SCIENCE FOCUS: DEAD ZONES

Creeping Dead Zones

This is not the title of a sequel to a Stephen King novel. "Dead zones" in this context are areas where the bottom water (the water at the sea floor) is *anoxic* — meaning that it has very low (or completely zero) concentrations of dissolved oxygen. These dead zones are occurring in many areas along the coasts of major continents, and they are spreading over larger areas of the sea floor. Because very few organisms can tolerate the lack of oxygen in these areas, they can destroy the habitat in which numerous organisms make their home.

The cause of anoxic bottom waters is fairly simple: the organic matter produced by phytoplankton at the surface of the ocean (in the *euphotic zone*) sinks to the bottom (the *benthic zone*), where it is subject to breakdown by the action of bacteria, a process known as bacterial respiration. The problem is, while phytoplankton use carbon dioxide and produce oxygen during photosynthesis, bacteria use oxygen and give off carbon dioxide during respiration. The oxygen used by bacteria is the oxygen dissolved in the water, and that's the same oxygen that all of the other oxygen-respiring animals on the bottom (crabs, clams, shrimp, and a host of mud-loving creatures) and swimming in the water (zooplankton, fish) require for life to continue.

The "creeping dead zones" are areas in the ocean where it appears that phytoplankton productivity has been enhanced, or natural water flow has been restricted, leading to increasing bottom water anoxia. If phytoplankton productivity is enhanced, more organic matter is produced, more organic matter sinks to the bottom and is respired by bacteria, and thus more oxygen is consumed. If water flow is restricted, the natural refreshing flow of oxic waters (water with normal dissolved oxygen concentrations) is reduced, so that the remaining oxygen is depleted faster.

Many of the areas where increasing bottom water anoxia has recently been observed are near the mouths of major river systems. While the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) couldn’tsee the bottom of the ocean, it could see the surface, where sediments from rivers mix with ocean waters. The images shown here are SeaWiFS observations of the Mississippi River delta, the Yangtze River mouth in China (which is not currently identified as an area with an associated dead zone, but such conditions could develop there in the future), and the Pearl River mouth in China, near Hong Kong.

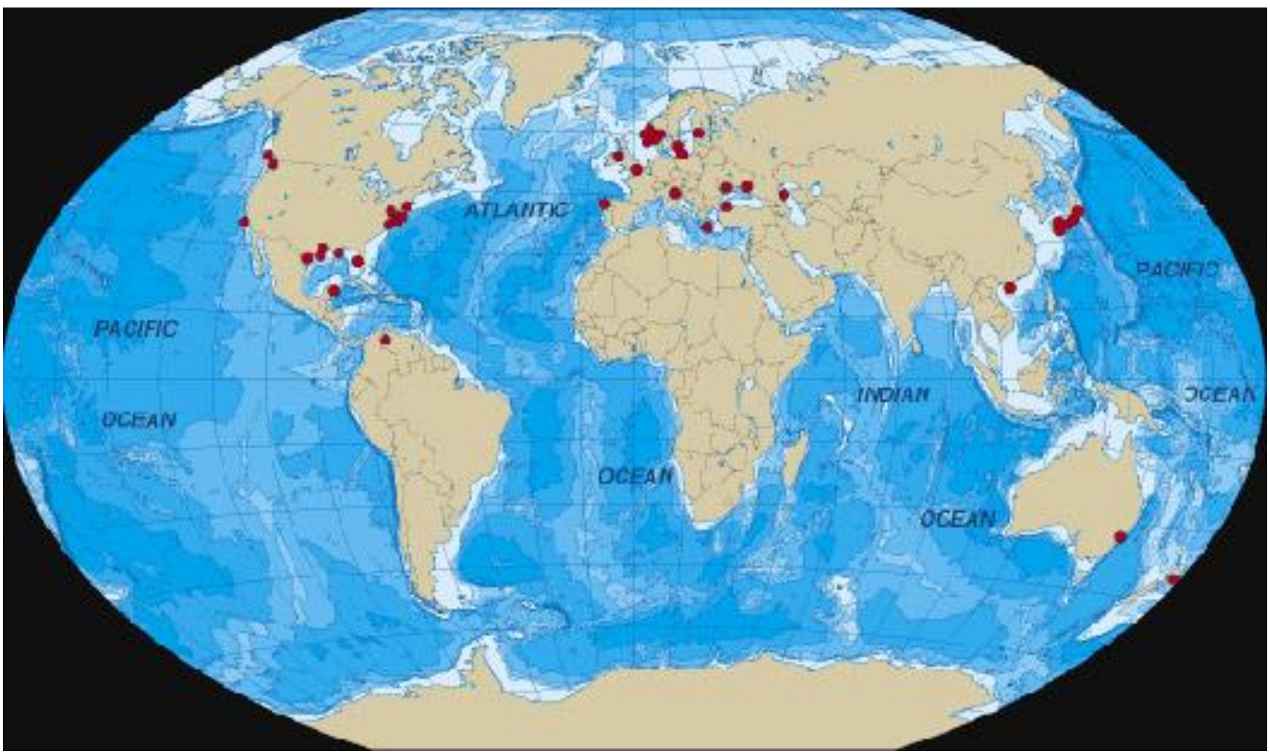
SeaWiFS can also observe areas where water flow is restricted, such as the Baltic Sea in Europe. The image on the left features Denmark after strong storms caused flooding and increased sediment suspension in the Baltic. On the right is an overview of the Baltic Sea, including a plankton bloom in the Skagerrak just north of Denmark.

The apparent cause of the creeping dead zones is agriculture, specifically fertilizer. While fertilizer is necessary to foster bumper agricultural crops, it also runs off the fields into the streams and rivers of a watershed. When the fertilizer reaches the ocean, it just becomes more nutrients for the phytoplankton, so they do what they do best: they grow and multiply. Which leads to more organic matter reaching the bottom, more bacterial respiration, and more anoxic bottom water.

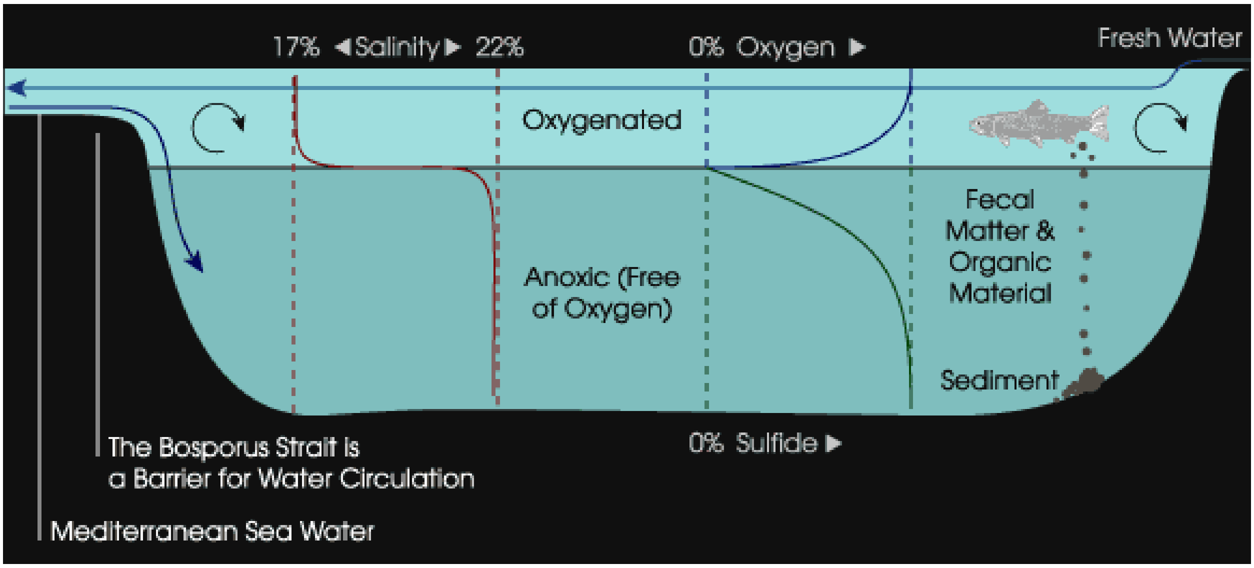
These effects can be magnified by catastrophe. When the heavy rains of Hurricane Floyd caused extensive flooding in North Carolina in September 1999, the heavy load of nutrients (from dead animals, flooded animal waste ponds, and numerous other sources) reached the sounds that lie between the coast and the Outer Banks, oxygen levels in the water plummeted. The picture at the top of the page shows the heavy load of sediments flowing into Pamlico Sound. SeaWiFS captured a remarkable image on September 23, 1999, when the sediment-laden water was carried into the Gulf Stream. In this image, note the turbidity in the sounds and the deep brown color at the river mouths. In some areas of the Neuse River, the water actually turned red.

In Europe, the flow of water into and out of the Baltic Sea is naturally restricted by the islands and narrow channels around Denmark. Thus, any increase in nutrients which augments biological productivity can be a problem — and that's what is being observed in the Baltic. The situation at the mouths of major rivers is similar: the area covered by anoxic bottom water appears to be increasing every year.

Dr. Robert Diaz of the Virginia Institute of Marine Science (VIMS) created a map of dead zones throughout the world (a version of this map also appeared in the March 2000 issue of *Discover* magazine). Diaz estimated then that the number of such sites would double within a decade.

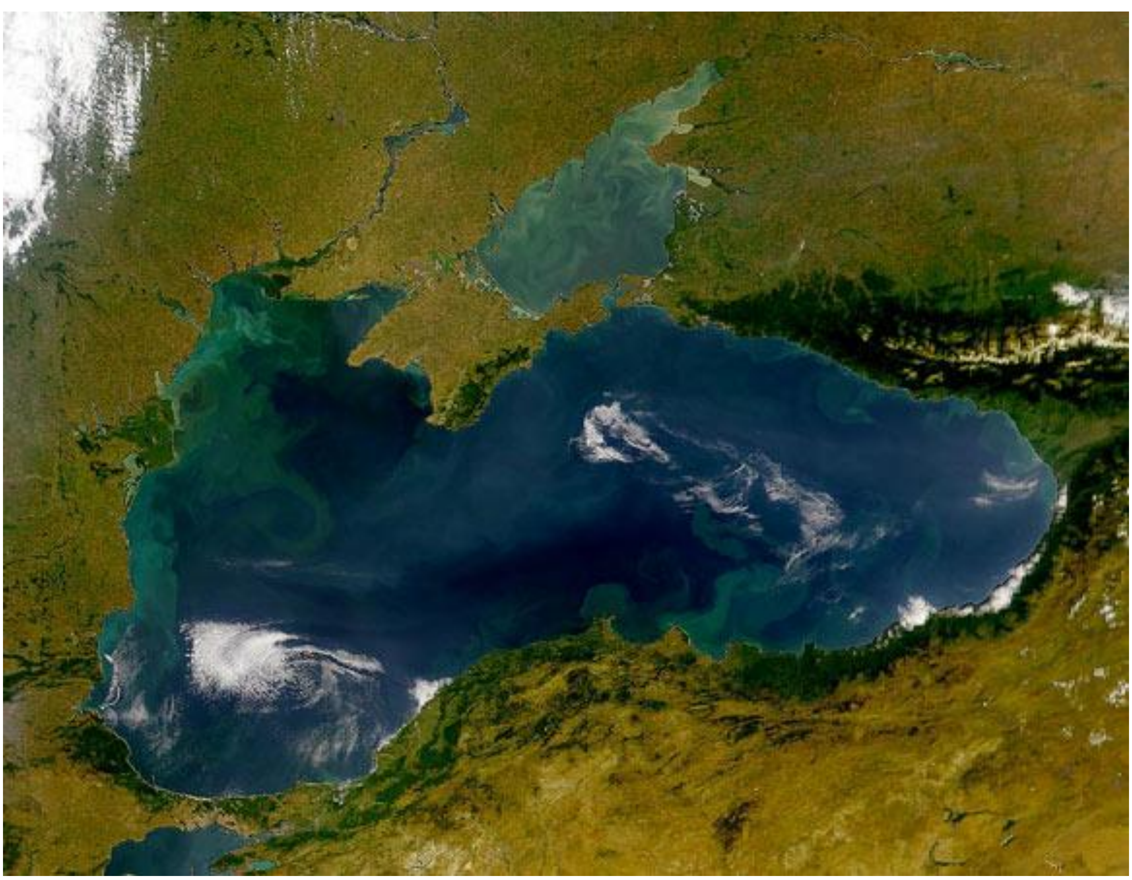


There is another interesting aspect to zones of anoxia—not all areas with anoxic bottom water are caused by pollution. The largest "dead zone" on the planet is the entire Black Sea below a depth of about 150 meters. Due to the fact that the exchange of water in the Black Sea with the Mediterranean Sea is limited to the flow through the narrow Bosporus, all of the mixing of freshwater and seawater takes place in the upper 150 meters, because the freshwater entering from rivers is less dense than seawater.



Graphic adapted from *Black Sea Sediments* by Holger Lueschen

Below the pycnocline (a density boundary where the water density increases abruptly), the Black Sea water column is entirely anoxic, down to the bottom 2000 meters below. SeaWiFS can't see that deep, either, but it can get a good image of the Black Sea on a clear day. Note the Bosporus in the lower-left corner of the image, and the delta of the Danube River on the western coast of the sea.



Geologists Walter Pitman and William Ryan suggested that the Black Sea had been a freshwater lake at one time, and it became an anoxic marine basin fairly recently. Around 5600 B.C., as sea levels rose due to glacial melting, a flood of seawater broke through the Bosporus and inundated the Black Sea basin. The influx of Mediterranean seawater raised the level of the lake about 150 meters, and created the density difference that prevented mixing. Once the Black Sea was filled, the development of anoxia would have happened relatively quickly. One indication of the event is the age of freshwater mussels that died as oxygen concentrations fell. The anoxic bottom waters also hold the promise of preserving ancient wooden vessels, and even buildings in coastal communities that existed before the flood.

(**NOTE:** As scientific examination of this hypothesis progressed since it was first proposed by Ryan and Pitman, the dramatic rapid infilling scenario could no longer be supported. See the Black Sea section of the "Associated URLs" below for a recent report on the status of understanding the paleohistory of the Black Sea and surrounding regions. There may have been a much more powerful flood earlier in time, approximately 15-16 thousand years ago, resulting from the overflow of the Caspian Sea into the ancient Black Sea basin. The Ryan and Pitman event, while still appearing to have occurred, did not involve as much water or as large a rise in the level of the Black Sea as first proposed.)

Dr. Robert Ballard, famed as the discoverer of the wreck of the Titanic, searched the Black Sea in 1999 and found indications of the ancient shoreline of the freshwater lake. In 2000, Ballard found evidence of ancient settlements on the underwater shore of this ancient lake, well-preserved due to the anoxic conditions, which preserve organic matter well. (Ryan and Pitman proposed that the sudden filling of the Black Sea was the basis for the Noah’s Flood story in the Bible, but we won’t get into that debate here.)

Another naturally occurring anoxic basin is the Cariaco Basin, near the coast of Venezuela. Because the sediments in anoxic basins are also without oxygen, they preserve organic matter which is normally consumed by bacteria. Thus, the Cariaco Trench is a natural sediment trap, recording how much organic matter is produced in the overlying waters year after year. Researchers are using SeaWiFS data to observe the productivity cycles in the surface water and then correlating these observations with the record preserved in the organic-rich bottom sediments.

Finally, one other anoxic zone. The Saanich Inlet on Vancouver Island, Canada, has a "sill" near the mouth of the inlet, about 70 meters deep, which restricts the exchange of water from the Pacific Ocean and the bottom of the inlet. For the same reasons given above, the bottom waters of the Saanich below 100 meters are also anoxic, and sediments from the Saanich have been studied to provide information about changing environmental conditions on the western coast of Canada. The Saanich sediments are particularly valuable because the have annual layers (*varves*). The study of the Saanich sediments can be compared to tree rings from trees over 12,000 years old that were found in a nearby lake.

Associated URLs

SeaWiFS

http://seawifs.gsfc.nasa.gov/SEAWIFS.html

Mississippi River Dead Zone

A Dead Zone Grows in the Gulf of Mexico (Scientific American)

Hypoxia in the Gulf of Mexico (NOAA)

Saanich Inlet
http://www-odp.tamu.edu/publications/prosp/169s_prs/169sintro.html

Cariaco Basin
http://imars.usf.edu/cariaco/

National Oceanic and Atmospheric Administration
Ecological and Economic Consequences of Hypoxia (PDF document)

Black Sea
http://www.trussel.com/prehist/news153.htm

http://www.nationalgeographic.com/blacksea/

November 2003: New perspectives on the Black Sea flood: Noah's Flood and the Late Quaternary Geological and Archaeological History of the Black Sea and Adjacent Basins (Geological Society of America meeting session with abstracts)

Locating Noah's Flood: Winnipeg-based Avalon Institute Sets New International Benchmark in Field of Paleo-Environmental Reconstruction