystems and managing coastal wetlands in ways that enhance their ability to build soils and migrate inland as sea level rises would preserve



Map available at http://www.wri.org/map/world-hypoxic-and-eutrophic-coastal-areas. Copyright 2008, World Resources Institute. Reprinted with permission.

or enhance their capacity as a sink for nutrients (Mitsch et al., 2001). There would be many additional, adaptive benefits from aggressive efforts to rebuild wetlands now, including water flow control, carbon sequestration, and critical habitat corridors for northward-retreating species.

Also, in the coming decades, if not years, there will be enormous pressure to find ways to reduce greenhouse gas emissions. There are pathways that could produce ancillary benefits in terms of reducing coastal dead zones (for example, carbon capture and sequestration from power plants could also eliminate nitrogen oxide emissions). However, as exemplified by the current corn-based ethanol boom, there are pathways that could make dead zones worse (Donner and Kucharik, 2008). In any case, it is now time to take climate change into account in our efforts to reduce coastal dead zones and to consider fully the collateral effects, including dead zones, in our efforts to slow global warming. ■

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mitigation project monitoring reports will be available for public review and our goal is to make these available via the web by the end of the year.

The Way Forward

The new rule will be the impetus for many important and necessary changes for regulators, permit applicants, mitigation providers, and others. Proper training and outreach on the rule will be critical for ensuring that these improved standards result in more effective compensation on the ground. To that end, the Corps and EPA have already conducted a number of critical outreach and training efforts throughout the country, and will continue to do so for the remainder of 2008. For a copy of the new rule, supporting materials, and other compensatory mitigation resources, go to http://www.epa.gov/wetlandsmitigation/. ■

Palmer Hough is an environmental scientist in the U.S. Environmental Protection Agency Wetlands Division. Mark Sudol is chief of the U.S. Army Corps of Engineers Regulatory Branch.

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