Hypoxia in Gulf of Mexico and Long Island Sound

Nutrient pollution is one of the most pervasive problems facing U.S. coastal waters, with more than half of the nation's estuaries experiencing one or more symptoms of eutrophication (Bricker et al., 2007; CENR, 2010; NRC, 2000; U.S. Commission on Ocean Policy, 2004). One symptom is low levels of dissolved oxygen (DO), or hypoxia. Hypoxia can occur naturally, particularly in areas where natural physical and chemical characteristics (e.g., salinity or mixing parameters) limit bottom-water DO. The occurrence of hypoxia in shallow coastal and estuarine areas is increasing, however, and is most likely accelerated by human activities (Breitburg et al., 2018; Díaz and Rosenberg, 2008; Rabalais et al., 2010).

This indicator tracks trends in hypoxia in the Gulf of Mexico and Long Island Sound, which are prime examples of coastal areas experiencing hypoxia. For consistency, this indicator focuses on occurrences of DO below 2 milligrams per liter (mg/L), but actual thresholds for "hypoxia" and associated effects can vary over time and space, depending on water temperature and salinity. Effects of hypoxia on aquatic life also vary, as some organisms are more sensitive to low DO than others. As a general rule, however, concentrations of DO above 5 mg/L are considered supportive of marine life, while concentrations below this are potentially harmful. At about 3 mg/L, bottom fishes may start to leave the area, and the growth of sensitive species such as crab larvae is reduced. At 2.5 mg/L, the larvae of less sensitive species of crustaceans may start to die, and the growth of crab species is more severely limited. Below 2 mg/L, some juvenile fish and crustaceans that cannot leave the area may die, and below 1 mg/L, fish totally avoid the area or begin to die in large numbers (Howell and Simpson, 1994; U.S. EPA, 2000; Vaquer-Sunyer and Duarte, 2008).

The Gulf of Mexico hypoxic zone on the Louisiana-Texas shelf is the second-largest zone of human-caused coastal hypoxia in the world (LUMCON, 2022). It exhibits seasonally low oxygen levels as a result of complex interactions involving excess nutrients carried to the Gulf by the Mississippi and Atchafalaya Rivers; physical changes in the river basin, such as channeling, construction of dams and levees, and loss of natural wetlands and riparian vegetation; and the stratification in the waters of the northern Gulf caused by the interaction of fresh river water and the salt water of the Gulf and thermal warming of upper water column waters (CENR, 2000, 2010; Rabalais and Turner, 2001; U.S. EPA, 2007). Increased nitrogen and phosphorus inputs from human activities throughout the basin support an overabundance of algae, which die and fall to the sea floor. Microbes deplete oxygen in the water as sinking organic matter in the form of algae and fecal pellets decomposes. Fresh water from the rivers entering the Gulf of Mexico forms a layer of fresh water above the saltier Gulf waters and prevents re-oxygenation of oxygen-depleted water along the bottom. Thermal warming of the water column in summer strengthens the density difference that prevents re-oxygenation. Variations in the amount of precipitation falling in the Mississippi River Basin and in concentrations of nitrogen can lead to large differences in the size of the hypoxic zone in the Gulf from one year to the next.

In Long Island Sound, seasonally low levels of oxygen usually occur in bottom waters from mid-July through September, and are more severe in the western portions of the Sound, where the nitrogen load is higher and stratification is stronger, reducing mixing and re-oxygenation processes (CENR, 2010; Welsh and Eller, 1991). While nitrogen fuels the growth of microscopic plants that leads to low levels of oxygen in the Sound, temperature, wind, rainfall, and salinity can affect the intensity and duration of hypoxia.

Data for the two water bodies are presented separately because they are collected through two different sampling programs, each with its own aims and technical approach. The Gulf of Mexico survey is conducted by the Louisiana Universities Marine Consortium (LUMCON) and is designed to measure the extent of bottom-water hypoxia in the summer, with samples collected during a cruise that generally occurs over a period of 5 to 7 days in mid- to late July (LUMCON, 2022). Samples are collected day and night along several transects designed to capture the overall extent of the hypoxic zone. The number of locations varies from 60 to 90 per year, depending on the length of the sampling cruise, the size of the hypoxic zone, logistical constraints, and the density of station locations. Long Island Sound sampling is conducted by the Connecticut Department of Energy and Environmental Protection's Long Island Sound Water Quality Monitoring Program, and is designed to determine both the maximum extent and the duration of hypoxia (Connecticut DEEP, 2022). Sampling is performed every month from October to May and every 2 weeks from June to September at a set of fixed locations throughout the Sound. All Long Island Sound samples are collected during the day.

What the Data Show

The size of the midsummer bottom-water hypoxia area (<2 mg/L DO) in the Northern Gulf of Mexico has varied considerably since 1985, ranging from 15 square miles in 1988 (a drought year in the Mississippi Basin in summer) to approximately 8,800 square miles in 2017 (Exhibit 1). The hypoxic zone has fluctuated considerably in the last five years (Exhibit 2). Over the full period of record (1985-2021), the area with DO less than 2 mg/L has averaged approximately 5,300 square miles. Variability can be explained by disruption by tropical storms, shifts in winds and currents, and freshwater inflow, but the variable that best explains the summer size is the nitrate load from the Mississippi River in May (Turner et al., 2012).

The maximum extent and duration of hypoxic events (<2 mg/L DO) in Long Island Sound also has varied considerably since the 1980s (Exhibits 3 and 4, respectively). Between 1987 and 2022, the average annual maximum extent was 52 square miles and the average annual maximum duration was 28 days. The largest hypoxic area was 212 square miles, which occurred in 1994 (Exhibit 3). The longest hypoxic event was 71 days in 1989 (Exhibit 4). In 2022, the hypoxic area was 53 square miles, with the lowest DO levels primarily occurring in the western end of the Sound (Exhibit 5).

Limitations

Gulf of Mexico:

- This indicator is based on a survey conducted over a 5- to 7-day period when hypoxia is expected to be at its maximal extent. Analyses indicate that the month of July is when the bottom-water areal extent of low oxygen is the greatest. The indicator does not capture periods of hypoxia or anoxia (no oxygen at all) occurring at times other than the mid-summer surveys. But, other data from frequently occupied transects off Terrebonne Bay and the Atchafalaya River show differences over time in hypoxia occurrence.
- Because the extent of hypoxia is measured through a single mid-summer sampling cruise, duration cannot be estimated. Other data from a real-time observing system can provide duration data but not over the large area where hypoxia occurs. For example, shorter monthly or bimonthly sampling cruises from 1985 to 2012 provided data on the temporal extent of hypoxia near Terrebonne and Atchafalaya Bays (not shown here; see www.gulfhypoxia.net).
- The survey design is intended to map as much of the low-oxygen area in as short a time as possible, using methods that are as consistent as possible over time, but limitations in ship time or other logistical constraints may prevent complete mapping. Some analyses have attempted to adjust for differences in survey coverage and account for the use of different sampling instruments, capable of being lowered to within different proximities of the sea floor, in different years. After making these adjustments, Obenour et al. (2013) determined that increases in hypoxic layer thickness from 1985 to 2011 were statistically significant, but increases in volume and area were not significant. However, palaeoindicators in accumulated sediments indicate that low oxygen in bottom waters was not present historically on this shelf (Rabalais et al., 2007).

Long Island Sound:

- Hypoxic or anoxic periods that may occur between the 2-week surveys are not captured in the indicator.
- Samples are taken in the daytime, approximately 1 meter off the bottom. This indicator does not capture oxygen conditions at night (which may be lower because of the lack of photosynthesis) or conditions near the sediment-water interface.

Data Sources

Maps and summary data from the 2006 to 2021 Gulf of Mexico surveys are published online (LUMCON, 2022). Data from prior years were provided by LUMCON (2007). Cruise data from all years are submitted to NOAA's National Center for Environmental Information.

Data on the extent and duration of hypoxia in Long Island Sound are published online in survey summaries and on the University of Connecticut's Long Island Sound Integrated Coastal Observing System website at http://lisicos.uconn.edu/dep_portal.php. Data were compiled by EPA's Long Island Sound Office (U.S. EPA, 2022). Concentration maps are also available online (Connecticut DEEP, 2022).

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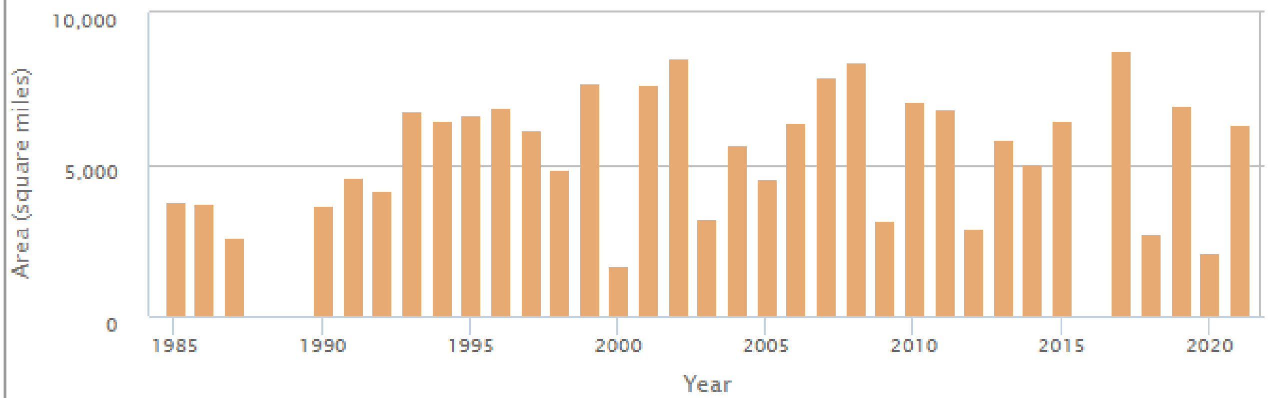
Exhibit 1. Extent of bottom-water dissolved oxygen less than 2.0 mg/L in the Gulf of Mexico in mid-summer, 1985-2021

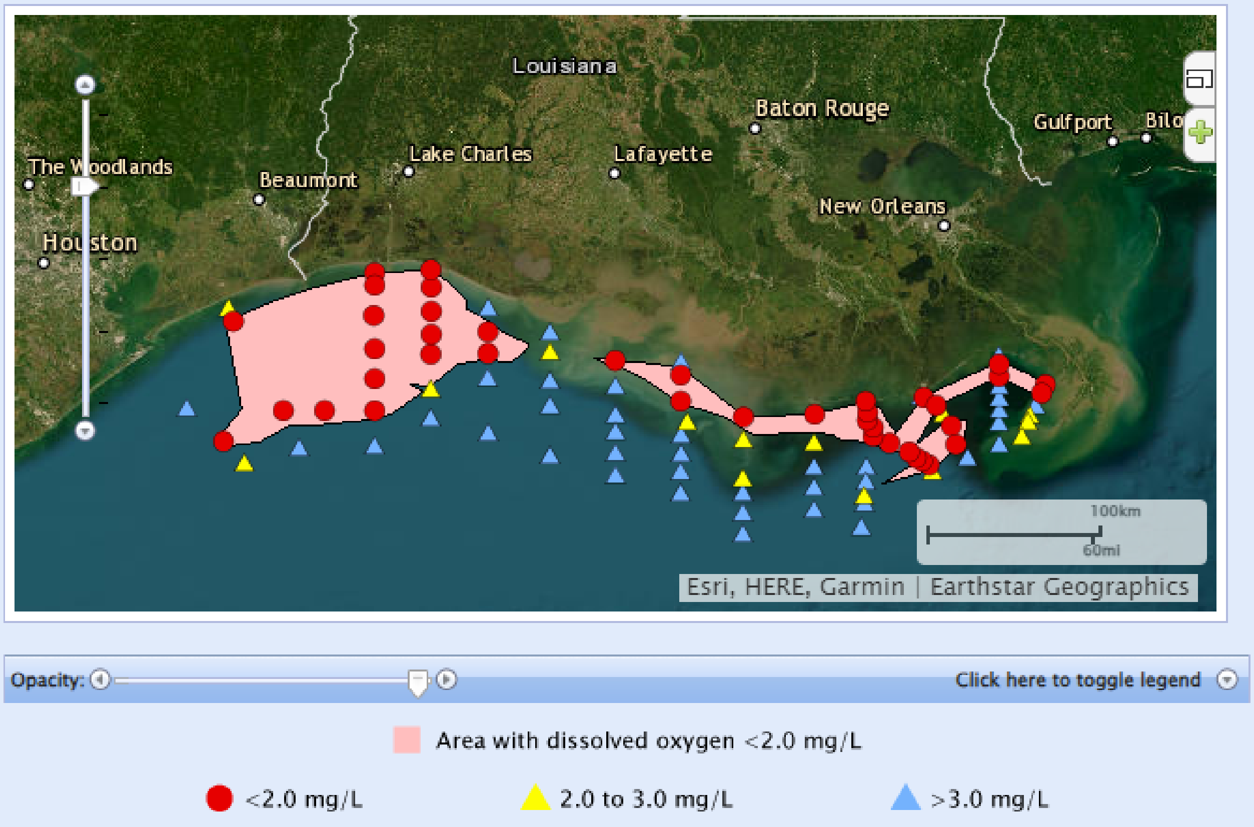


Only 15 square miles were affected in 1988. No data were collected in 1989 and 2016.

When the measurements shown here are adjusted for year-to-year differences in the instruments used and the area samples, analysis shows that the trend is not statistically significant. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: LUMCON, 2021

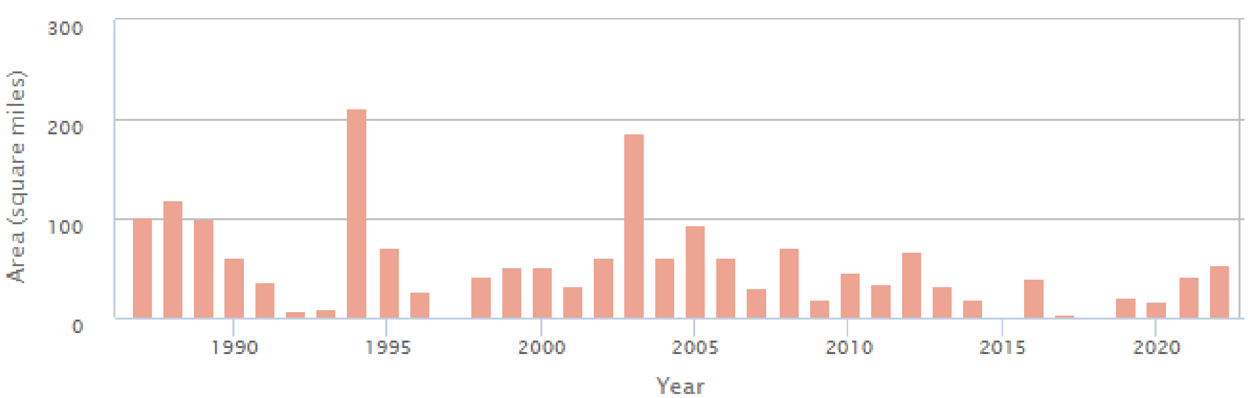
Exhibit 2. Dissolved oxygen less than 2.0 mg/L in Gulf of Mexico bottom waters, July 25–31, 2021



Trend analysis has not been conducted because these data represent a single snapshot in time. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: LUMCON, 2021

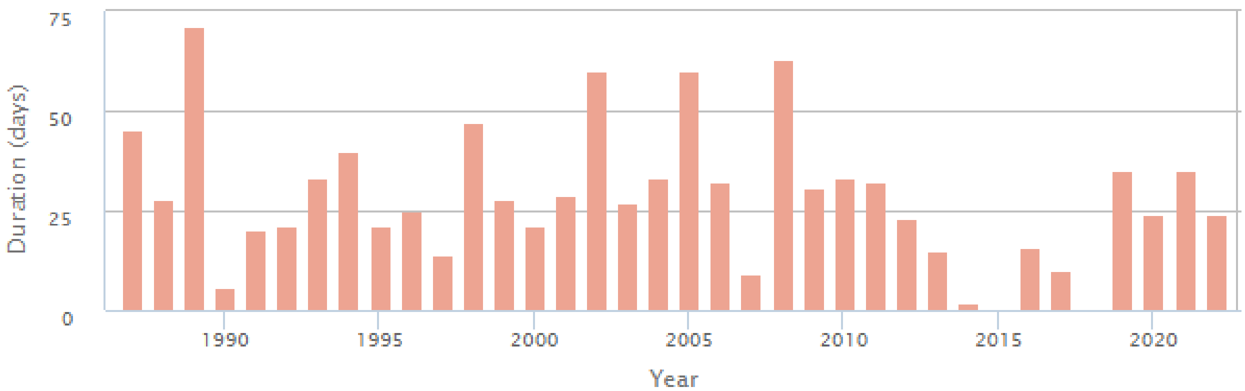
Exhibit 3. Maximum extent of dissolved oxygen less than 2.0 mg/L in Long Island Sound bottom waters, 1987–2022



Statistical analysis suggests a downward trend of -2.0 square miles per year in hypoxic zone extent, which is statistically significant to a 95 percent level (p= 0.035). For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: Connecticut DEEP, 2022

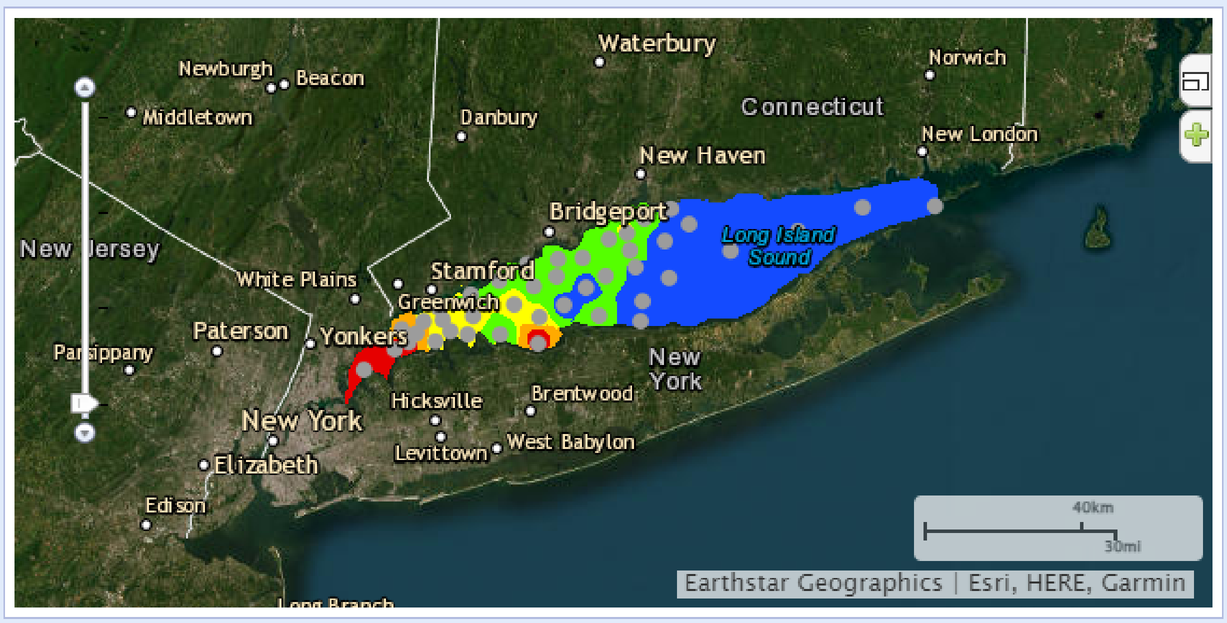
Exhibit 4. Duration of dissolved oxygen less than 2.0 mg/L in Long Island Sound bottom waters, 1987–2022



Statistical analysis suggests a downward trend of -0.7 days per year in hypoxic zone duration, which is statistically significant to a 95 percent level (p= 0.045). For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: Connecticut DEEP, 2022

Exhibit 5. Dissolved oxygen in Long Island Sound bottom waters, August 1–3, 2022



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Sampling Location

Dissolved oxygen:

1.0 to <2.0 mg/L 2.0 to <3.0 mg/L 3.0 to <3.5 mg/L 3.5 to <4.8 mg/L >= 4.8 mg/L

Trend analysis has not been conducted because these data represent a single snapshot in time. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: Connecticut DEEP, 2022