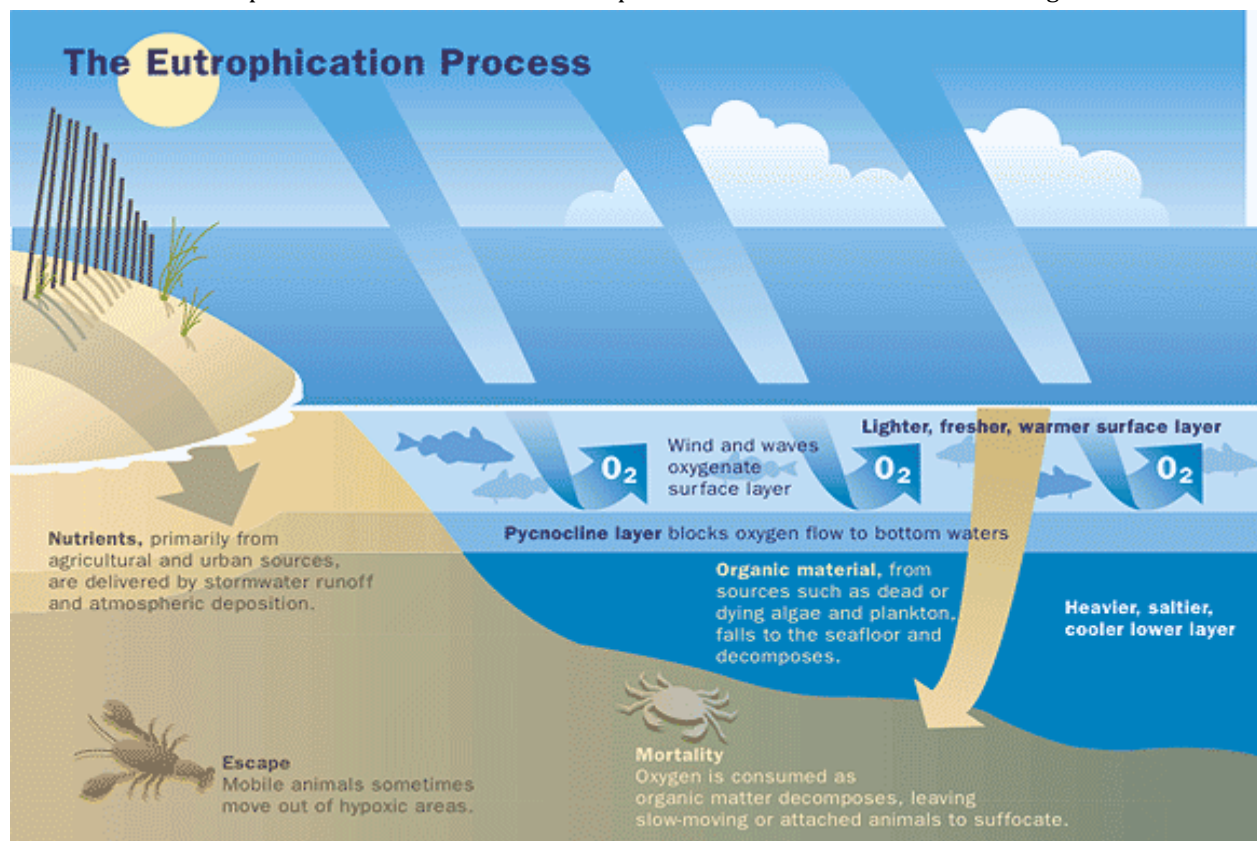


Eutrophication & Hypoxia

➤ Eutrophication

- **Eutrophication** is an increase in the concentration of chemical nutrients in an ecosystem to an extent that increases the primary productivity of the ecosystem.
- A set of physical, chemical, & biological changes brought about by excessive nutrients released into water.
- Depending on the degree of eutrophication, subsequent negative environmental effects such as **anoxia** & severe reductions in water quality, fish, & other animal populations may occur.
- Eutrophication is often the result of **anthropogenic pollution** with nutrients, particularly the release of **sewage effluent & agricultural run-off carrying fertilizers** into natural waters.
- However, it also occurs naturally in situations where nutrients accumulate (e.g. depositional environments) or where they flow into systems on an ephemeral basis.
- Eutrophication generally **promotes excessive plant growth & decay**, favors simple algae & plankton over other more complicated plants, & causes a **severe reduction in water quality**.
- In contrast to freshwater systems, nitrogen is more commonly the key limiting nutrient of marine waters; thus, nitrogen levels have greater importance to understanding eutrophication problems in salt water.
- Estuaries tend to be naturally eutrophic because land-derived nutrients are concentrated where run-off enters the marine environment in a confined channel.
- Upwelling in coastal systems also promotes increased productivity by conveying deep, nutrient-rich waters to the surface, where the nutrients can be assimilated by algae.
- In aquatic environments, enhanced growth of choking aquatic vegetation or phytoplankton (e.g. algal blooms) disrupts normal functioning of the ecosystem, causing a variety of problems such as a lack of oxygen in the water, needed for fish & shellfish to survive.
- The water then becomes cloudy, coloured a shade of green, yellow, brown, or red.
- Human society is impacted as well: eutrophication decreases the resource value of rivers, lakes, & estuaries such that recreation, fishing, hunting, & aesthetic enjoyment are hindered.
- Health-related problems can occur where eutrophic conditions interfere with drinking water treatment.



Eutrophication & Hypoxia

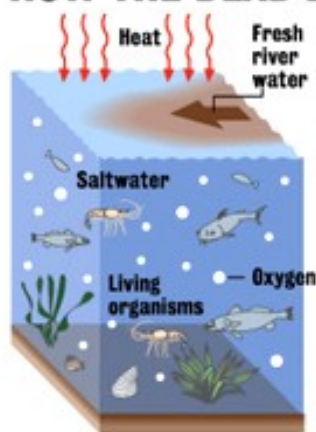
➤ Hypoxia

- **Hypoxia** or **oxygen depletion** is a phenomenon that occurs in aquatic environments as **dissolved oxygen (DO)**; molecular oxygen dissolved in the water) becomes reduced in concentration to a point detrimental to aquatic organisms living in the system.
- Dissolved oxygen is typically expressed as a percentage of the oxygen that would dissolve in the water at the prevailing temperature & salinity (both of which affect the solubility of oxygen in water; see oxygen saturation & underwater).
- An aquatic system lacking dissolved oxygen (0% saturation) is termed **anaerobic, reducing, or anoxic**
- a system with low concentration—in the range between **1-30% saturation**—is called **hypoxic** or **dysoxic**.
- Most fish cannot live below 30% saturation.
- A "healthy" aquatic environment should seldom experience less than 80%.
- The **exaerobic** zone is found at the boundary of anoxic & hypoxic zones.

• Causes of Hypoxia

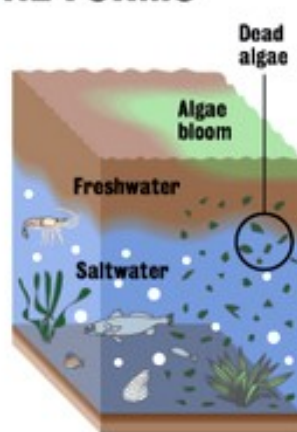
- Oxygen depletion can be the result of a number of factors including natural ones, but is of most concern as a consequence of pollution & eutrophication in which plant nutrients enter a river, lake, or ocean, & phytoplankton blooms are encouraged.
- Hypoxia may also occur in the absence of pollutants.
- In estuaries, for example, because freshwater flowing from a river into the sea is less dense than salt water, stratification in the water column can result.
- Vertical mixing between the water bodies is therefore reduced, restricting the supply of oxygen from the surface waters to the more saline bottom waters.
- The oxygen concentration in the bottom layer may then become low enough for hypoxia to occur. Areas particularly prone to this include shallow waters of semi-enclosed water bodies such as the Waddenzee or the Gulf of Mexico, where land run-off is substantial.
- In these areas a so-called "**dead zone**" can be created.

HOW THE DEAD ZONE FORMS

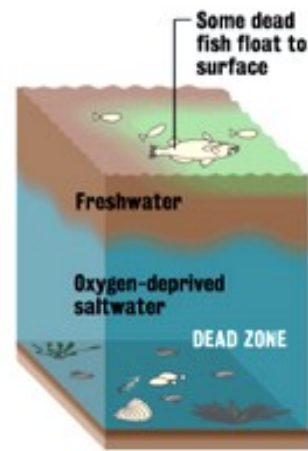


1 During the spring, sun-heated freshwater runoff from the Mississippi River creates a barrier layer in the Gulf, cutting off the saltier water below from contact with oxygen in the air.

Source: Staff research



2 Nitrogen and phosphorus from fertilizer and sewage in the freshwater layer ignite huge algae blooms. When the algae die, they sink into the saltier water below and decompose, using up oxygen in the deeper water.



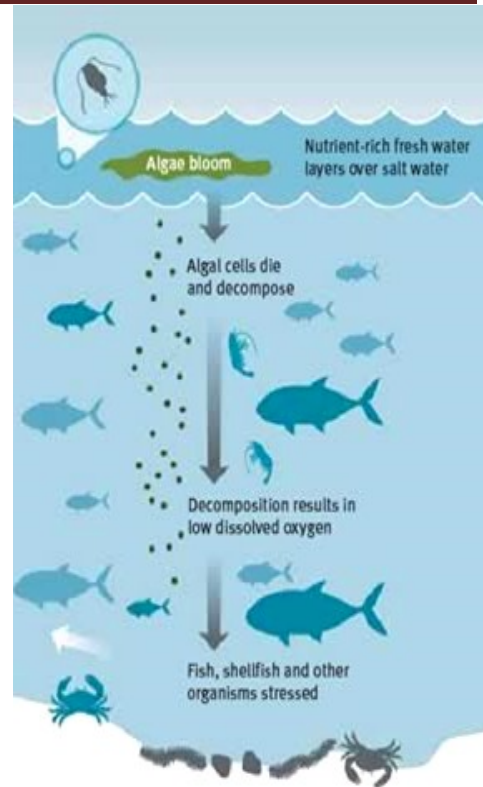
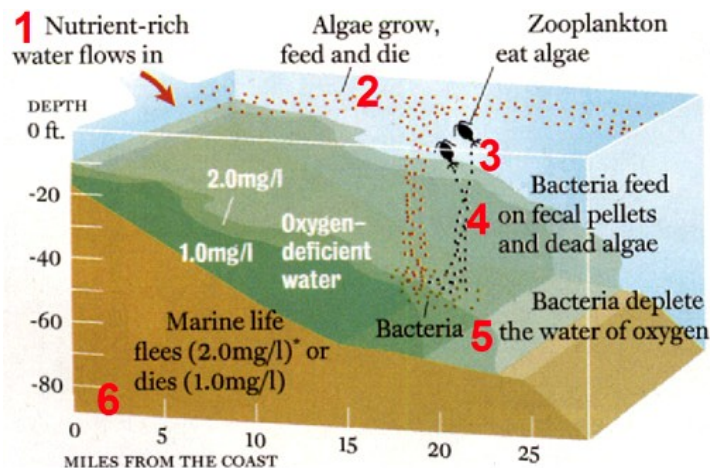
3 Starved of oxygen and cut off from resupply, the deeper water becomes a dead zone. Fish avoid the area or die in massive numbers. Tiny organisms that form the vital base of the Gulf food chain also die. Winter brings respite, but spring runoffs start the cycle anew.

STAFF GRAPHIC BY DAN SWENSON

Eutrophication & Hypoxia

• Formation of Hypoxic Zones

1. Nutrient-rich water flows in
2. Algae grow, feed, & die
3. Zooplankton eat the algae
4. Bacteria feed on the fecal pellets & dead algae
5. Bacteria deplete the water of oxygen
6. Marine life flees (2.0 mg/l) or dies (1.0 mg/l)



• Describe the major events that lead up to hypoxia in the “dead zone”

- Hypoxic is caused by the simultaneous occurrence of two main factors:
 - 1) stratification of the water column
 - 2) increased nutrient concentrations within the watershed
- As is typical of most estuaries, the water column of the Mississippi river delta is stratified, with the river fresh water lying above the more dense oceanic salt water.
- As will be discussed in much greater depth in the following questions, poor agricultural practices have allowed massive nutrient depletion of the Mississippi River Basin (encompassing almost 41% of America).
- Cultivation of the land has caused soil erosion, which allows the nutrients to be released from the substrate & transported down the Mississippi River to the Gulf coast.
- The stratified water column combined with the anthropogenic nutrient loading causes massive increases in the abundance of the filamentous algae which feed on these nutrients, resulting in algal blooms.
- When the algae eventually die they sink to the bottom of water column, where benthic bacteria consume their remains.
- During consumption of the algae the bacteria use up the surrounding dissolved oxygen, which combined with the stratified water column, causes the formation of an anoxic layer.
- This region of anoxia is often referred to as hypoxia.
- Given that very few marine organisms can survive in anoxic conditions, organisms flee the hypoxic area, thus altering their typical migration patterns & making them more vulnerable to predation.
- Off shore water movement can intensify the effect of hypoxia by forcing the hypoxic region closer to the shore, thus trapping fish & other organisms between the shoreline & the hypoxia.
- If the organisms are trapped here long enough the forced alteration in their natural food web combined with the increasingly anoxic conditions will cause massive fish kills (which is why hypoxic regions are also referred to as “dead zones”).

Eutrophication & Hypoxia

- **Describe in detail the events as they occur in the Gulf of Mexico**
 - The current hypoxic areas present in the Gulf of Mexico are the result of more than 200 years of poor land management in the midwestern United States.
 - When European settlers first arrived in America land seemed to be an unlimited resource, especially when compared to their homelands, & as a result for the first couple centuries of settlement land was viewed as cheap & expendable, & thus little, if any, attention was paid to sustainable cultivation of the land.
 - By 1860 at least 15% of the Mississippi River Basin (MRB), which encompasses roughly 41% of the contiguous United States, was either under cultivation or its nutrients had already been exhausted.
 - As the MRB drains predominantly through south eastern Louisiana, it is perhaps no surprise that records show New Orleans had the highest suspended sediment concentrations during the 1800s, when land development for agricultural purposes was at its height.
 - While the specific hypoxic repercussions of America's poor land management may not have been anticipated two hundred years ago, the rapid & extensive rate of nutrient depletion due to agriculture was recognized, as shown in the following quote by a visitor to the US in the 1800s, "There is no portion of the globe that is being exhausted of its fertility by injudicious cultivation, so rapidly as the Mississippi Valley."
 - Despite this early acknowledgement, land continued to be treated as expendable well into the 1900s.
 - It wasn't until the 1930s that Americans were forced to face consequences of their poor land management, when a nationwide drought brought agriculture to a standstill & the already exhausted Midwest became a barren "dust bowl."
 - The dramatic change from the native diverse forms of land cover to only a handful of agricultural crops resulted in massive soil erosion throughout the MRB, with the nutrients being washed into the surrounding watersheds & eventually carried down stream by the Mississippi River & emptying into the Gulf of Mexico.
 - Nutrient loading of the watersheds was further exasperated by the addition of loose fertilizers to the now impoverished farmland.
 - These nutrient rich waters have been accumulating over time at the mouth of the Mississippi River delta, where the coastal Gulf waters are becoming polluted to the point where hypoxic conditions occur.
 - The high nutrient concentrations have greatly affected the atomic ratio of silicate to nitrate.
 - Historic silicate to nitrate ratios have fallen from 4:1 to nearly 1:1, which has severe consequences to the surrounding coastal food web, as dips below this 1:1 ratio causes the microbial loop to switch from a diatom based system to a flagellated algae dominated system.
 - As diatoms are at the base of the food chain for the coastal fisheries, this anthropogenically induced nutrient loading of the coasts could cause the local fisheries to collapse.
 - In addition, the eutrophic conditions cause massive increases in the populations of the flagellated algae, forming "harmful algal blooms" (HABs).
 - As the algae die they will sink to the bottom of the water column, where benthic bacteria will consume them.
 - The bacteria use dissolved oxygen in the water in order to breakdown the algal corpses; however, due to the large amount of algae being consumed combined with the stratified water column (formed by the fresh river water laying on top of the more dense oceanic salt water), causes the oxygen to be almost entirely used up forming an hypoxic layer.
 - Louisiana fisheries feed on benthic fish & shrimp, however, these organisms are not adapted to survive in anoxic condition & thus either flee the hypoxic regions or die.
 - Since these benthic organisms are a crucial part of the food chain for local fisheries, the fish are being forced to the periphery of the hypoxic zones in search of food, or they are being trapped between the coast & the hypoxic area where they eventually starve resulting in massive fish kills (thus giving hypoxic regions their alternative name, "dead zones").
 - In effect hundreds of years of careless agricultural practices & overall poor land management have brought about the present hypoxic conditions along the mouth of the Mississippi River, & out into the surrounding Gulf of Mexico.
 - In addition to dramatically altering the distribution & makeup of the coastal marine food web, hypoxia has also caused massive increases in harmful algal blooms (HABs), & greatly threatens the stability & sustainability of the coastal fisheries, which bring in billions of dollars into the Louisiana economy alone every year.

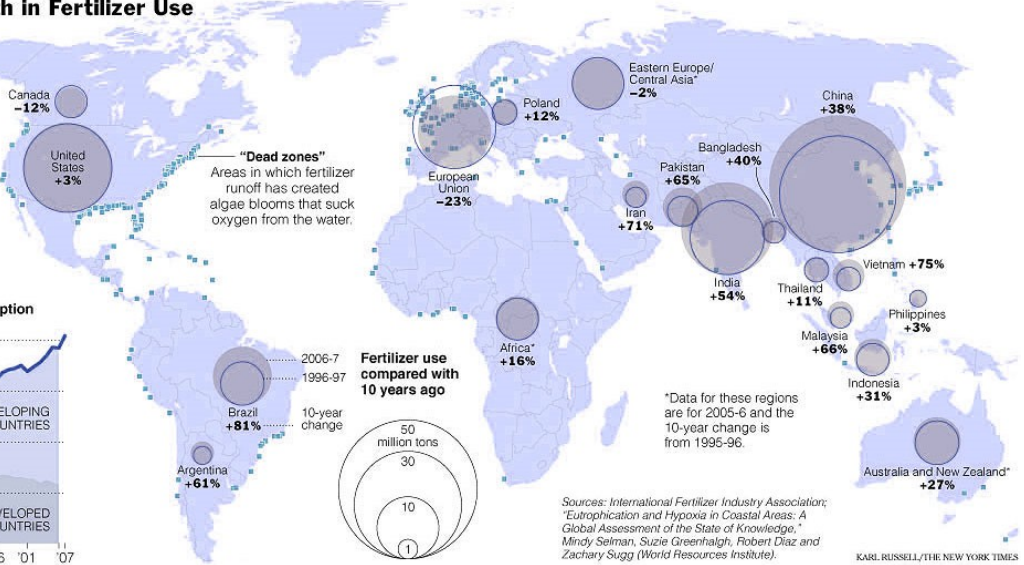
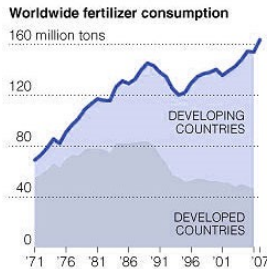
Eutrophication & Hypoxia

- **Global Hypoxia**

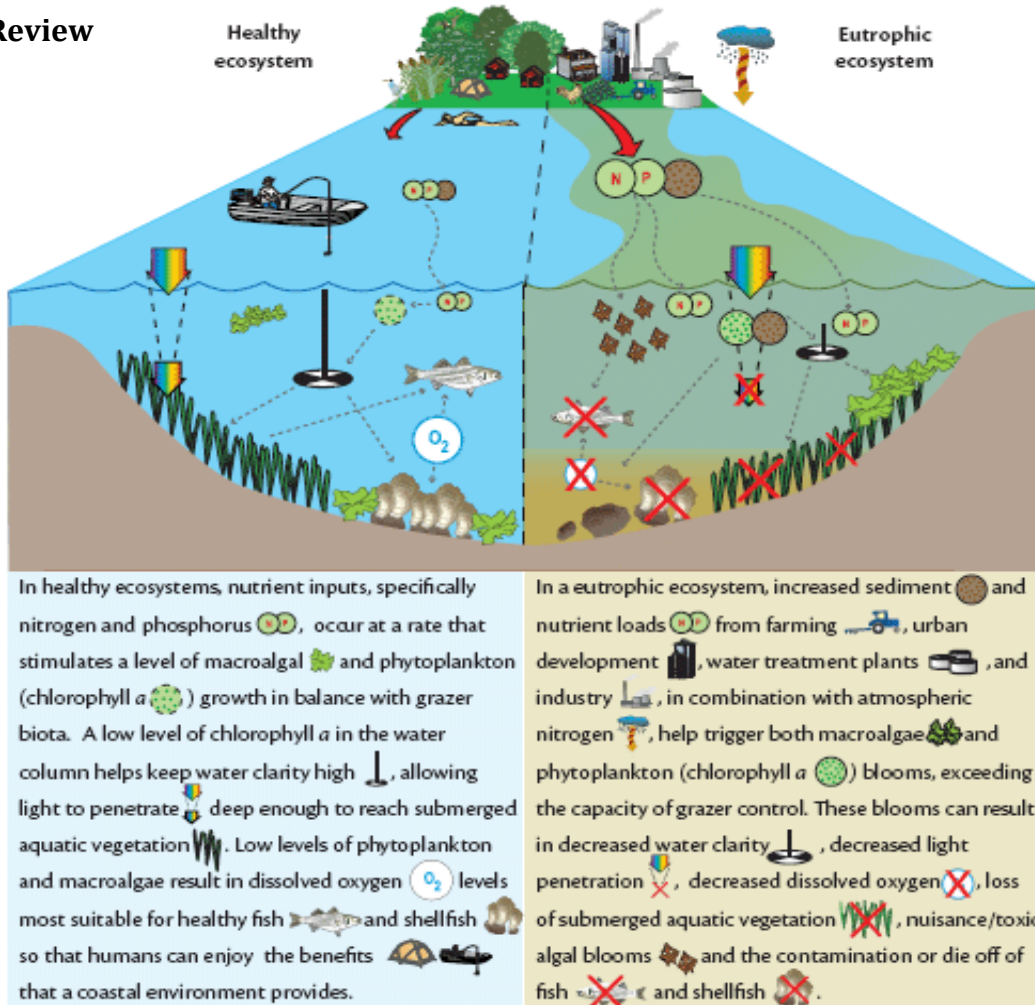
The World Resources Institute has identified **375 hypoxic coastal zones** around the world, concentrated in coastal areas in Western Europe, the Eastern & Southern coasts of the US, & East Asia, particularly in Japan

Worldwide Growth in Fertilizer Use

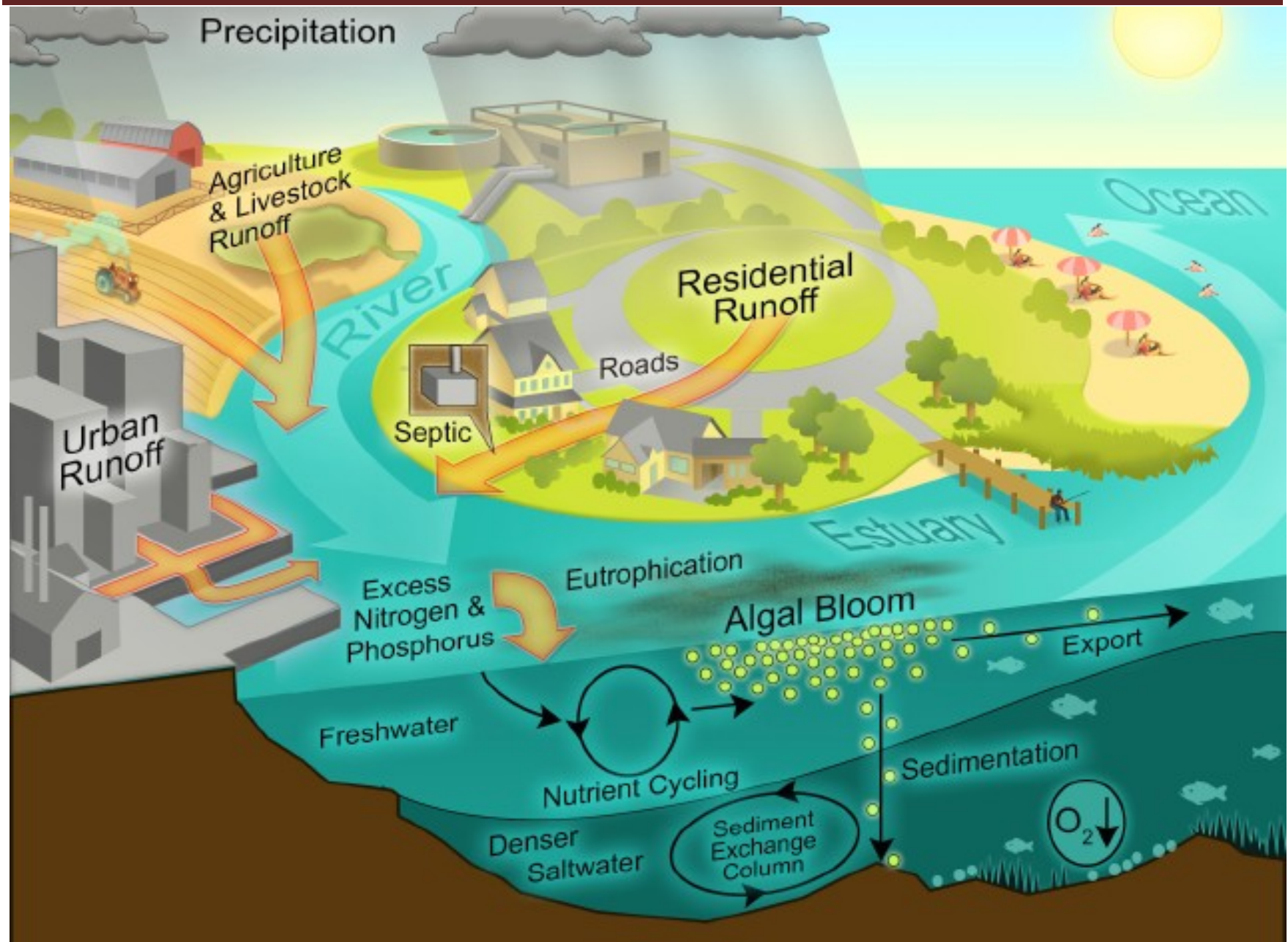
Fertilizer use has been growing faster in developing countries than in the industrialized world in recent years. But rising demand has produced a big price jump. Increased fertilizer runoff is expected to worsen the problem of dead zones along ocean shores.



- **Review**



Eutrophication & Hypoxia



Eutrophication & Hypoxia

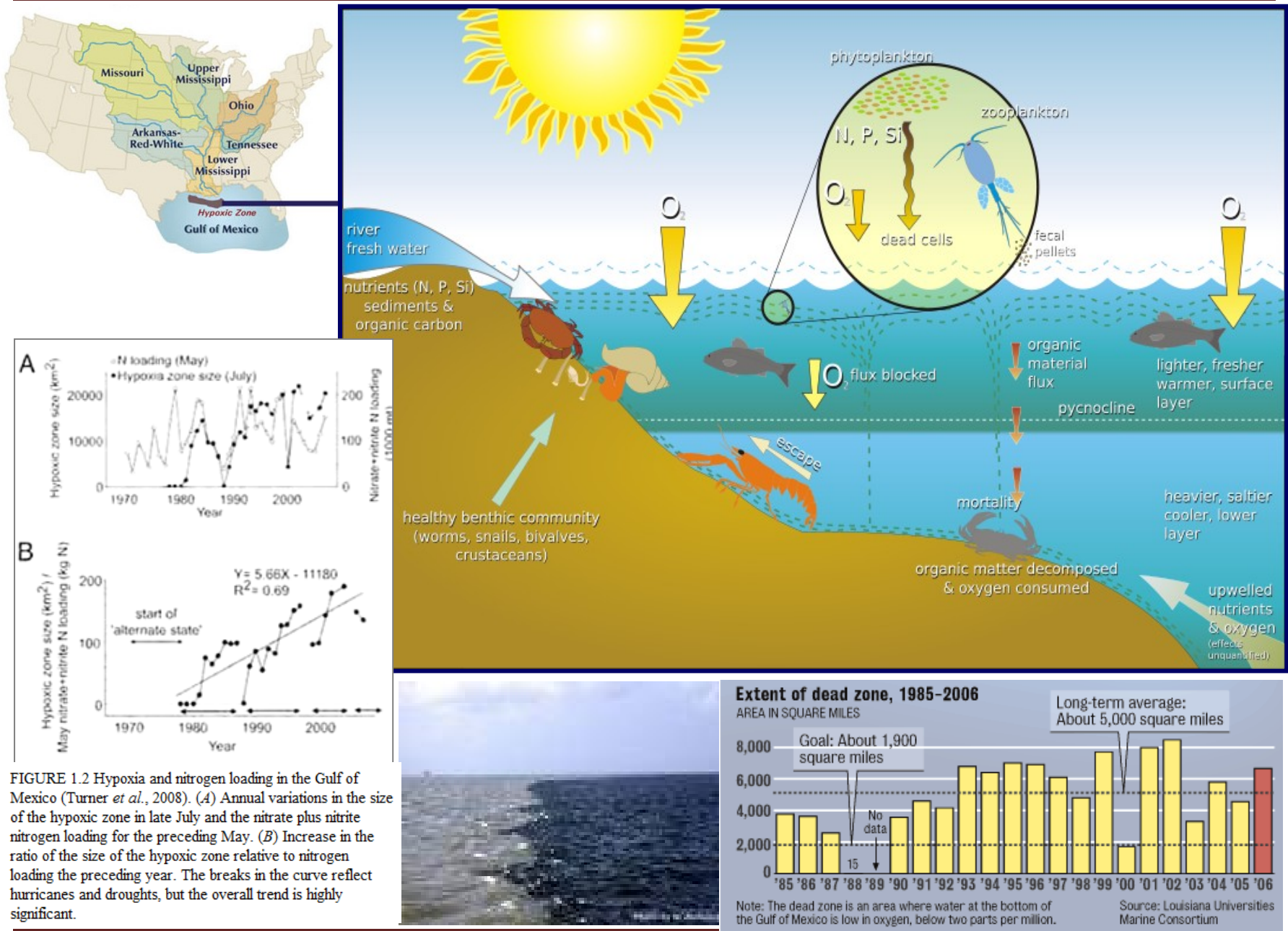


FIGURE 1.2 Hypoxia and nitrogen loading in the Gulf of Mexico (Turner *et al.*, 2008). (A) Annual variations in the size of the hypoxic zone in late July and the nitrate plus nitrite nitrogen loading for the preceding May. (B) Increase in the ratio of the size of the hypoxic zone relative to nitrogen loading the preceding year. The breaks in the curve reflect hurricanes and droughts, but the overall trend is highly significant.