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NEST Indicator: Hypoxia in U.S. Coastal Waters

What is the status and trends of this indicator?

A recent review of worldwide scientific literature concluded that hypoxic conditions in coastal waters – commonly referred to as "dead zones" – have spread exponentially since the 1960s and are now reported from more than 400 waterbodies (Diaz and Rosenberg, 2008). In nearly all instances, where new cases of hypoxia have been documented or where conditions have recently worsened, the putative cause is anthropogenic: excessive algal growth fueled by nutrient over-enrichment, municipal and industrial wastewater discharges, groundwater contamination, and altered ecosystem (e.g., introduction and proliferation of non-indigenous species). Climate-related changes in water stratification, nutrient delivery from coastal watersheds, agricultural and forestry practices, and coastal development may alter the patterns and severity of hypoxia in ways that are presently not known.

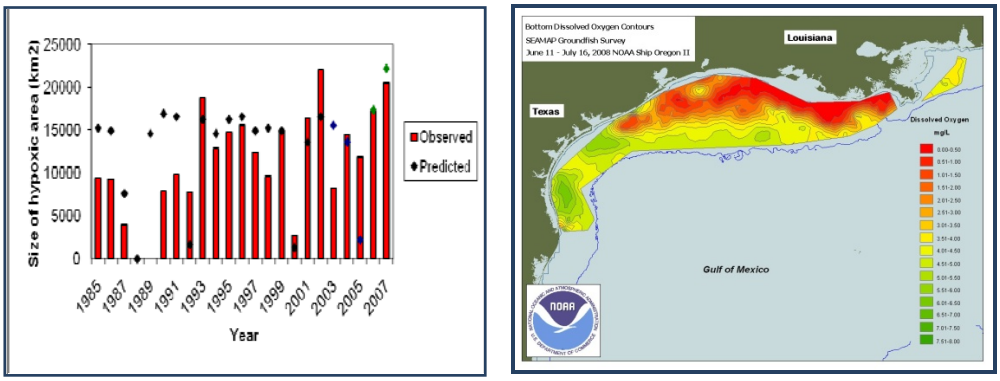

Figure 1: [left panel] Yearly estimates of the spatial extent hypoxia in northern Gulf of Mexico (black dots indicate historic hindcasts, blue and green dots indicate model-based forecasts); [right panel] Observed extent of the hypoxic zone, June-July 2008 data (sources: NOAA/CCMA; NOAA/NCDDC)

In the United States, large waterbodies showing persistent signs of hypoxia include the northern Gulf of Mexico and Chesapeake Bay, although hypoxic conditions are a matter of concern in many other waterbodies, for example, Long Island Sound, Narragansett Bay, Lake Erie, and Hood Canal (Puget Sound). In the northern Gulf of Mexico, the spatial extent of near-bottom hypoxic waters has ranged from 3,000 to 22,000 sq km during the period 1985 to 2007 (Figure 1, left panel). Although the hypoxic area is increasing over time there is considerable year to year variability, reflecting variations in nutrient flux, freshwater flow, and weather-related phenomena, including hurricanes (Turner, et al., 2008). The dissolved oxygen map in Figure 1 (right panel) is derived from NOAA's SEAMAP sampling that covers an extended period of time during summer; monitoring data from the Louisiana Universities Marine Consortium (LUMCON), obtained each year during late July, when the hypoxic zone is typically at its peak,

show a more intense phenomenon. In Chesapeake Bay, the data are reported on a water volume basis: hypoxic conditions over a 50-year period (1950-2001) have increased from 3.4 to 9.2 cubic km; for 2008, the hypoxia forecast was 9.9 cubic km, and the measured volume 8.6 cubic km (EcoCheck Project, 2009).

What is this indicator?

The NEST hypoxia indicator denotes waters having dissolved oxygen concentration of 2 mg/L or less. It is intended to document temporal change in hypoxia conditions in coastal waters, and consists of two distinct elements: (i) percent of the area of assessed estuaries and coastal bays where dissolved oxygen concentration falls below 2 mg/L as determined from periodic national surveys; and (ii) annual change in the size and severity of hypoxic zones in selected waterbodies with more comprehensive and long-term hypoxia records and where management actions for hypoxia control exist or will soon be implemented (examples include: Chesapeake Bay, northern Gulf of Mexico, Long Island Sound, Lake Erie, and Narragansett Bay). The selected waterbodies could be used as "index sites," i.e., sites for integrating focused research, watershed-to-bay monitoring, and process-based modeling capable of evaluating alternatives for managing hypoxia.

Oxygen depletion occurs in many waterbodies under conditions that affect water movement in both the vertical (stratification) and horizontal (flushing) directions, and where decomposition of an increased supply of organic matter and respiratory processes, both in the water column and on the sea bottom, consume dissolved oxygen in excess of its replenishment (largely at the air-sea interface and through photosynthesis in the surface layers). Several oxygen-deficit areas have been recognized for a long time, e.g., oxygen minimum zones in the northeast Pacific Ocean and the Arabian Sea, and in estuaries characterized by intense human use activities and retarded vertical mixing during summer, for example, the Baltic Sea, Black Sea, among several others. New ones are being reported in continental shelf water far away from human population centers (for example, off the New Jersey coast from Sandy Hook to Atlantic City (Glenn, et al., 2004), and along the Washington-Oregon coast (Grantham, et al., 2004). In these two instances the primary cause appears to be wind-induced and topographically steered upwelling, and the resulting high algal biomass, rather than riverine input or other localized nutrient sources.

The term "hypoxic waters" is defined operationally to denote waters with measured dissolved oxygen concentration of 2 mg/L or less. The threshold may have been based on the precision of off-the-shelf oxygen measuring devices, 0.2 mg/L (and therefore denoting anoxic conditions), and multiplying that value by 10. Hypoxic waters have been associated with reduced trawl catches of fish, crabs, and shrimp and other animals, such as sharks and rays, move out of the area at 3 mg/L. A wide variety of adverse biological effects, such as mortality, morbidity and reduced growth, have been documented at considerably higher oxygen concentrations than 2 mg/L, notably in oxygen-sensitive species and in larval forms.

In Europe, dissolved oxygen concentrations are typically expressed as ml/L and hypoxic waters are those with oxygen concentration of 2 ml/L (equivalent to 1.4 mg/L). The range of spatial coverage and intensity of hypoxia under this threshold would be quite different if applied to U.S. coastal waters.

Water quality standards for freshwater and marine waters, adopted and promulgated by coastal states, tribes, etc., far exceed 2 mg/L; they are generally in the vicinity of 5-6 mg/L. In some states, the water quality standard is based on a percent of oxygen saturation value under natural conditions, for example, not to decrease below 80 percent of oxygen saturation value. Note that colder water can hold more dissolved oxygen, freshwater can hold more oxygen than seawater, and there is more oxygen in water at sea-level than at high elevations. Thus oxygen saturation concentration in freshwater at 10 C at sea-level is about 11 mg/L, and in seawater of 25 parts per thousand salinity at the same temperature and location it is 9 mg/L. For the same waters, oxygen saturation concentration at 20 C will be about 9 and 7.5 mg/L respectively.

Quite often, water quality restoration targets – attained through sewage treatment upgrades, reductions in nonpoint source runoff, limitations on industrial waste streams and agricultural effluents, and effluent trading – are based on alleviating the occurrence, duration and intensity of hypoxia, i.e., 2 mg/L. Occasionally, the restoration target is set at 3.5 mg/L. In waterbodies that are naturally prone to oxygen depletion, higher restoration targets are considered cost prohibitive.

Why is this indictor important?

Oxygen depletion is the most readily recognized symptom of environmental degradation and its remediation evokes little controversy, particularly when there is agreement on the cause or causes. This is largely because humans are well aware of life-risks posed by oxygen deficit in blood, high altitude sickness, and asphyxiation. Understandably, there is always a strong public reaction to incidences of mass mortality (fish, krill, crabs and clams), loss of bivalve and coral reefs, economic impacts on commercial and sport fisheries, and degradation of ecosystem health. Several such events have been associated with chronic hypoxia or a combination of environmental factors that cause acute depletion of dissolved oxygen. Cumulative economic losses associated with hypoxic conditions could be in billions of dollars due to reduced commercial and recreational uses that include fishing and shellfish harvest, sightseeing and recreational use, swimming, boating and snorkeling, tourism, and real estate values. In waterbodies that supply drinking water to coastal communities, for example, Lake Erie, hypoxic conditions can impair direct water use (due to increased acidity and metal precipitation) and necessitate alternative water storage and treatment procedures. Clearly, hypoxic events and associated economic scenarios accentuate the need for developing comprehensive watershed and coastal management plans that focus on ways to alleviate oxygen depletion and involve both public and private sector financing amounting to billions of dollars over the long-term. Only in very few instances, exclusion of oxygen-sensitive predator species has resulted in population increase of oxygen-tolerant prey species under low-oxygen conditions, for example, increase in the commercially harvested quahog (clam) population in Narragansett Bay where hypoxic conditions now prevail (Altieri, 2008).

How is information on this indicator determined?

Periodic, nationwide assessment of dissolved oxygen are published by the U.S. Environmental Protection Agency, for example, as part of the interagency “coastal condition report” for the National Estuary Program (NEP). The assessment classifies waterbodies or portions thereof as having good (concentrations exceeding 5 mg/L), fair (concentrations between 2 and 5 mg/L), and

poor (concentrations less than 2 mg/L) conditions. Field sampling for this assessment offers a snapshot of conditions for a given time (typically on a summer day). The data are not necessarily representative of all conditions in the summertime and may even miss day-night variation in dissolved oxygen, which is often substantial during summer. Further, most of the 28 NEP estuaries are not located in areas where severe and recurring hypoxic conditions have historically occurred, and Chesapeake Bay is not among the NEP estuaries. Long-term monitoring records for dissolved oxygen are also available from NOAA National Estuarine Research Reserves, a network of 27 areas representing different coastal ecosystems.

In waterbodies with large recurring or newly formed hypoxic areas, NOAA's Coastal Hypoxia Research Program and state-supported programs have sponsored dissolved oxygen monitoring. A few such programs have evolved to include data from continuously recording sensors that provide excellent temporal resolution in data as well as new insights into the water movement and mixing processes that influence the size and persistence of hypoxic conditions. NOAA also sponsors studies for forecasting the size of the hypoxic zone in the northern Gulf of Mexico and the main stem of Chesapeake Bay. The primary input for these forecasts is nutrient flux data from the U.S. Geological Survey's stream gauge network. Annual forecasts are verified by field monitoring programs.

What is the source(s) of information on this indicator?

A summary of the status of hypoxia in U.S. coastal waters, current level of scientific understanding, and measures for controlling or mitigating its effects has recently been produced by the Joint Subcommittee on Ocean Science and Technology (draft dated May 2009). The report is required under provisions of the Harmful Algal Bloom and Hypoxia Research and Control Act. Other principal sources of information on this indicator are from NOAA's Coastal Hypoxia Research Program, the National Coastal Data Development Center, the National Oceanographic Data Center, and the Center for Coastal Monitoring and Assessment. U.S. EPA data are summarized as major published reports: National Coastal Condition Report III (2008), and National Estuary Program Coastal Condition Report (2007). Nearly every state or tribe involved in water quality-based monitoring has relevant data that may be available in digital form.

Related links to more information on this indicator

http://www.cop.noaa.gov/stressors/pollution/current/chrp.html
http://www.epa.gov/owow/oceans/nccr/
http://www.eco-check.org
http://ccma.nos.noaa.gov/ecoforecasting/welcome.html
http://www.epa.gov/med/grosseile_site.gom.html
http://ecowatch.ncddc.noaa.gov/hypoxia/products
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