

BREATH OF LIFE

DISSOLVED OXYGEN IN CHESAPEAKE BAY

This newsletter describes why dissolved oxygen is an important indicator of ecosystem health. It focuses on dissolved oxygen in Chesapeake Bay and its tributaries and describes the factors that affect dissolved oxygen. Additionally, the management decisions and actions that are being taken to reduce the amount of low dissolved oxygen in the Bay are described.

ESSENTIAL FOR ALL ANIMAL LIFE IN CHESAPEAKE BAY

All animal life in Chesapeake Bay, from the worms that inhabit its muddy bottom, to the fish and crabs found in its rivers, to the people that live on its land, need oxygen to survive. We breathe oxygen, which lets us extract energy from the food we eat. Our bodies use this energy to function. This process is essentially the same in all species with one major difference: worms, fish, and crabs use some form of gills instead of lungs to extract oxygen from the water. As water moves across the gills, dissolved oxygen is removed from the water and passed into the blood. As dissolved oxygen concentrations in water decrease, the animals that inhabit the Bay struggle to extract the oxygen they need to survive.

Chesapeake Bay scientists generally agree that dissolved oxygen concentrations of 5.0 mg l^{-1} (milligrams of oxygen per liter of water) or greater will allow the Bay's aquatic creatures to thrive. However, the amount of dissolved oxygen needed before organisms become stressed varies from species to species. Although some are more tolerant of low dissolved oxygen than others, in some parts of the Bay dissolved oxygen can fall to the point where no animals can survive. When the levels drop below 2.0 mg l^{-1} , the water is hypoxic, and when it drops below 0.2 mg l^{-1} the water is considered anoxic (Figure 1).

In an estuary such as Chesapeake Bay, there are several sources of dissolved oxygen. The most important is the atmosphere. At sea level, air contains about 21% oxygen, while the Bay's waters contain only a small fraction of a percent. This large difference between the amount of oxygen results in oxygen naturally dissolving into the water. This process is further enhanced by the wind, which mixes the surface of the water. Two other important sources of oxygen in the water are phytoplankton and aquatic grasses. Phytoplankton are single-celled algae and aquatic grasses are vascular plants; both produce oxygen during photosynthesis. Another source of dissolved oxygen in the Bay comes from water flowing into the estuary from streams, rivers, and the Atlantic Ocean.

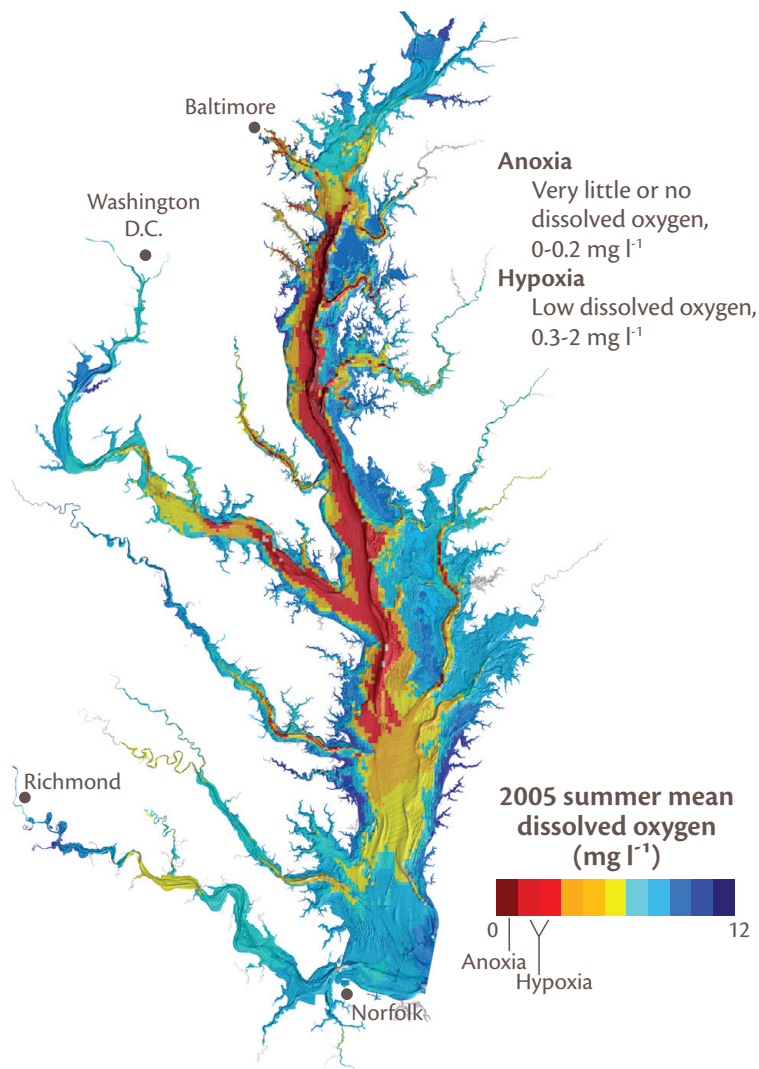


Figure 1: This map of bottom dissolved oxygen illustrates areas that are off limits to Bay organisms due to low dissolved oxygen.

Less tolerant ← → More tolerant



These organisms tolerate different levels of dissolved oxygen in the water, but not all can move to a different location when dissolved oxygen levels are too low. From left to right: striped bass, hard clams, blue crab, spot, and bristleworm. (Photo credits: NOAA Photo Library, D. Wilson, www.jaxshells.org, USGS, URI)

EXCESS NUTRIENTS AN IMPORTANT CAUSE OF LOW DISSOLVED OXYGEN

Low summer-time dissolved oxygen in the Bay mainstem is related to the quantity of water flowing out of the Susquehanna River during the preceding spring. The freshwater flowing out of the Susquehanna floats on top of the heavier seawater flowing in from the ocean. An actual boundary forms where the lighter water on the surface meets the heavier water below. This boundary is called the pycnocline and it can prevent dissolved oxygen from reaching the deeper waters of the Bay (Figure 2).



Organisms crowd into shallow waters to escape low dissolved oxygen. Note the flounder and rays. Location: Mobile Bay, AL. NOAA

Spring flow is also important as a source of nutrients to the Bay. The large blooms of phytoplankton (microalgae) that are generated from excess nutrients overwhelm the filter feeders that eat them. When the extra algae die, a large quantity of them settle below the pycnocline. There, they are decomposed by bacteria, a process which consumes dissolved oxygen (Figure 2). We can express the quantity of nutrients entering the Bay each spring as a nutrient index. The mean anoxic volume each summer is directly related to this index (Figure 3). As summer begins, water temperatures increase, which enhances decomposition and the subsequent oxygen loss. The pycnocline keeps the oxygen rich surface waters from mixing with the now oxygen depleted deeper waters

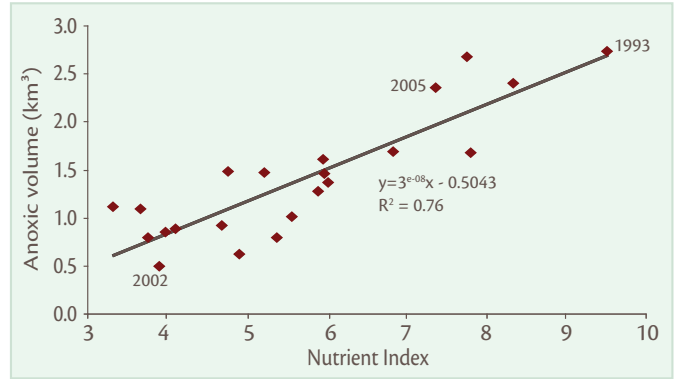


Figure 3: Low dissolved oxygen in the summer is directly related to the amount of nutrients that enter the Bay in the spring.

(Figure 2). This situation will persist until the pycnocline is disrupted, usually by strong winds associated with storms, or by cooling of surface waters during the fall.

The persistent anoxia that the Chesapeake Bay Program monitors and quantifies each summer is a different phenomenon than the low oxygen events that occasionally trigger fish kills in the smaller creeks and embayments of the Bay. Like the persistent anoxic zone, these events are triggered by phytoplankton, but on shorter time scales and with a slightly different chain of events. These events generally occur just before or at dawn when phytoplankton oxygen production is at its lowest. As a result, water column concentrations of dissolved oxygen are low enough to stress or kill the local fish population.

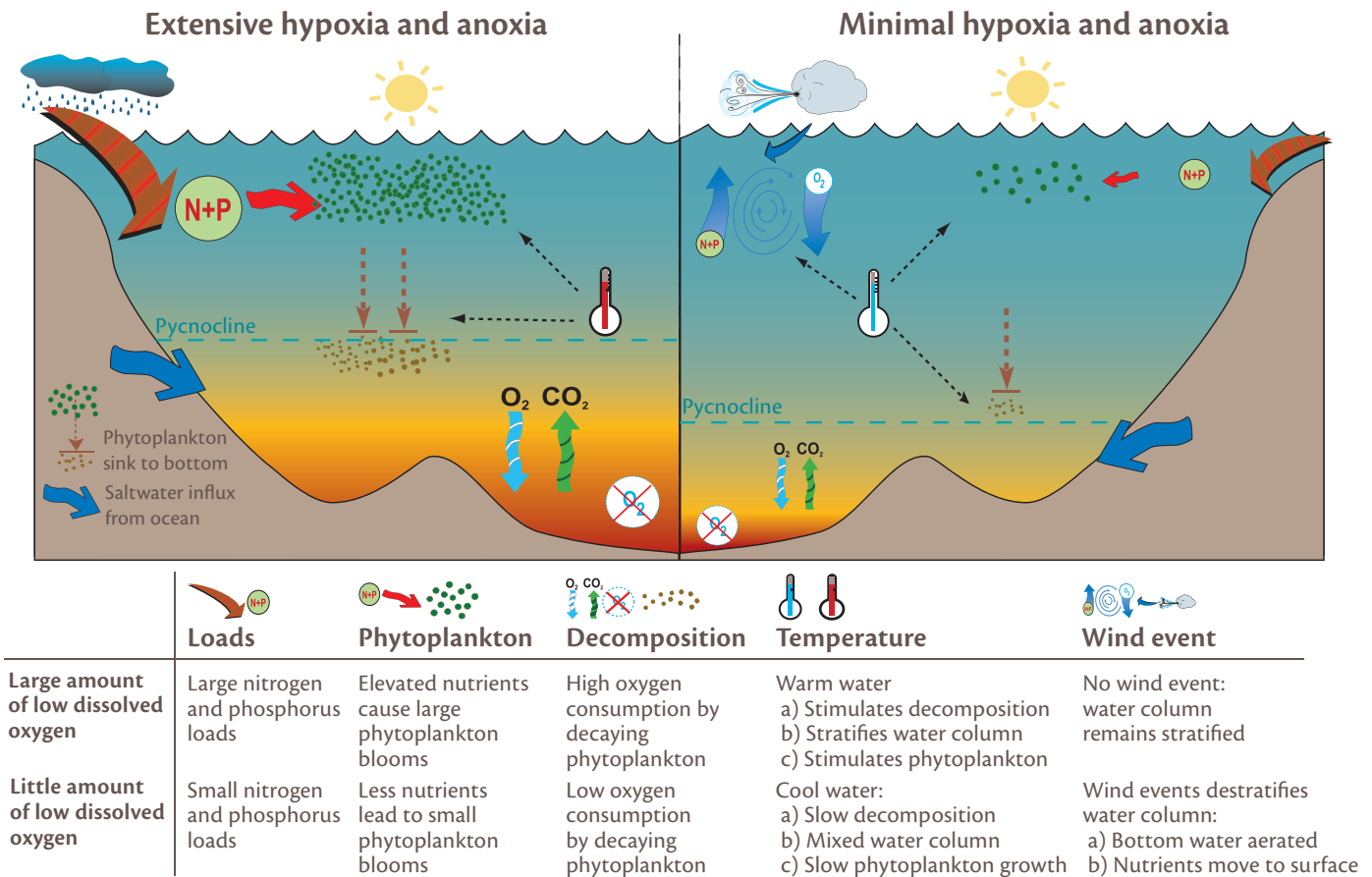


Figure 2: This conceptual diagram illustrates the factors that affect dissolved oxygen in Chesapeake Bay.

HISTORY OF LOW DISSOLVED OXYGEN IN CHESAPEAKE BAY

The temporal patterns of hypoxia and anoxia are tightly linked, with both typically occurring in the mainstem of the Bay starting in May (Figure 4). Conditions continue to worsen through the summer with peak anoxia and hypoxia occurring in July or August. Water temperatures are highest during these months, which accelerates the processes that consume dissolved oxygen. Anoxia is typically gone by October and hypoxia by November. Cooler air temperatures at this time of year chill the surface waters, while the deeper water remains warm. Cooler water is heavier, making it more likely that wind associated with a storm will cause this cold water to sink and disrupt the pycnocline.

Low dissolved oxygen linked to temperature

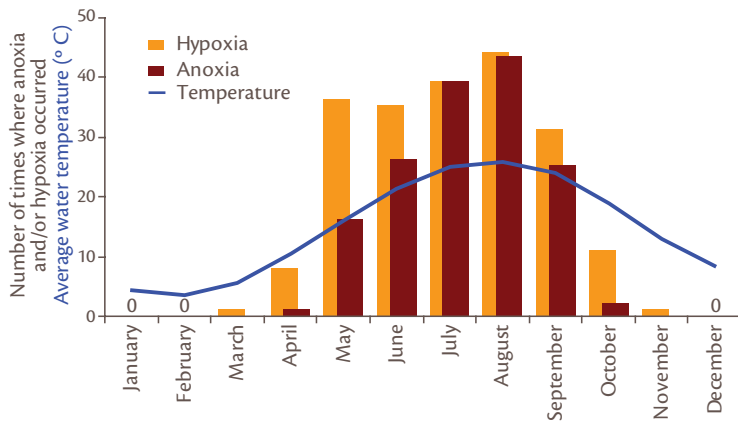


Figure 4: Occurrences of hypoxia and anoxia are higher in the summer months than the winter months because oxygen-consuming processes increase with temperature. Data from 1985–2005.

The volume of anoxic and hypoxic water in the mainstem is variable from month to month during the summer, with historical anoxic volumes ranging from 0.0 to 7.2 km³ (Figure 5). Typically, the largest volumes occur in years with the highest spring flows. For instance, 1993 had the largest cumulative spring flow of the past 22 years and the largest average summer anoxic volume. The summer of 1993 was the worst on record with an average of 5.2% of the mainstem becoming anoxic. Conversely, 2002 was a drought year and also had the smallest average volume of anoxia. Although the amount of anoxia is primarily controlled by spring flow, there is evidence that wind, on short time scales, can help mix oxygen into deeper waters.

Rapid population growth in the Bay watershed after World War II, coupled with widespread use of man-made fertilizers, led to increases in nutrient inputs to the Bay and subsequent increases in anoxia and hypoxia. However, there is evidence that hypoxia occurred



Dissolved oxygen is measured with oxygen sensors.

Range and average hypoxia and anoxia

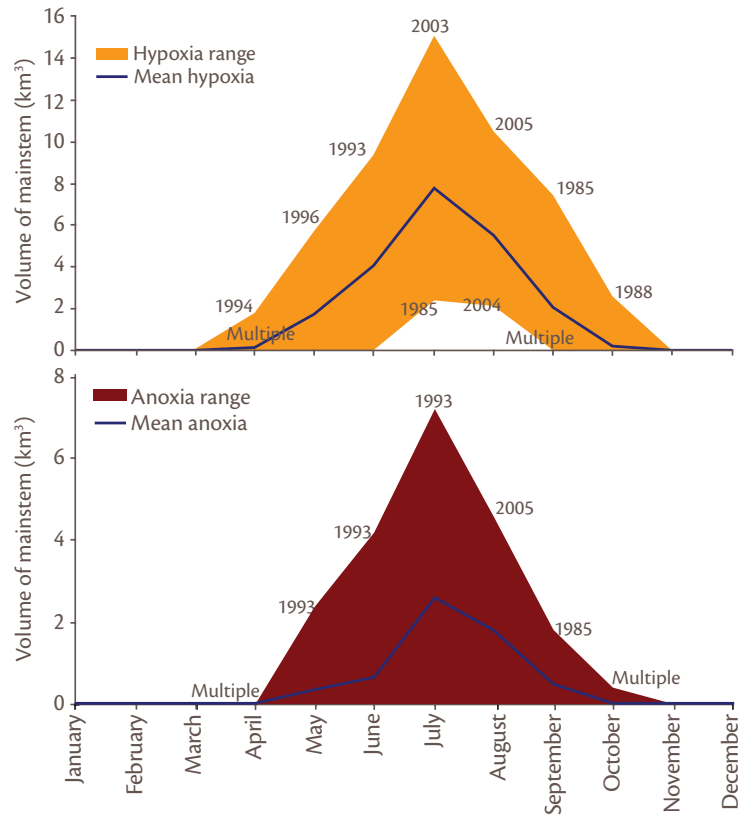


Figure 5: The range of and average hypoxic and anoxic volume in the mainstem of Chesapeake Bay, 1985–2005.

occasionally from 1700–1900, possibly due to the nutrients associated with sediment runoff from agricultural land clearing (Kemp et al. 2005). In recent years, there has been no apparent trend in hypoxia or anoxia, with changes year to year controlled primarily by spring flow (Figure 6). Recent analysis suggest that the Bay is more susceptible to the oxygen-depleting effects of nutrient loading in recent years than it was in the 1950's and 1960's (Hagy et al. 2004). This may be due to the loss of buffering capabilities by filter feeders and aquatic grasses.

Mainstem low dissolved oxygen over the past 20 years

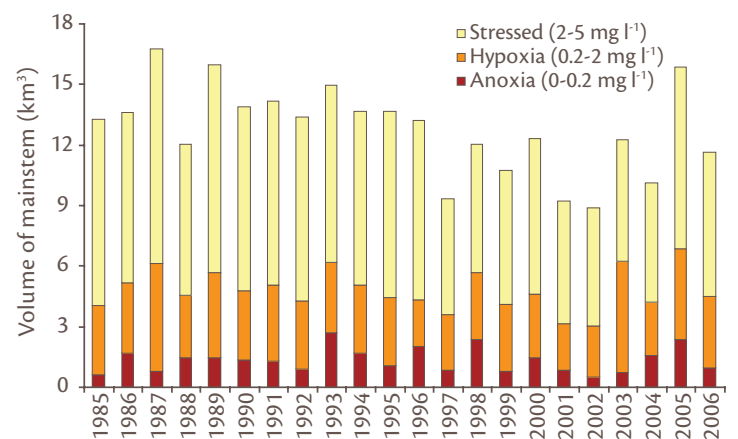


Figure 6: The amount of hypoxia and anoxia over the past 21 years illustrates that conditions have not improved overall. Data from June–September.

LOW DISSOLVED OXYGEN ADDS TO HABITAT SQUEEZE

In the summertime, the waters of Chesapeake Bay heat up, algae blooms increase, and dissolved oxygen decreases. The temperature increase is most pronounced in the surface waters, while dissolved oxygen depletion is most pronounced in deeper waters. This results in a habitat squeeze for many species, where surface waters are too hot and deep water dissolved oxygen levels are too low (Figure 7). For instance, striped bass require water temperatures $<25^{\circ}\text{C}$ and dissolved oxygen of $>3.0\text{ mg l}^{-1}$. These fish are confined to the middle depths of the Bay during the summer. The potential consequences of a habitat squeeze include increased mortality and disease, and decreased habitat capacity. Reducing nutrients into the Bay will help improve dissolved oxygen and lessen the impacts of habitat squeezes on Bay organisms.

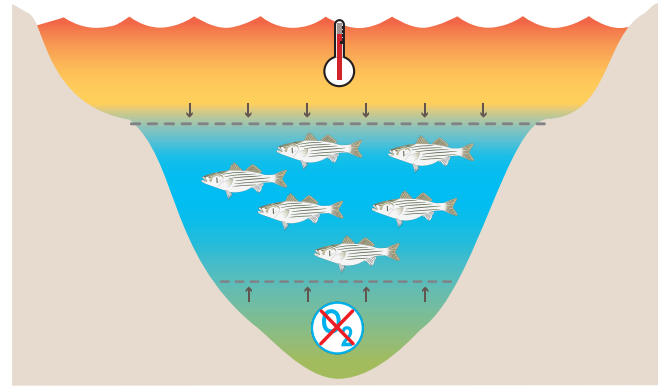


Figure 7: High surface temperatures and low dissolved oxygen levels in deep waters lead to a striped bass habitat squeeze.

REDUCE NUTRIENTS FOR BETTER DISSOLVED OXYGEN

Targeted management strategies

1. Agriculture best management practices (nonpoint sources)
 - Cover crops retain nutrients and sediment in the winter.
 - Conservation tillage reduces sediment disturbance.
 - Nutrient management plans ensure proper fertilization and waste handling.
 - Riparian buffers filter nutrients running off land.
2. Urban nutrient management
 - Enhanced nutrient removal (wastewater treatment plants) decreases nutrient effluent.
 - Low-impact development practices reduce nutrient and sediment loads to the Bay.
 - Good development and infiltration practices reduce volume and increase quality of stormwater runoff.
 - Septic system upgrades reduce nutrients entering waterway via groundwater.
3. Airshed (nonpoint source)
 - Federal Clean Air Act regulates all air pollutants, including car emissions and smokestacks, but many parts are implemented and enforced by the states.
4. Wetland restoration helps filter nutrients and sediments out of the water.



B. Longstaff

Cover crops stop excess sediments from running into the Bay during the winter.

Reducing your nutrient input to the Bay is critical!

1. Reduce pollution
 - Reduce amount of driving by carpooling and cutting down your commute (Figure 8).
 - Buy a low emissions, efficient automobile.
 - Reduce or stop fertilizing your lawn. If you must fertilize, only do it when sunny and dry, preferably in autumn.
2. Encourage local and state legislators to enact stricter nutrient reduction laws for all industry and agriculture.
3. Conserve energy by using energy efficient light bulbs and turn off lights when not in use; purchase energy-efficient home appliances.
4. Pick up after your pet.
5. Use low impact landscaping practices.

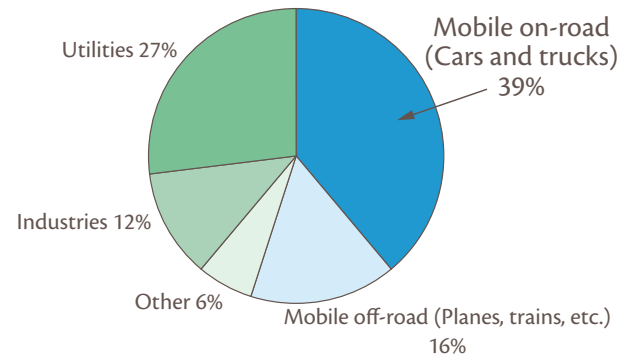


Figure 8: Relative percent contribution of nitrogen oxide (NO_x) emission sources in the Chesapeake Bay Airshed.

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Further information located at:

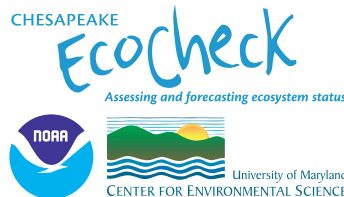
<http://www.chesapeakebay.net/bayforecastspring2006.htm>
www.eco-check.org

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- Chesapeake Bay Program

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References:

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R. Dennis and M. Kerschner, States included: MD, VA, PA, NY, WV, NJ, OH, KY, NC, SC, TN, IN, MI, DE.