Dead Zones

All of us have in our veins the exact same percentage of salt in our blood that exists in the ocean, and, therefore, we have salt in our blood, in our sweat, in our tears. We are tied to the ocean. And when we go back to the sea - whether it is to sail or to watch it - we are going back from whence we came.
– John F. Kennedy

It is a curious situation that the sea, from which life first arose should now be threatened by the activities of one form of that life. But the sea, though changed in a sinister way, will continue to exist; the threat is rather to life itself.
– Rachel Carson, The Sea Around Us

In the fall of 2006, a low oxygen ocean zone appeared off the coast of Oregon. As the oxygen levels dropped the fish that could leave the area escaped. Some fish weren't as lucky and slowly suffocated and died. Less mobile sea creatures such as crabs, sea stars and sea worms had no chance at all and died in huge numbers. Oregon State University (OSU), in partnership with others, deployed an underwater vehicle to investigate the extent of what was going on under the surface of the Pacific Ocean just off of Cape Perpetua.[1]

Ordinarily, the area would be teeming with rockfish, ling cod and kelp greenling. The seafloor normally also crawls with large populations of Dungeness crab, sea stars, sea anemones, and other marine life. Now, there were no fish and the bottom was covered with massive amounts of the remains of dead ocean creatures.

> *"We saw a crab graveyard and no fish the entire day," said Jane Lubchenco, the Valley Professor of Marine Biology at OSU. "Thousands and thousands of dead crab and molts were littering the ocean floor, many sea stars were dead, and the fish have either left the area or have died and been washed away. Seeing so much carnage on the video screens was shocking and depressing," she said.*

The university survey found that the oxygen level in the water was 10-30 times lower than normal. This was the fifth year for this low oxygen water area off the Oregon coast, but this was the largest drop to date and it caused the suffocation of marine life on a massive scale. The huge growth of microscopic plants, called phytoplankton, contributed to this low oxygen region and turned parts of the ocean a dirty chocolate brown.

As they pulled up their crab traps, fishermen found silver dollar sized octopuses inching their way up the lines toward the buoys floating on the surface. Dennis Krulich, a longtime fisherman in Newport Oregon, later realized that these babies were coming up from oxygen-depleted waters that hover near the seafloor in order to survive. Krulich noted that in 30 years of crabbing he had never seen anything like it before.[2]

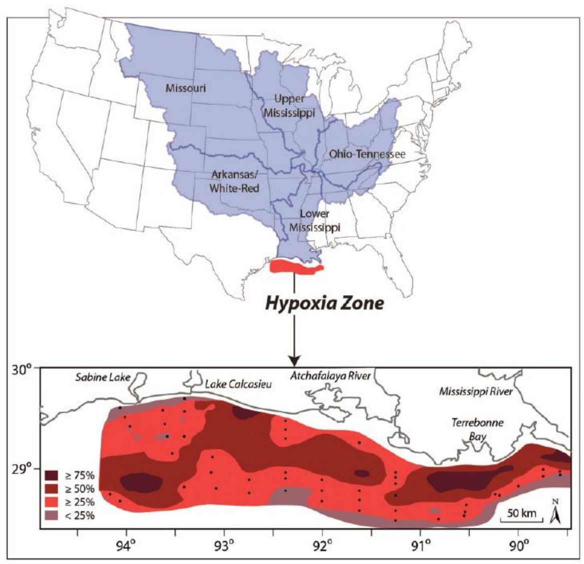
During the same year across the shallow waters off the coast of California, severely low oxygen levels were also detected. Five decades of available records on oxygen levels show little evidence of this low oxygen level phenomenon before the year 2000. Surveys of those waters found the complete absence of all fish that would normally inhabit rocky reefs in that area, and a "near-complete mortality" of bottom invertebrates such as crabs.[3] In 2017 the worst low oxygen zone in a decade was found off the Oregon coast.

> *"When the oxygen levels were high, the crabs were happy and then the oxygen started to decline and then the crabs started to slow down and not move so much and over time they died. They suffocated on the sea floor," said OSU marine ecologist Francis Chan.*[4]

Every summer, enormous amounts of industrial fertilizer and pesticides run off the land in the Midwest ending up in the Mississippi River. These chemicals flow down the river and into the Gulf of Mexico. The discharging fresh water from the river flows over the top of the denser and heavier salty gulf waters. This fresh water on the surface forms a barrier, preventing oxygen from penetrating the bottom layers of the ocean. The nitrogen and phosphorus in the fertilizer stimulate the rapid growth of phytoplankton that naturally grows in the top layer of the sea. When the phytoplankton use up all the nutrients, they die and sink to the bottom where they are decomposed by bacteria. As the bacteria decompose the phytoplankton, they use up much of the remaining oxygen in that bottom layer.

Dissolved oxygen of 4-6 parts per million (PPM) in water is considered normal. Where oxygen is below 4 parts per million fish try to relocate to waters where they can breathe more easily. Below 2 PPM is called hypoxia, where there is a deficiency in the amount of oxygen reaching the tissues of most aquatic animals. Anoxia means there is no oxygen at all. The excessive nutrients that cause these massive phytoplankton blooms, and resulting loss of oxygen from the water is a process known as eutrophication.

In 2002 the Gulf of Mexico hypoxic zone reached 21,973 kilometers (8,484 square miles), larger than the state of Massachusetts.[5] Each year the size of the zone fluctuates based on a number of different factors, including weather and rainfall, which determine how much water pollutants make it to the gulf. In 2015 the gulf zone was 16,767 square kilometers (6,474 square miles), or roughly the size of Connecticut and Rhode Island combined.[6] In 2017 the zone expanded to at least 22,730 square kilometers (8,776 square miles), roughly the size of New Jersey. It was the largest recorded since tracking began in 1985.[7]



Gulf of Mexico drainage basin. Inset: Frequency of midsummer bottom-water hypoxia (2 mg/L O^2) off the coast of Louisiana and Texas for 60 to 80 stations (small dots) sampled during the summer from 1985 to 2008.

Low oxygen levels radically alter the ecology of coastal systems. Fish and mobile invertebrates (like shrimp and crabs) can migrate out of hypoxic areas. Animals that are slow moving or attached to the bottom (like clams, worms and starfish) cannot escape from the dangers of hypoxic water and die with extended exposure. These extremely low oxygen ocean areas have been given the rather ominous although appropriate name of "dead zones."

> *In the northern Gulf of Mexico, the occurrence and extent of the dead zone are tightly coupled with freshwater discharge from the Mississippi River, which delivers large quantities of nutrients from U.S. agricultural activities. During years with low river flow, the area of hypoxia shrinks to < 5000 km^2 [1,930 mi^2], only to increase to > 15,000 km^2 [> 5,790 mi^2] when river flow is high.*[8]

What is very worrisome is that dead zones have been appearing worldwide at an increasing rate. Nutrient over-enrichment is the main cause of these dead zones, and nutrient-fed hypoxia is now widely considered an important threat to the health of aquatic ecosystems. Prior to 1970, there were only scattered reports of coastal hypoxic zones in Europe and North America, with only 49 dead zones identified in the 1960s.[9] However, by 1995, there were over 195 cases reported worldwide. This number doubled to just over 400 zones by 2008, and an additional 115 sites in the Baltic Sea were added to the list in 2011.[10] These world dead zones cover an area four times bigger than they were in 1950. The largest, in the partially enclosed Baltic Sea in Europe, often covers more than 51,800 square kilometers (20,000 square miles).[11]

The observed increase in these dead zones has lagged about 10 years behind the increased use of industrially manufactured nitrogen-based fertilizers that began in the late 1940s, with explosive growth in the 1960s and 1970s. Since that time, the number of dead zones has approximately doubled each decade.[12] The main causes of these dead zones are linked to nutrient use (particularly nitrogen and phosphorus in fertilizers) in agricultural production, wastewater from human populations and industrial sources, and the burning of fossil fuels. Triple the amount of nitrogen and phosphorus is being deposited into the world's oceans today than in preindustrial times.[13] Each year, more than one million tons of nitrogen flows through the Mississippi River system and into the Gulf of Mexico.

> *Forty-one percent of the continental United States (1.2 million square miles) drains into the Mississippi River and then out to the Gulf of Mexico. The majority of the land in Mississippi's watershed is farm land. Seventy percent of nutrient loads that cause hypoxia are a result of agricultural runoff caused by rain washing fertilizer off of the land and into streams and rivers. Additionally, 12 million people live in urban areas that border the Mississippi, and these areas constantly discharge treated sewage into rivers.*[14]

According to a 2017 report by the environmental group Mighty, a major factor in the generation of the Gulf of Mexico dead zone is American's voracious appetite for meat.[15] In the United States, people eat roughly 87 kilograms (193 pounds) of beef, pork and chicken a year,[16] with total meat consumption projected to increase to nearly 99 kilograms (219 pounds) per person per year by the year 2025.[17]

To meet this demand, a highly industrialized and centralized factory farm system has converted vast tracts of native grassland in the Midwest to grow soy and corn to feed livestock. Toxins from manure and fertilizers that wash into waterways are exacerbating the harmful algal blooms that create oxygen-deprived stretches down in the gulf. Tyson Foods is identified by the report as a "dominant" influence in the pollution due to its market strength in chicken, beef and pork.

> *To keep up with orders from companies like McDonald's and Walmart, Tyson slaughters 125,000 head of cattle, 35 million chickens, and 415,000 hogs every week—nearly equal to the human population of California. To raise all of this meat, Tyson requires an estimated five million acres of corn—greater than the size of New Jersey—each year, not to mention other feed like soybeans, which it buys from the major feed suppliers.*[18]

One third of the planet's arable land is occupied by livestock feed crop cultivation.[19] In the United States, just over 70% of the soybeans[20] and nearly half of the corn[21] grown are used as animal feed. In addition to the fertilizers used to grow the feed, the waste generated by the huge number of animals is contributing to the downstream problem. Tyson alone generated 55 million tons of manure in 2016. According to the Environmental Protection Agency (EPA), Tyson also dumped 104 million pounds of pollutants directly into waterways from 2010 to 2014, making it the second biggest polluter in the United States just after AK Steel Holding Corporation.[22]

The raw materials of the global food system are controlled by a very small number of large multinational corporations. Known as the ABCD of food, ADM, Bunge, Cargill, and (Louis) Dreyfus, account for between 75% and 90% of the global grain trade.[23] Because these companies don't sell directly to individual consumers they don't have much of a public reputation, yet they supply the feed for the animals that end up in restaurants and in grocery stores. Even so, these companies bear no responsibility for the soil erosion and run-off from enormous portions of America's crop fields that are washing into the waterways, causing environmental havoc including dead zones.[24]

The biofuel industry is also decreasing prairies and replacing them with fertilized fields of corn and soy. A 2015 study showed that just over a four year period, 7 million acres of new land in the United States was converted for crops to create biofuels.[25] Nearly 30% of the corn grown in the United States is used to produce ethanol.[26]

Increasingly, parts of the United States are being plowed up to raise corn and soy, primarily to feed livestock and create biofuels. China has become the world's biggest importer of soybeans, with 1.171 billion bushels being exported from the United States in 2014-2015.[27] The growth in China's soybean imports is driven by increased demand for meat and expanding livestock production, resulting from the fast growth of China's economy and incomes since the early 2000s.[28]

Heavy rainfall, soil erosion and the destruction of wetlands and grasslands that absorb runoff are all factors that allow chemical fertilizers and manure that are applied to these fields to eventually end up polluting surrounding waterways. Because crops only take up on average half the nitrogen applied to the fields, the remainder washes into streams and eventually into the Mississippi River.[29] The amount of nitrogen that flows down the Mississippi River and into to the Gulf of Mexico has averaged about 1.26 million metric tons per year.[30] The huge dead zone in the Gulf of Mexico and the 400 or so other dead zones in the world are in large part from these animal agriculture and biofuel industries.

In pre-industrial times, most coastal and offshore ecosystems rarely became hypoxic. A combination of natural processes, as well as possible human activities such as land clearing, may have resulted in the development of algal blooms and associated low-oxygen bottom water on the Louisiana shelf prior to 1950. However, analysis indicates that the low-oxygen events of the last few decades have been more extreme than any that occurred in the previous 150 years.[31]

While many dead zones such as the one in the Gulf of Mexico are caused by agricultural runoff, the dead zone off the coast of Oregon had to be different because there just wasn't enough farming and associated fertilizer runoff in the area to explain it. There had to be other factors in the case of Oregon's massive sea life die-off in 2006 and 2017.

Scientists hypothesize that climate change may be a contributing factor in the formation of dead zones. Increasing land-sea temperature differences can drive an increase in coastal winds.[32] The stronger winds produce a longer coastal upwelling, which causes an increase in the numbers of phytoplankton. The excess of phytoplankton which isn't eaten dies and drifts down to the seafloor, rotting and using up oxygen in the process.[33] A 2014 analysis in the journal *Science* indicates a trend of windier conditions over the last 60 years off the west coast of North America, the coast of Peru and Chile and the west coast of southern Africa.[34] Researchers can't definitively say that climate change is to blame, but they said finding a pattern that was consistent across several parts of the planet provides a strong indicator that it is a factor. There are not only shifts in costal wind intensity, but there are other disturbing changes taking place.

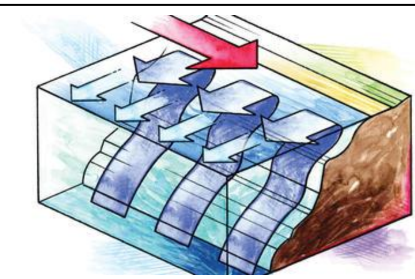


Illustration of the coastal upwelling process, in which winds blowing along the shore cause nutrient-poor surface waters to be replaced with nutrient-rich, cold water from deep in the ocean.

Surface ocean waters down to about 100 meters (325 feet) generally have oxygen concentrations close to equilibrium with the Earth's atmosphere. Oxygen enters the ocean in the surface water through contact with the atmosphere and by photosynthesis by aquatic plants. The mixing of surface waters by wind and waves increases the rate that oxygen is absorbed from the air into the water. Farther out to sea, beyond the continental shelf, water at a depth of roughly 600–1,200 meters (1,970-3,940 feet) is permanently oxygen deprived. Called an oxygen minimum zone (OMZ), this layer is a normal feature in many parts of the ocean which are too deep to mix with the oxygen-rich surface waters. Oxygen essentially only enters these deeper parts of the ocean by the slow motion of water currents.

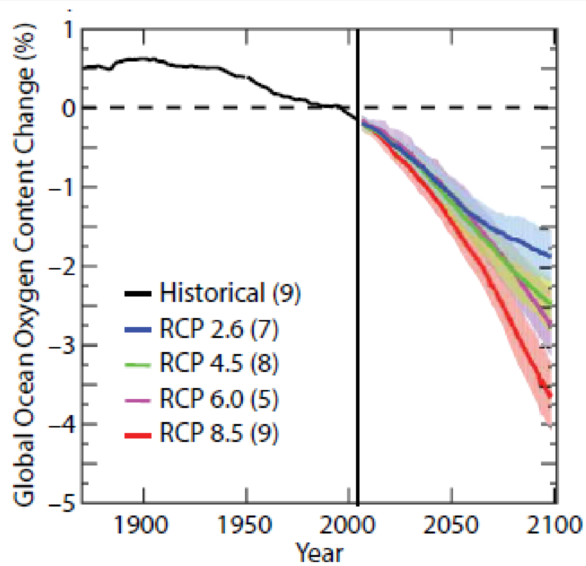
Usually, in the spring, occasional periods of northerly wind blows surface waters offshore, allowing cool waters, rich in nutrients but poor in oxygen, to upwell from deeper, offshore layers. That nutrient-rich upwelling is what makes Oregon's fisheries so productive. Researchers have found that over the last 30 years the oxygen level of the OMZ off the Oregon coast is steadily losing oxygen. These are the waters that move up towards the shallower waters in the spring and summer. Because of this decreasing oxygen content, the chances of seeing a hypoxic event off the Oregon coast increased from 10% to 60%.[35] This in part helped explain the increasing low oxygen water die-offs that had been occurring where they hadn't before. But why was the oxygen level dropping in this naturally occurring OMZ?

Around the globe, many OMZs are losing oxygen and expanding horizontally and vertically. According to Lisa Levin, a marine biologist at the Scripps Institution of Oceanography, deeper waters off the continental shelf have experienced a 20-30% decline in oxygen.

> *"Right now, it's still out of sight, out of mind," says Levin of the low-oxygen water. But the hypoxic conditions are creeping up the water column, rising by as much as 90 meters [300 feet] between 1984 and 2006 off the coast of Santa Barbara, California.*[36]

Just off the coast of West Africa, there is a dead zone the size of the continental United States. It has grown by 15% since 1960 and by 10% just since 1995. A recent study that measured the oxygen level of this dead zone found the lowest oxygen levels ever recorded in the open Atlantic.

> *...the minimum levels of oxygen now measured are some 20 times lower than the previous minimum, making the dead zones nearly void of all oxygen and unsuitable for most marine animals.*[37]



A number of greenhouse gas concentration trajectories scenarios (Representative Concentration Pathways or RCPs) show global ocean oxygen concentration is projected to decrease.

Globally, these low-oxygen areas have expanded by more than 4.5 million square kilometers (1.7 million square miles) in the past 50 years.[38] As these areas have expanded vertically, they have pushed diving marine creatures such as sailfish, sharks, tuna, swordfish, and Pacific cod, as well as the smaller sardines, herring, shad, and mackerel that they eat, into ever narrower bands of oxygen-rich water closer to the surface.

> *"The natural thing to expect is that as the ocean gets warmer, circulation will slow down and get more sluggish and the waters going into the deep ocean will hang around longer," says Curtis Deutsch, a chemical oceanography professor at the University of Washington, in Seattle. "And indeed, oxygen seems to be declining."*[39]

Because the oceans are large and complex no one is certain why OMZs have increased in size. However, climate models have suggested that ocean oxygen concentrations have and will decline in the future because of the warming of ocean waters.

> *…the ocean likely will lose a substantial amount of oxygen in the coming decades and centuries in response to global warming, a process termed "ocean deoxygenation". Global models suggest a loss of between 1 to 7% for this century for a business as usual scenario.*[40]

If ocean circulation slows over the coming decades, as it is theorized to do, then there will be less ocean oxygen mixing causing many OMZs to continue to increase in size. This raises the risk that upwelling currents, which carry oxygen minimum waters to shore areas, will cause an increase in dead zones like the ones that occur off the Oregon coast. While parts of the ocean have shown some increase in oxygen levels, other areas, particularly in the tropics, have decreased levels.

> *…results show expanding low-oxygen-minimum zones in all three tropical oceans between the time periods 1960–1974 and 1990–2008. The low oxygen zones expand both horizontally and vertically.*[41]

Although not definitively proven, it appears that warming oceans are at least in part causing the increase in these low oxygen zones. If true, this has the potential to expand naturally occurring OMZs into shallower coastal waters and further damaging fisheries.

> *…our analysis strongly supports the notion that if anthropogenic [human caused] climate change continues to evolve unabated, the ocean is bound to deoxygenate with poorly understood consequences for marine life. This is a source of concern, especially when considering that ocean deoxygenation is not occurring in isolation, but together with ocean acidification and ocean warming.*[42]

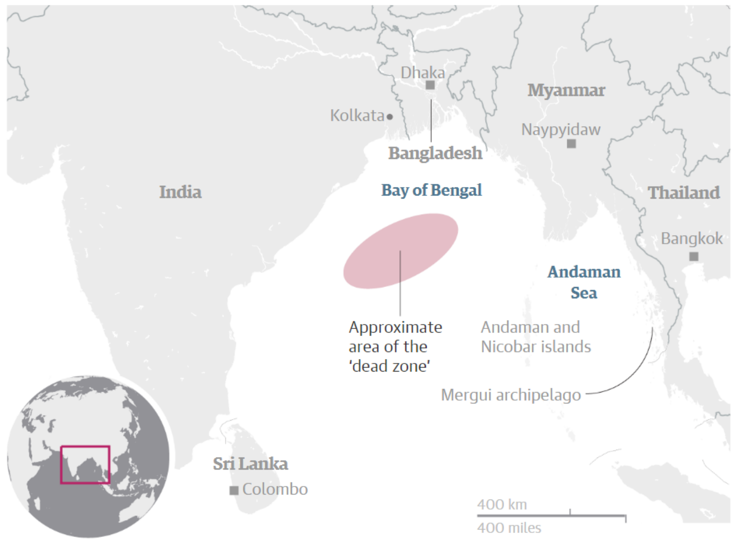
> *Our investigation of the OMZ in the tropical eastern North Atlantic reveals significant deoxygenation in the core of the OMZ... if continued, the OMZ would go anoxic in less than 100 years… links to global warming and possible changes in the hydrologic cycle as the causes for the long-term observed temperature and salinity changes in the Atlantic.*[43]

Large-scale climate change causes the oceans to absorb more heat, resulting in less dissolved oxygen at the surface since a smaller amount of oxygen dissolves in warmer water. Increased layering between the upper oxygen-rich layers of the ocean and the lower oxygen-poor layers also occurs, which reduces the mixing and transfer of oxygen from the atmosphere into the deeper waters.[44] The decrease in movement of oxygen to lower layers happens because as the water heats up, it expands, becoming lighter than the water below it and less likely to sink.

To maintain a habitable deep ocean, oxygen must be supplied via the downward transport of surface water, rich in the oxygen obtained from the atmosphere and photosynthesis. A reduction in oxygen levels at the surface and reduced transport to the deeper ocean can change oxygen levels over time.[45] This appears to have at least in part caused the observed expansion of OMZ areas.

Because there is a lot of variability in the natural warming and cooling of the ocean, oxygen concentrations are constantly changing making it difficult to detect the effects of a warming climate on ocean oxygen levels. Cutting through this natural variability, a 2016 study indicates that forced ocean deoxygenation due to climate change should already be evident in the southern Indian Ocean and parts of the eastern tropical Pacific and Atlantic oceans.[46]

This decline in oxygen due to climate warming might already be manifesting in the Indian Ocean. At the end of 2016, a multinational team of scientists reported that a very large dead zone had appeared in the Bay of Bengal. This zone already spans some 60,000 square kilometers (23,160 square miles), or roughly the combined areas of the states of New Jersey, Maryland and Delaware. The zone appears to be increasing in size.



The dead zone of the Bay of Bengal is now at a point where a further reduction in its oxygen content could strip the water of nitrogen, a key nutrient.

The bay has also been under assault with several large rivers emptying their contents of untreated sewage, plastic and aquaculture, as well as industrial and agricultural waste into it for years.[47]

> *The impact of this pollution could be catastrophic. The high load of organic pollutants, coupled with the diminution of the fish that keep them in control, could lead to massive plankton blooms, further reducing the water's oxygen content.*[48]

Approximately 200 million people living along the Bay of Bengal are fully or partly reliant on fishing. If the bay's fisheries collapse it would be nothing short of catastrophic. The scientists who identified the bay's dead zone warn that this stretch of ocean is approaching a tipping point. If the last of the oxygen is removed due to continued nutrient input from rivers along with the effects of climate change, it could have serious consequences for the planet's oceans and the global nitrogen cycle.[49] A report presented to the United Nations by marine scientists at the University of Oxford highlighted the extremely precarious situation in the bay.

> *"Nutrients like nitrate act as a fertiliser to algae, stimulating bacteria growth, which competes with fish and marine organisms for oxygen. If oxygen levels in the Bay of Bengal decrease any further, the area is at risk of flipping to a 'no oxygen' status. This would result in the formation of new bacteria that then remove nitrates from the water, destabilising the bay's ocean ecosystem. The denitrified water could then be carried away by ocean currents and reduce productivity elsewhere."*[50]

Another massive dead zone exists in the Gulf of Oman just off the coasts of Iran, Pakistan, Oman, and the United Arab Emirates. Agricultural runoff and sewage have created a dire environmental problem, with increasing ocean temperatures making the situation even worse. Research led by Doctor Bastien Queste from UEA's School of Environmental Sciences found a dead zone larger than the size of Scotland almost completely devoid of oxygen.[51] At 102,515 square kilometers (39,500 square miles),[52] it is about 4.5 times larger than the Gulf of Mexico dead zone's maximum recorded size. Dr. Queste commented on what he and his team found:

> *"Our research shows that the situation is actually worse than feared -- and that the area of dead zone is vast and growing. The ocean is suffocating."*

Inexpensive fertilizers, used on crops to feed rising populations in a hungry world, in part led countries to apply fertilizer with reckless abandon. In China their nitrogen-use efficiency has dropped from an average of more than 60% in 1961 to just 25% today. The result is the Chinese ecosystems are under siege.[53]

> *Nitrogen kills fish in huge numbers from the Yellow River in the north to the Pearl River in the south. Algal blooms are reported in a third of the country's lakes. Massive "red tides" of toxic algae spread from river estuaries across the East China Sea.*

Currently, hypoxia and anoxia are among the most widespread harmful human-caused influences on estuarine and marine environments, and now rank with overfishing, habitat loss and harmful algal blooms as major global environmental problems. The expansion of OMZs into shallow waters, as we have seen off the coast of Oregon, may interact with nutrient-induced areas just off the coast to intensify and increase the total number of dead zones.[54] Keryn Gedan, a marine ecologist at the University of Maryland, cautioned:

> *"If an area has low oxygen to begin with, then any change is going to have fairly significant ecological repercussions. We know that the shallow, coastal ocean is warming faster than the open ocean, especially in estuaries that are fairly sheltered. We're seeing numerous dead zones pop up all around the world, and that's going to become more common."*[55]

Researchers warn that it is likely that the open-ocean dead zone just off the West African coast may at some point flood the Cape Verde archipelago with low-oxygen water. If this happens it would put severe stress on the coastal ecosystems and cause marine life die-offs.[56]

> *"Climate change will drive expansion of dead zones, and has likely contributed to the observed spread of dead zones over recent decades," Altieri and Gedan write in a new paper that appears today in Global Change Biology... As temperatures increase, animals such as fish and crabs require more oxygen to survive. But with less oxygen available, "that could quickly cause stress and mortality and, at larger scales, drive an ecosystem to collapse," Altieri and Gedan warn.*[57]

The irony is that the human food supplied by the oceans is in part jeopardized by modern industrial land-based agriculture. Around 75,000 metric tons (83,000 tons) of sea life are lost in the Chesapeake Bay dead zone each year. The Gulf of Mexico dead zone causes the annual loss of 212,000 metric tons (235,000 tons) of food.[58]

The key to reducing dead zones will be to keep fertilizers on the land and out of the sea. For agricultural systems in general, methods need to be developed that close the nutrient cycle from soil to crop and back to the agricultural soil. Cover crops can reduce nitrogen runoff by 30%, yet in

2016 Iowa farmers planted them on less than 3% of the state's cropped land.[59] When these fertilizers and other sources of pollution are kept away from the oceans, the resultant dead zones can be reversed.

> *From 1973 to 1990, the hypoxic zone on the northwestern continental shelf of the Black Sea had expanded to 40,000 km^2; however, since 1989, the loss of fertilizer subsidies from the former Soviet Union reduced nutrient loading by a factor of 2 to 4, with the result that, by 1995, the hypoxic zone had gone.*[60]

Since 1995, over $30 billion in federal conservation funding and voluntary limits on fertilizer use has failed to reduce the size of the Gulf of Mexico dead zone, with it reaching a record size in 2017.[61] Demands on industrial fertilizer-intensive farming are only increasing and will only raise the amount of nitrogen and other chemicals dumped into waterways. Human production of nitrogen is already five times higher than it was 60 years ago.[62]

> *Farmers rely so heavily on fertilizer to boost yield and profits. It's cheap insurance for expensive seed, and billion-dollar industries have formed around its unbridled use—from fertilizer manufacturers to equipment makers and ag [agriculture] consultants.*[63]

The Energy Independence and Security Act (EISA) passed by the U.S. Congress set a required renewable fuel standard, requiring that at least 136 billion liters of biofuels be used by 2022. That mandate will increase the total nitrogen flux by 21% to more than 100%.[64] This governmental mandate for biofuels alone may raise nitrogen spilling into the Gulf of Mexico to a whopping 3 million metric tons per year. Total world fertilizer consumption by major crops is projected to increase from 166 million metric tons in 2007 to 263 million metric tons by 2050 – a 58% increase.[65] In addition, less and less of the nitrogen poured onto fields is being incorporated into crops, with more than half washing from fields into rivers. The nitrogen-use efficiency of the world's farmers has decreased from more than 50% in 1961 to about 42% today.[66]

On top of already enormous agricultural related nitrogen increases that are expected to be drained into the gulf, a 2017 study indicates climate change may raise this amount still further. Climate change models project that both total and extreme precipitation in the Northeast as well as the corn belt of the United States will substantially increase. This will raise the amount of fertilizer washed off of fields, causing total nitrogen loading within the Mississippi River Basin to go up by 18% by the end of the century.[67]

In early 2018 nitrogen experts from around the world met to discuss what a nitrogen-soaked planet might look like. Many concluded that the amount of nitrogen being dumped into the environment should be reduced by 50% by the year 2050 or ecosystems will face epidemics of toxic tides, lifeless rivers and dead oceans.[68] Rather than decreasing nitrogen use, all indicators show fertilizer use is on an ever growing trajectory.

This increasing fertilizer overload, along with growing use of fossil fuels and wastewater from human and industrial sources, will no doubt increase the number and size of dead zones. In addition, if warming-induced changes advance, observed decreasing ocean oxygen trends may very well continue, causing a further expansion in OMZs.

> *The multiplicative effects of oxygen stress on shelf systems are predicted to yield ecosystem-level changes. Increases in jellyfish blooms are likely be part of this response. Long-term consequences may include impacts on ocean CO_2 uptake and commercial fisheries.*[69]

Climate models, that have replicated some of the oxygen changes that have already occurred, predict that the oxygen in the world's oceans will drop between 1 and 7% by the next century. That could be enough to have a profound effect on life in the ocean, according to Daniel Pauly, a fisheries biologist at the University of British Columbia.[70] Jellyfish, which can tolerate lower oxygen levels than fish, may thrive in the new conditions. Pauly and his colleagues predict that the drop in the ocean's oxygen and pH levels will together decrease the world's fish catch by 20 to 30% by 2050.

> *The links between human activity and local jellyfish blooms are strong. In the Black Sea, invasive comb jellies dumped from the ballast of tankers have spawned deliriously and destroyed the region's fishing industry. In the Sea of Japan, fertiliser run-off has left an oxygen-depleted sea where little other than jellies can thrive.*[71]

The present deoxygenation of the ocean is similar to an event that occurred 93-94 million years ago, known as the Oceanic Anoxic Event-2 (OEA-2).[72] OAE-2 developed over about 50,000 years, and was believed to be caused by undersea volcanic activity triggering an extinction event that suffocated about 27% of marine invertebrates in Earth's oceans.[73] Dr Sune Nielsen, of Woods Hole Oceanographic Institution, commented:

> *"Our results show that marine deoxygenation rates prior to the ancient event were likely occurring over tens of thousands of years, and surprisingly similar to the two per cent oxygen depletion trend we're seeing induced by anthropogenic activity over the last 50 years. We don't know if the ocean is headed toward another global anoxic event, but the trend is, of course, worrying."*[74]

In 2018 a dead zone along about 150 miles of Florida's Gulf Coast resulted in 267 tons of marine life washing up onto Florida's white, sandy beaches.[75] While this is "toxic algae bloom" is not completely new, scientist believe they may be getting worse after decades of unchecked development, water mismanagement and a changing climate.[76]

> *Generations of sugar cane farming has altered the chemistry of Florida's biggest lake [Lake Okeechobee] and a vast system of dikes and dams built to "drain the swamp" and create a retirement wonderland has killed half of the Everglades and put the rest of this vital wetland on life support. In the wet season, Florida dumps massive amounts of Okeechobee's nutrient-rich water into the most delicate ecosystems, while in the dry season, that water is diverted to farms and cities.*

Increasing fertilizer intensive industrial agriculture, primarily driven by consumer appetite for animal protein and desire for biofuels, combined with a warming climate will continue to be an ever increasing oxygen-depleting assault on the ocean. These onslaughts will have dire consequences to life in the oceans with growing threats to the world's food stocks.

For centuries, people have been exploiting the seas with very little restriction, with proof of extensive deterioration of the marine environment hidden beneath the waves. The result of our past and current actions is an overall decline in the ocean's health and resilience. Now, humankind faces an immediate choice between exerting ecological restraint and proceeding towards increasing global ocean life-smothering catastrophes.

Pictures:

Gulf of Mexico drainage basin – S. S. Rabotyagov, et al., “The Economics of Dead Zones: Causes, Impacts, Policy Challenges, and a Model of the Gulf of Mexico Hypoxic Zone,” Review of Environmental Economics and Policy, January 4, 2014, pp. 58-79, https://doi.org/10.1093/reep/ret024

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This is one chapter from an upcoming book – Moving Back from Midnight – A World in Peril.

If you have feedback or you would like to help with working on this book in any way please contact us at movingbackfrommidnight@gmail.com. Our planet is under major threats and it will take all of us taking action to reverse course and make it a sustainable world.

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