Algal Blooms in the Gulf of Mexico:

A case study of nonpoint-source pollution and eutrophication

Introduction
What cause the “dead zone?”
The time course of eutrophication
What can we do about it?

What is nonpoint source pollution?

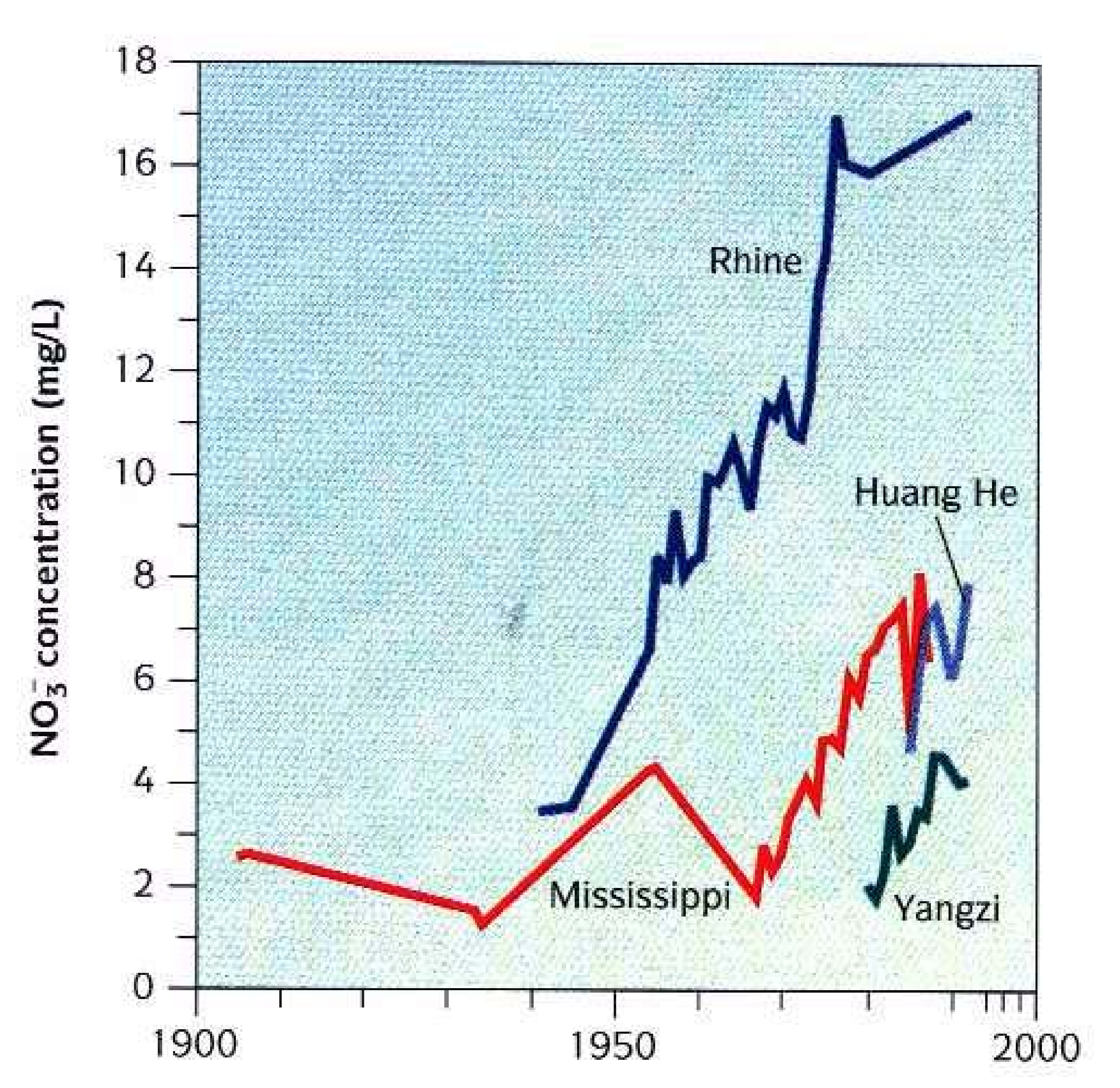
Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, **comes from many diffuse sources**. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water.

These pollutants include:

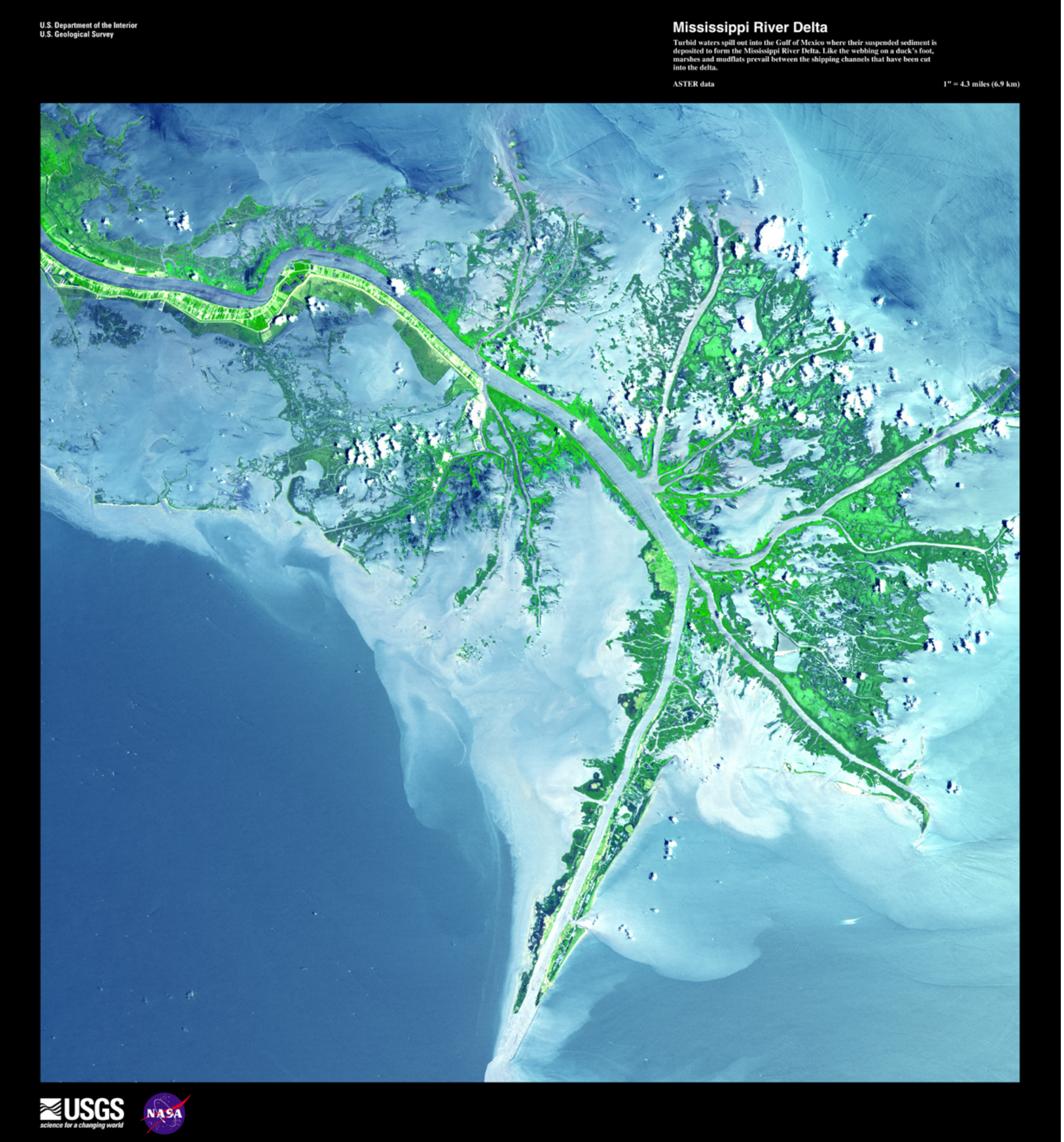
- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;
- Oil, grease, and toxic chemicals from urban runoff and energy production;
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks;
- Salt from irrigation practices and acid drainage from abandoned mines;
- Bacteria and nutrients from livestock, pet wastes, and faulty septicsystems;

Atmospheric deposition and hydromodification are also sources of nonpoint source pollution.

In contrast, pollution from **point sources** comes in large amounts from a single source, such as an industrial operation or a wastewater treatment plant.



NO_3^- concentration (mg/L)
0
2
4
6
8
10
12
14
16
18
1900
1950
2000
Rhine
Huang He
Mississippi
Yangzi



Mississippi River Delta
Image taken 5/24/2001 by ASTER on Landsat-7.

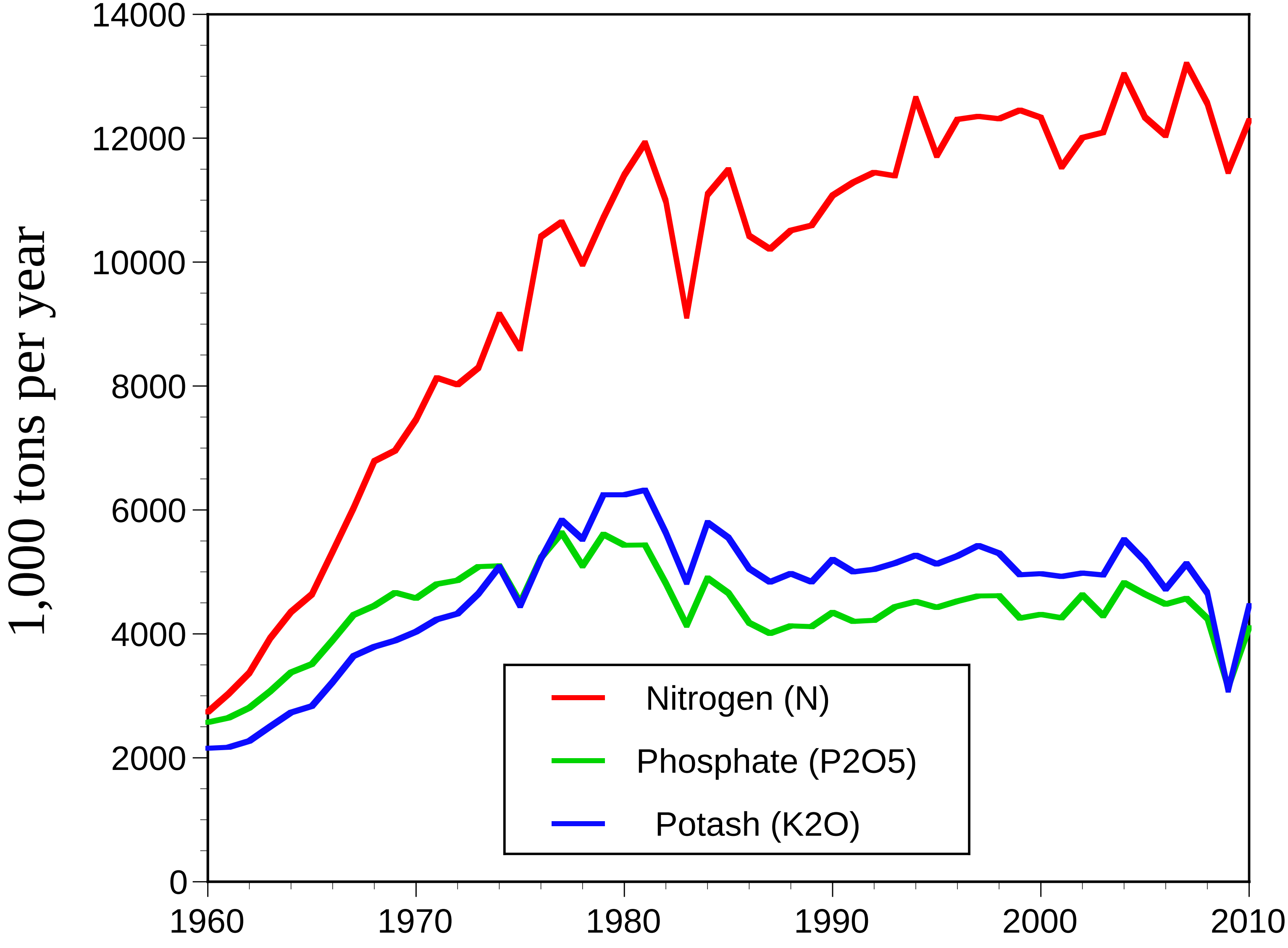
Turbid waters spill out into the Gulf of Mexico where their suspended sediment is deposited to form the Mississippi River Delta. Like the webbing on a duck's foot, marshes and mudflats prevail between the shipping channels that have been cut into the delta.

Eutrophication and Hypoxia (<2 mg O_2 /L)

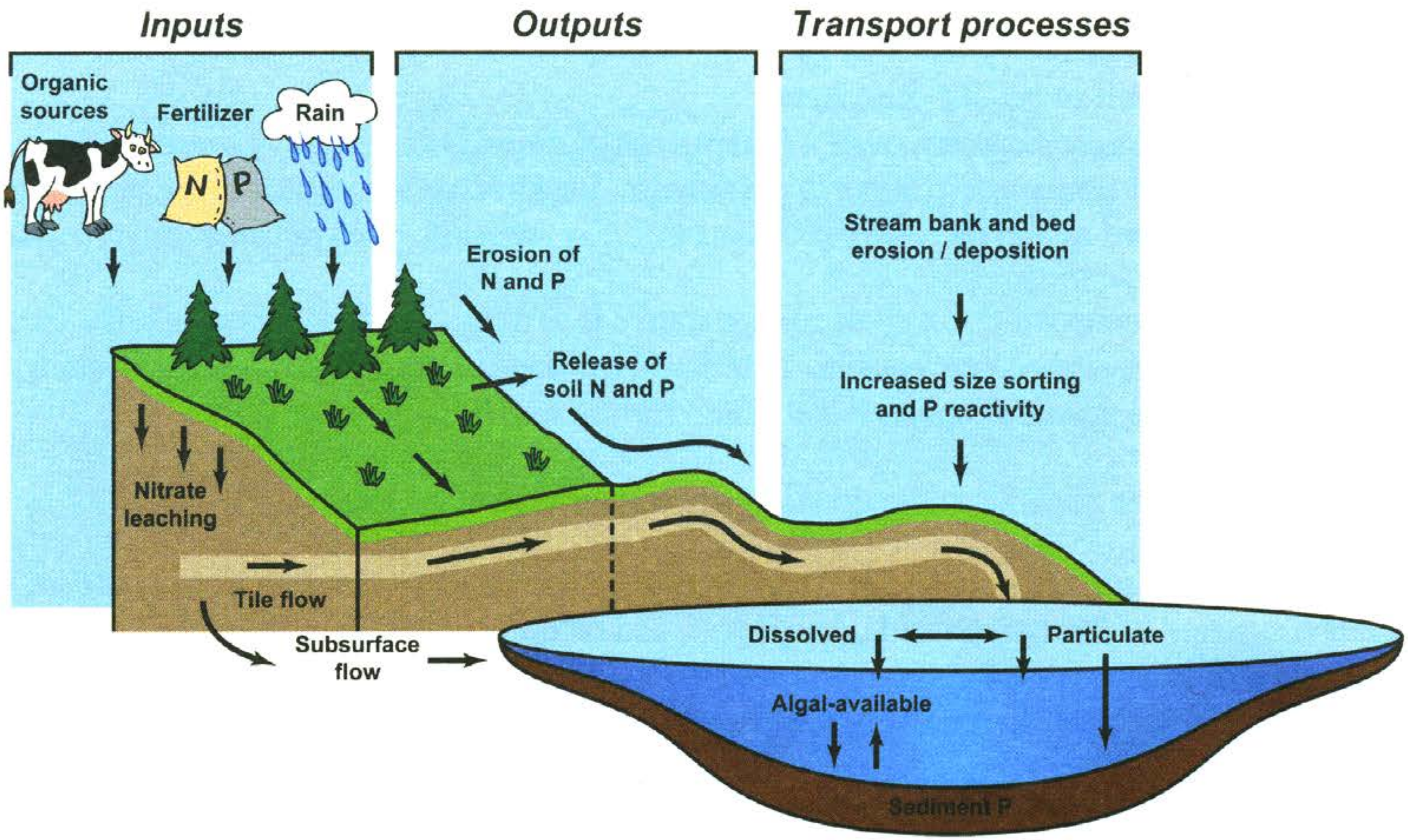
Increased nutrient input to aquatic ecosystems may cause eutrophication. **Eutrophication** leads to excessive growth of algae and cyanobacteria. Later after death of these excessive biomass, much increased decomposition by bacteria depletes oxygen in the water, which causes fish kills and other detrimental effects –the Dead Zone.

What cause the “dead zone?”

Use of N, P and K fertilizers in USA 1960-2010



From: USDA Economic Research Service Web page



Artwork by W. Feeny

Figure 1 - Nutrients in manure and fertilizers are transported to lakes, rivers, and oceans. Excessive nutrient inputs result in degradation of water quality, causing the disruption of aquatic ecosystems.

From Issues in Ecology #3

Based on our review of the scientific literature, we are certain that:

1. Eutrophication caused by over-enrichment with P and N is a **widespread** problem in rivers, lakes, estuaries, and coastal oceans.

2. Nonpoint pollution is a major source of P and N to surface waters of the United States. The major sources of nonpoint pollution are **agriculture and urban activity**, including industry and transportation.

3. In the U.S. and many other nations, inputs of P and N to agriculture in the form of **fertilizers** exceed outputs of those nutrients in the form of crops.

4. High densities of livestock have created situations in which **manure** production exceeds the needs of crops to which the manure is applied. The density of animals on the land is directly related to nutrient flows to aquatic ecosystems.

5. **Excess fertilization and manure production cause a P surplus**, which accumulates in soil. Some of this surplus is transported in soil runoff to aquatic ecosystems.

6. **Excess fertilization and manure production create a N surplus** on agricultural lands. Surplus N is mobile in many soils, and much leaches into surface waters or percolates into groundwater. Surplus N can also volatilize to the atmosphere and be redeposited far downwind as acid rain or dry pollutants that may eventually reach distant aquatic ecosystems.

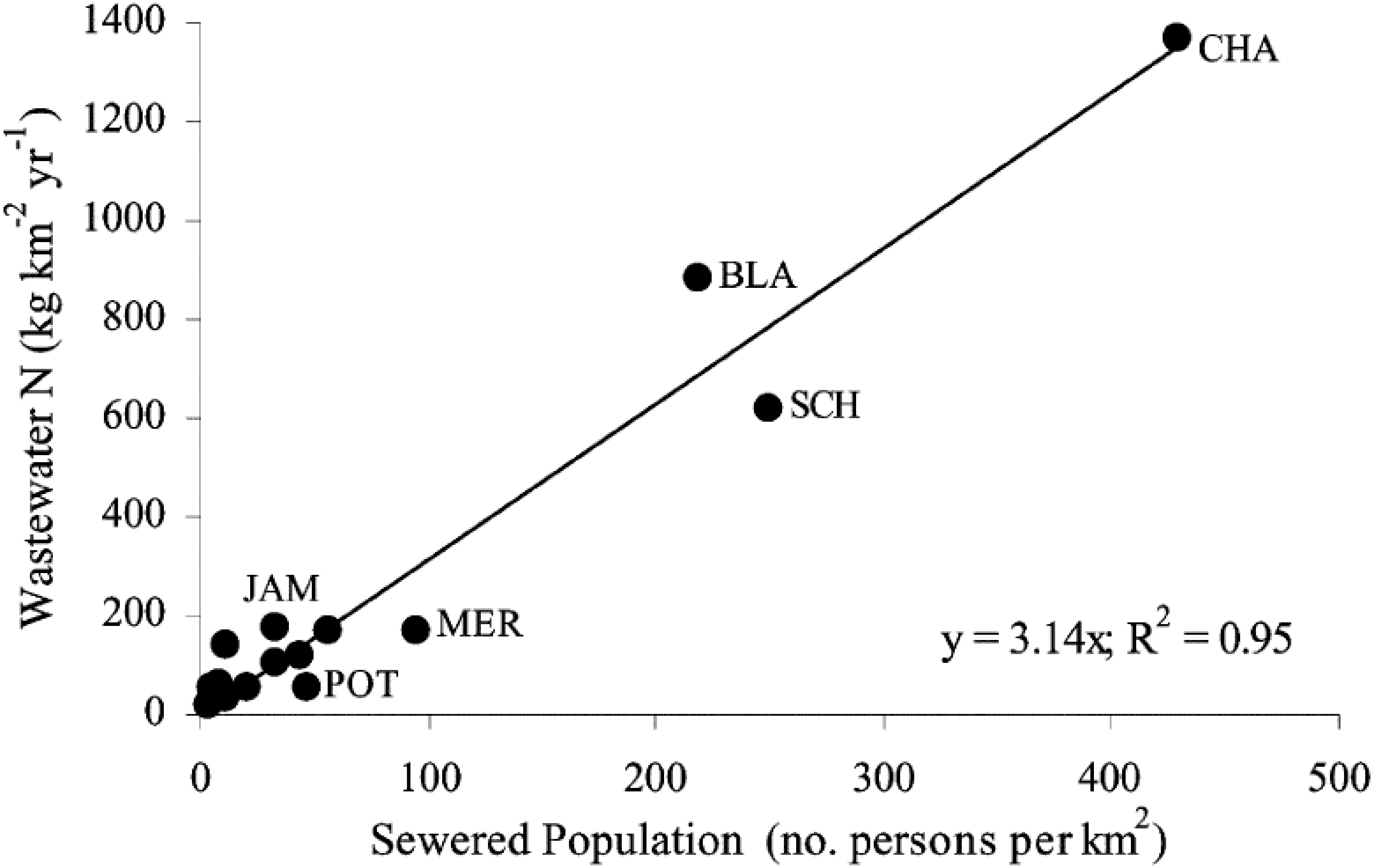


Figure 4. Relationship between sewered population and nitrogen fluxes due to sewage wastewater. The regression line indicates a per capita load in wastewater of 3.1 kg N yr^{-1} per person.

From: Van Breemen et al. 2002. Biogeochemistry 57/58:267-293

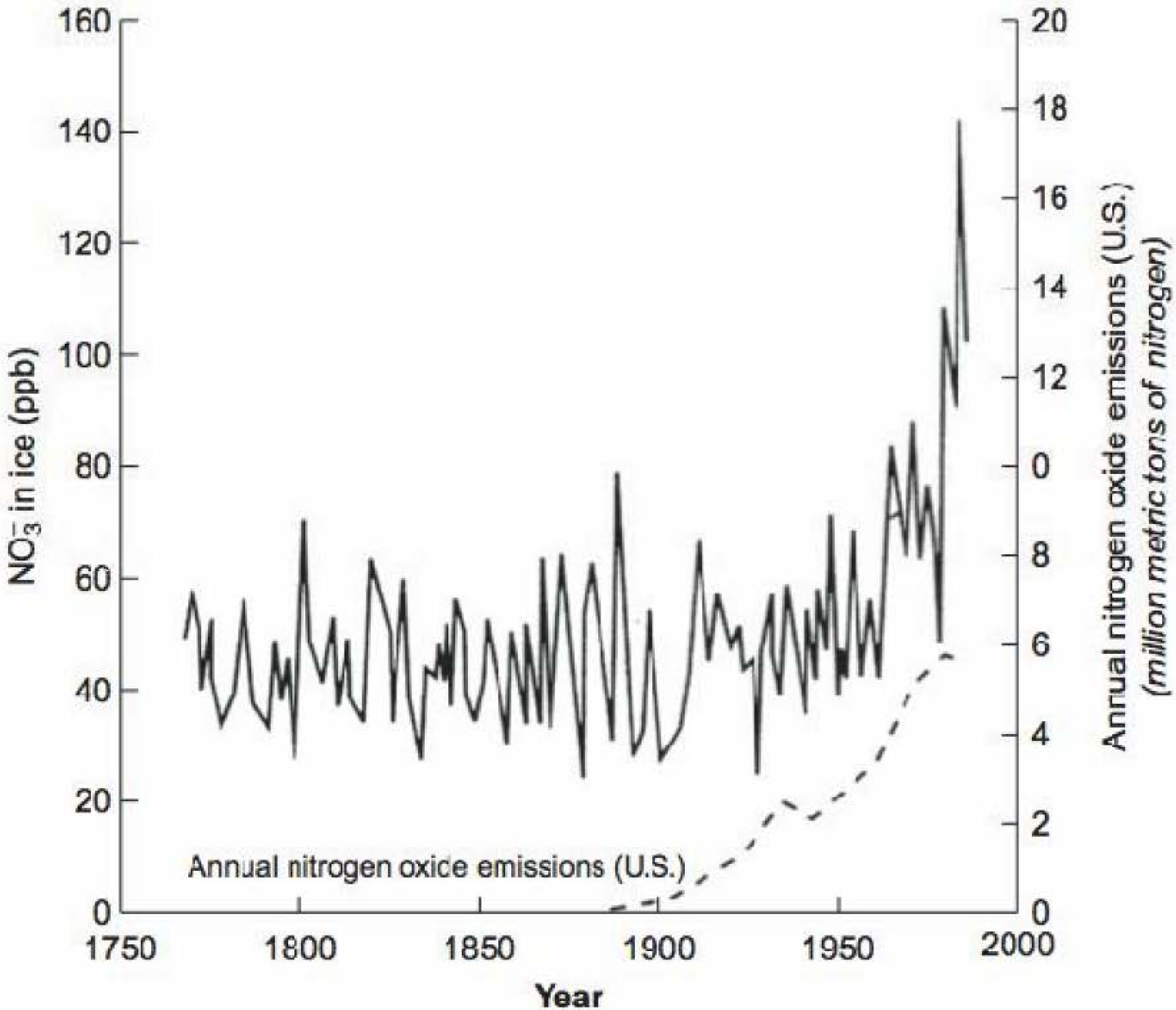


FIGURE 12.4 The 200-year record of nitrate in layers of the Greenland ice pack and the annual production of nitric oxides by fossil fuel combustion in the United States. *Source: Modified from Mayewski et al. (1990).*

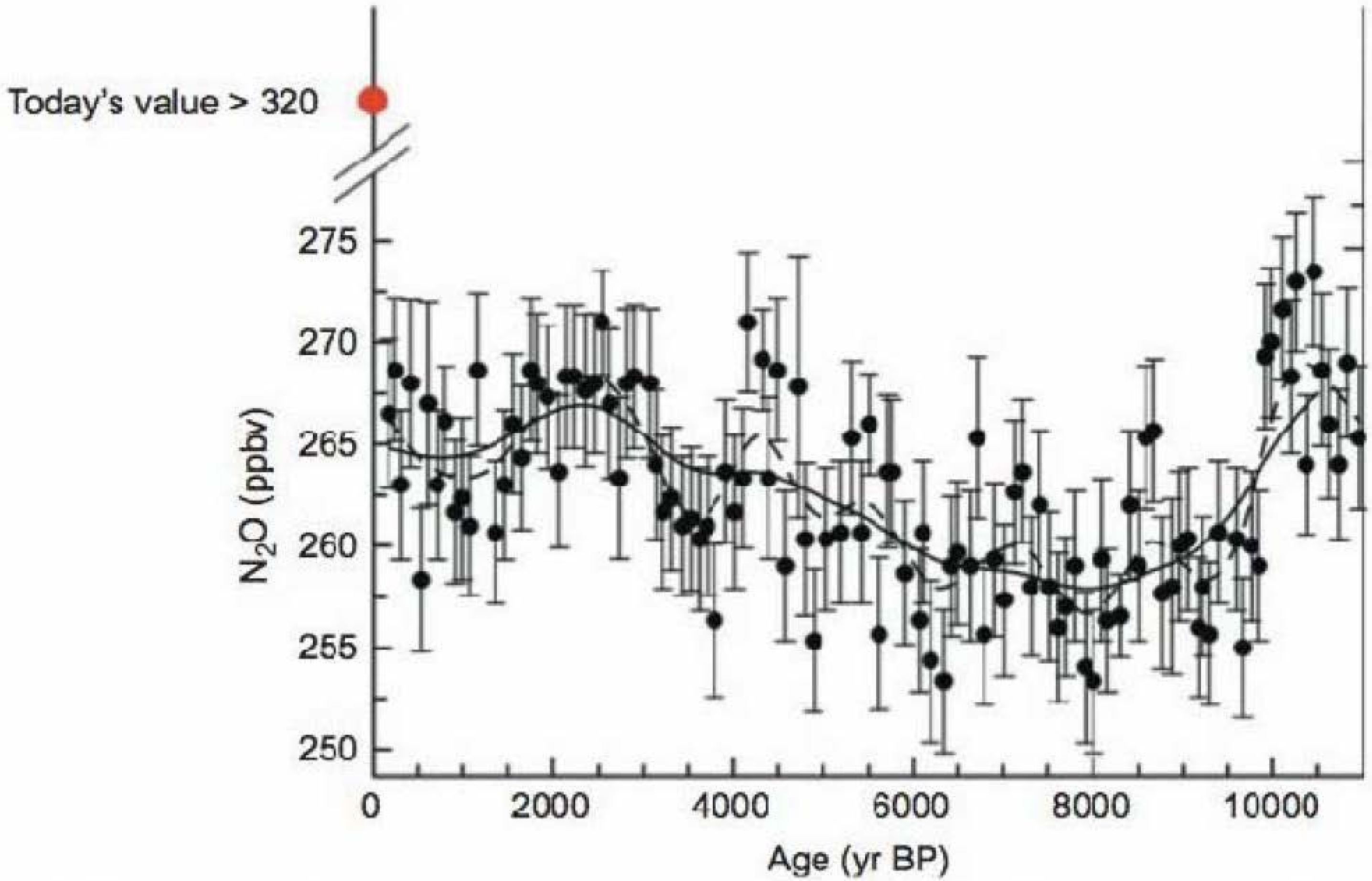
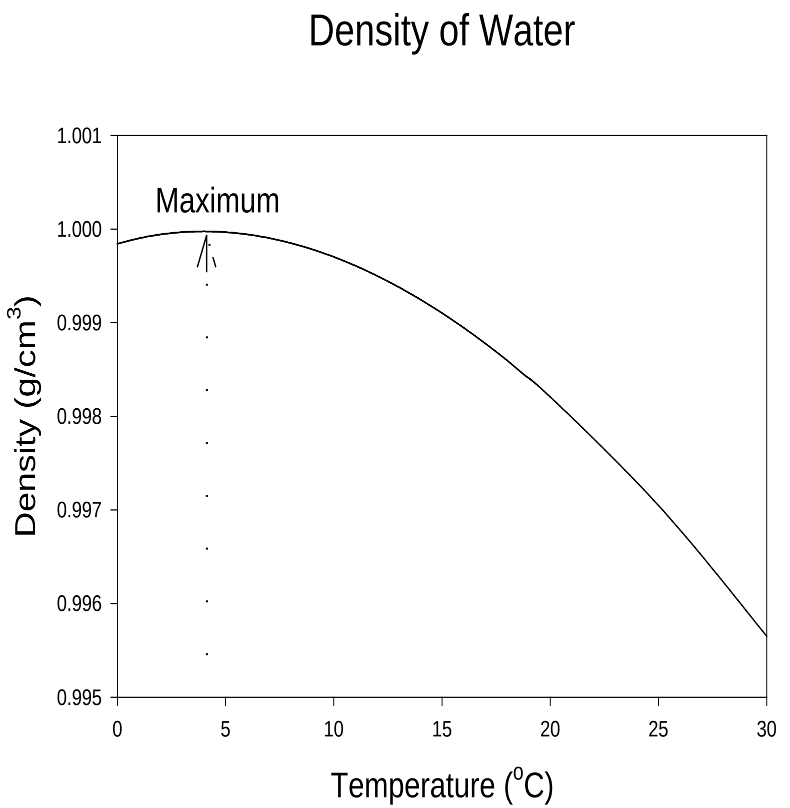
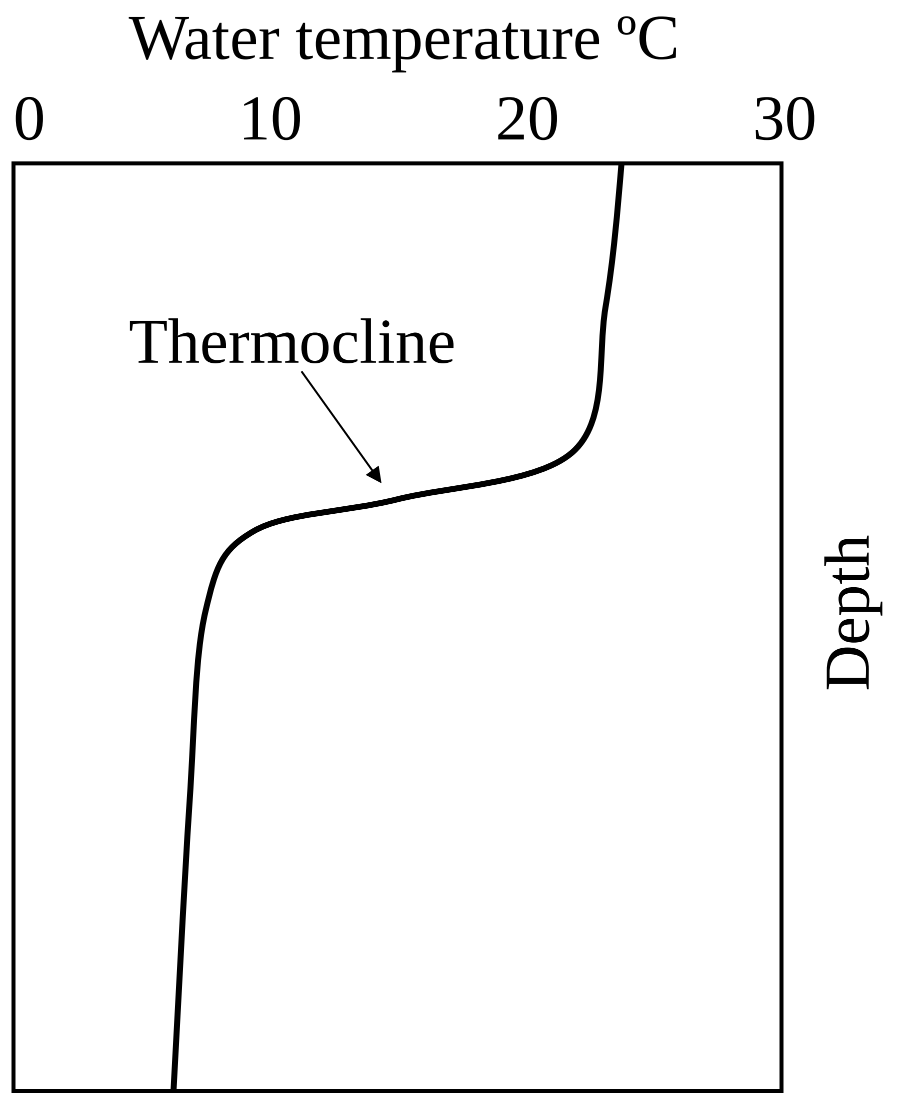


FIGURE 12.6 Nitrous oxide measurements from ice-core samples in Antarctica. *Source: From Flückiger et al. (2002).*

Thermal Stratification





So, nutrient (N & P) loading from fresh water sources and thermal stratification in the Gulf are the two primary causes of the “dead zone” phenomenon.

The time course of eutrophication
and
Hypoxia (<2 mg O_2 /L)

Turner & Rabalais 2003. BioScience 53:563-572

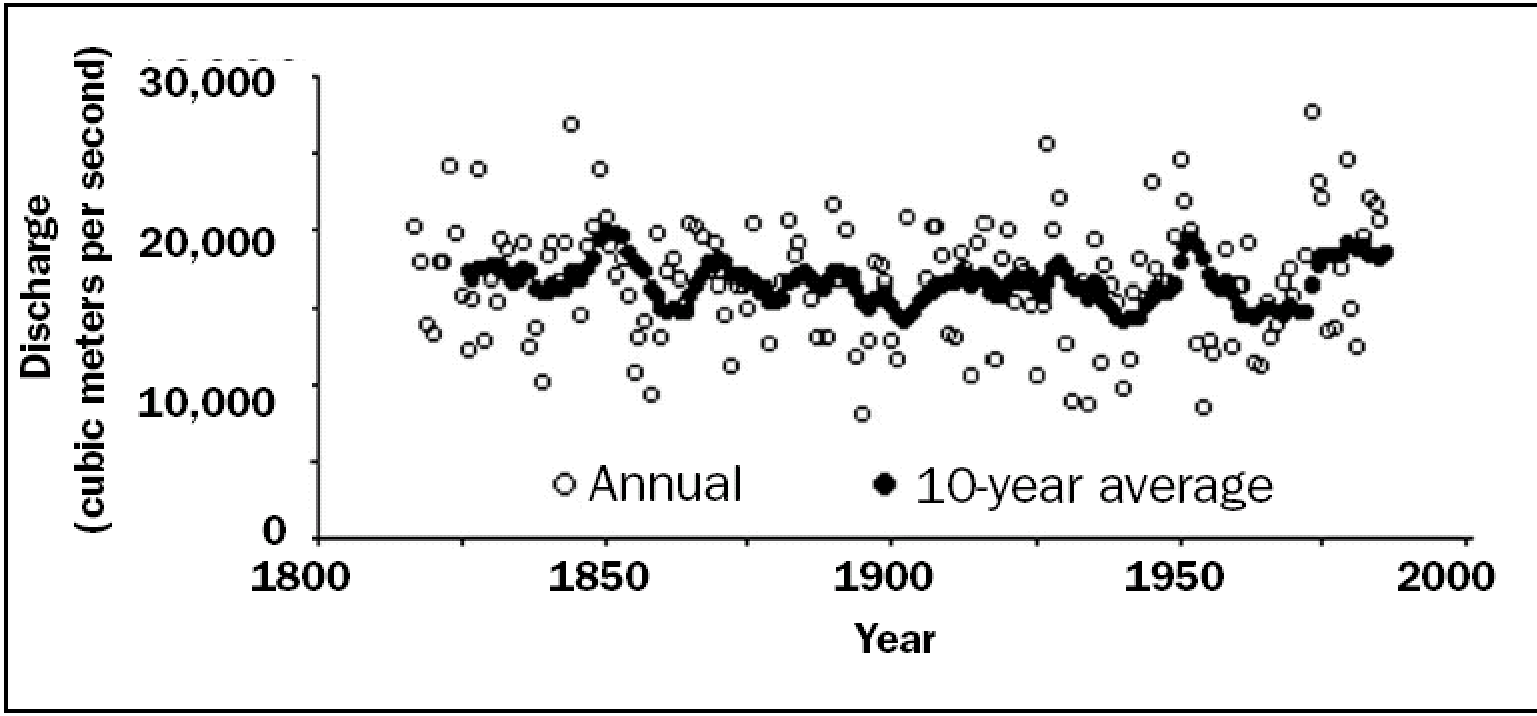


Figure 3. Mississippi River discharge at Vicksburg, Mississippi, for individual years and a 10-year moving average.

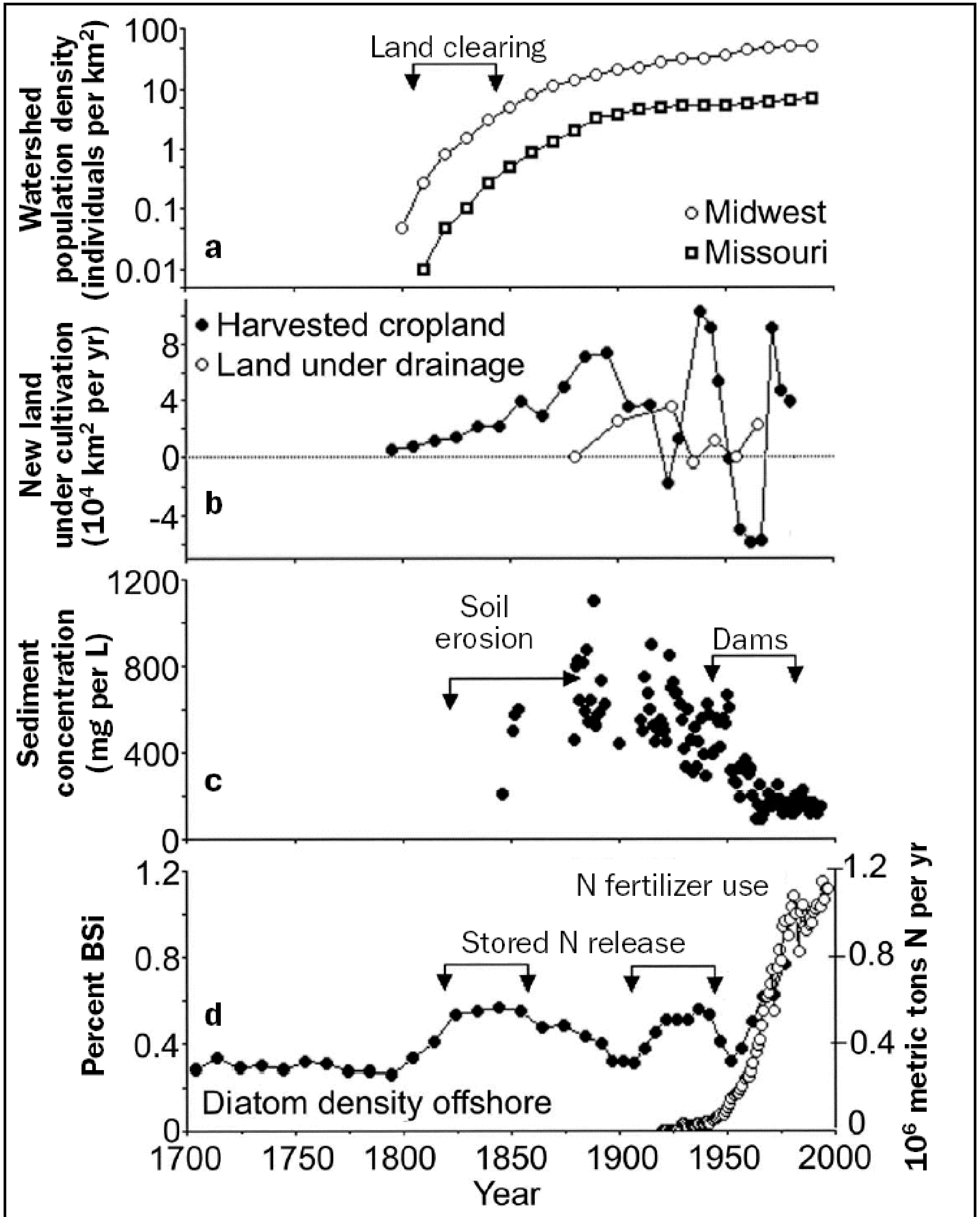


Figure 2. A summary interpretation of the relationships among population growth, land conversion to agriculture, and fertilizer use in the Mississippi River Basin (MRB) and coastal diatom production. (a) Population density in two regional groupings of states. The Midwest group consists of Ohio, Indiana, Illinois, Iowa,Michigan,Wisconsin, and Minnesota. The Missouri group consists ofMontana,Wyoming, North Dakota, South Dakota, Nebraska, and Missouri. Population data are from the US Census Bureau and exclude Native Americans and slaves in most cases before 1850 (Anonymous 1992). (b) The new area of harvested cropland and land under drainage added each year in the MRB. Cropland data for before 1860 are from Humphreys and Abbot (1876), and subsequent census estimates are from the US Department of Agriculture (USDA). The rise in harvested cropland after a decade of decline is probably taking place on previously farmed land. The new land under drainage is from USDA census estimates (irregular intervals) (USCB 1961, 1973). (c) The annual average suspended sediment concentration (milligrams per liter) at New Orleans, Louisiana. Data are from the annual reports of the New Orleans Water and Sewerage Board, Quinn (1894), and Humphreys and Abbot (1876). (d) The percentage of biogenic silica (BSi) in sediments from dated sediment cores collected near the mouth of the Mississippi River (Turner and Rabalais 1994). Percentage BSi is an indicator of biogenic silica found in diatom remains (dry weight basis). Also included is the annual flux of nitrogen in the Mississippi River from 1920 to 1987.

Turner & Rabalais 2003. BioScience 53:563-572

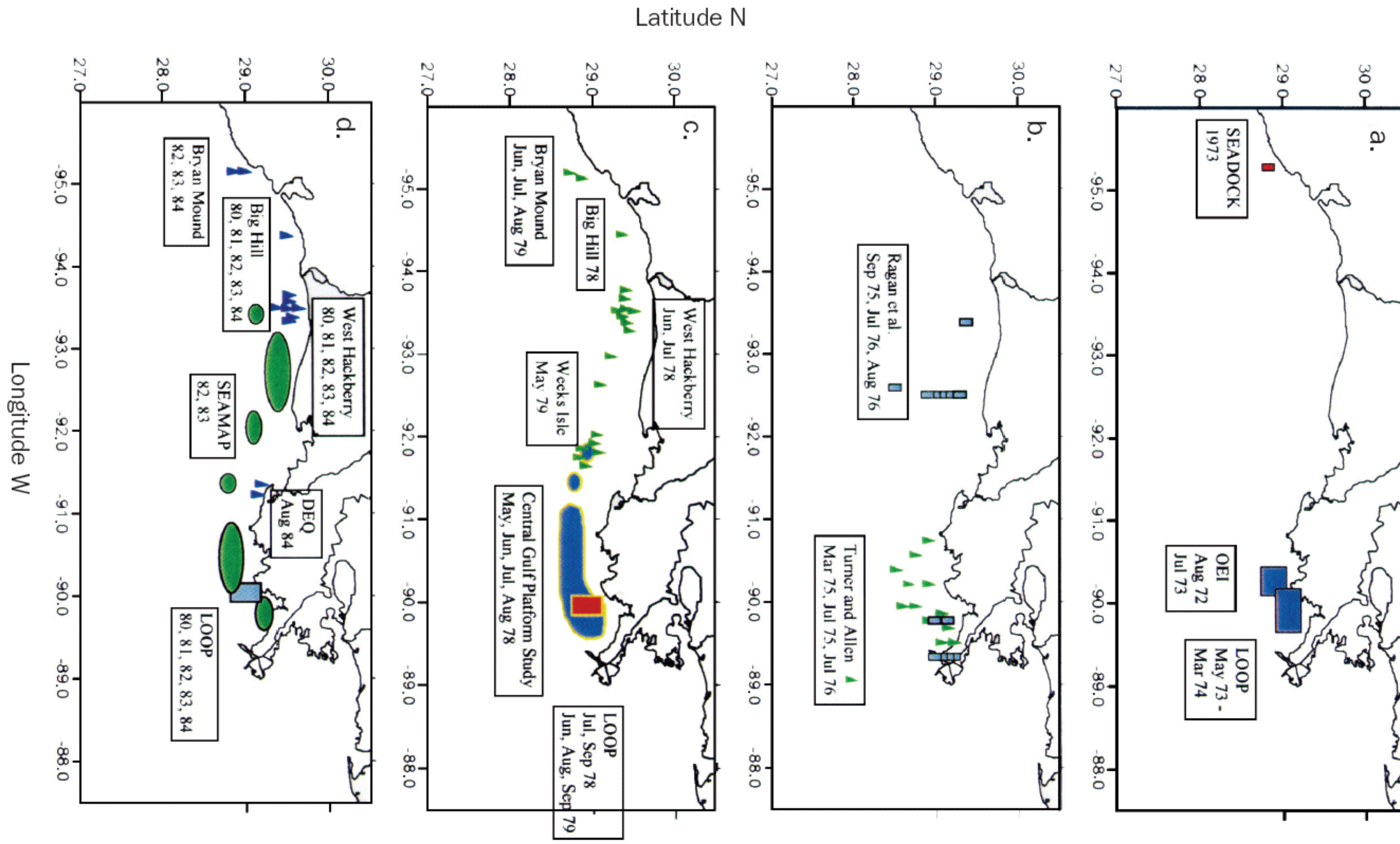


Figure 2. Reports of hypoxia: Summary of studies, locations, and dates. Panel a, Seadock (Oetking et al. 1974) and LOOP, Louisiana Offshore Oil Port (Turner et al. 1998b); sites of proposed offshore oil offloading facilities; and OEI, Offshore Ecology Investigation (Oetking et al. 1974,Ward et al. 1979). Panel b, Ragan et al. (1978) and Turner and Allen (1982). Panel c, Central Gulf Platform Study (Bedinger et al. 1981) is in blue; Strategic Petroleum Reserve Program is identified by green triangles (Jackson and Faw 1980,Harper et al. 1981, Kelly et al. 1983, 1984, Gaston 1985, Pokryfki and Randall 1987); and continued monitoring at LOOP, red rectangle (Turner et al. 1998b). Panel d, SEAMAP (Southeast Area Monitoring and Assessment Program) groundfish surveys, ovals (Gulf States Marine Fisheries Commission 1982, Leming and Stuntz 1984, Renaud 1986, Craig et al. 2001); continued Strategic Petroleum ReserveProgram, purple triangles; and continued LOOP, rectangle.

From: Rbalais, Turner & Scavia. 2002. Bioscience 52:129-142.

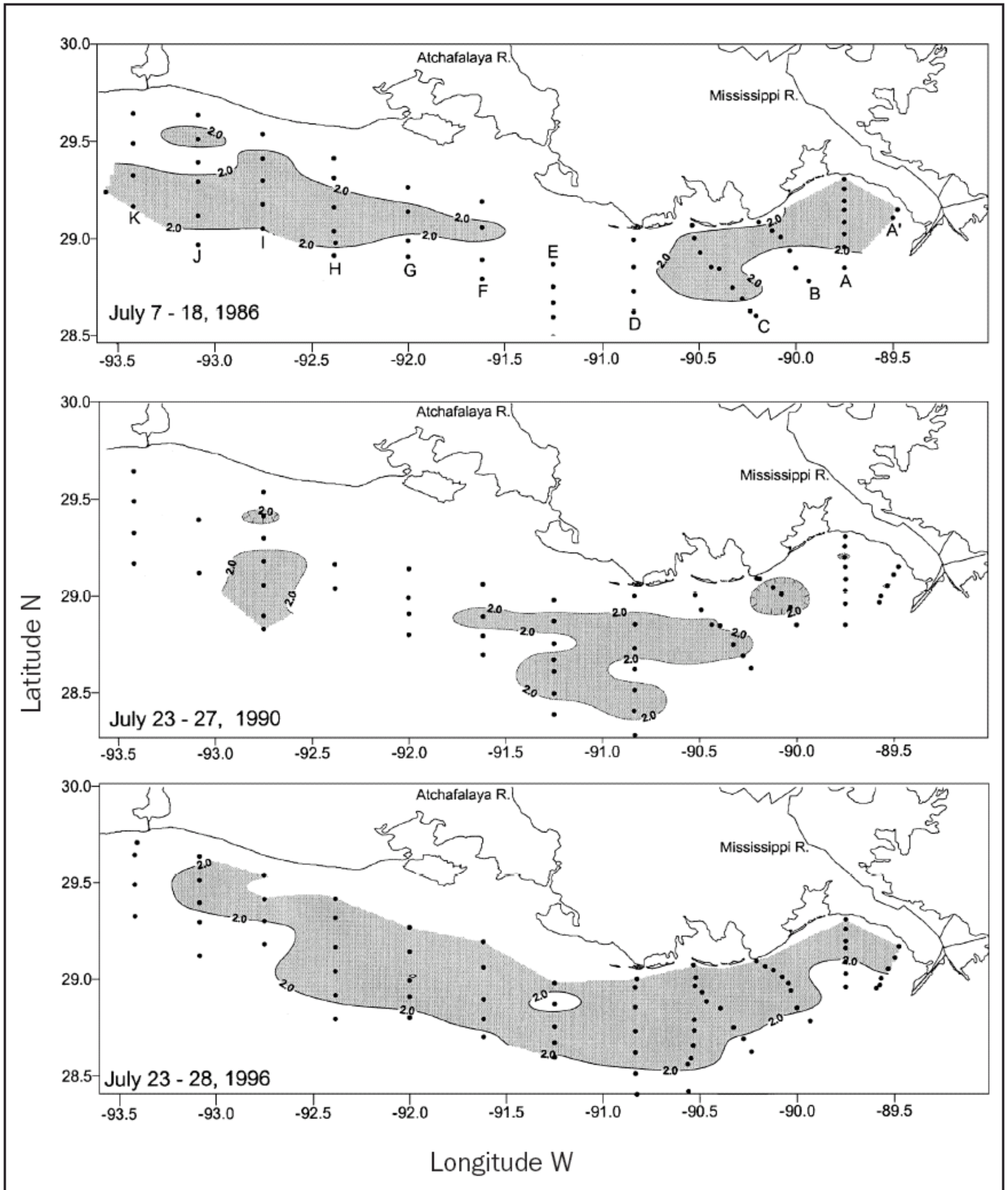


Figure 3. Midsummer distribution of bottom water with less than 2 mg per L dissolved oxygen. From Rabalais et al. 1991, 1999.

From: Rbalais, Turner & Scavia. 2002. Bioscience 52:129-142.

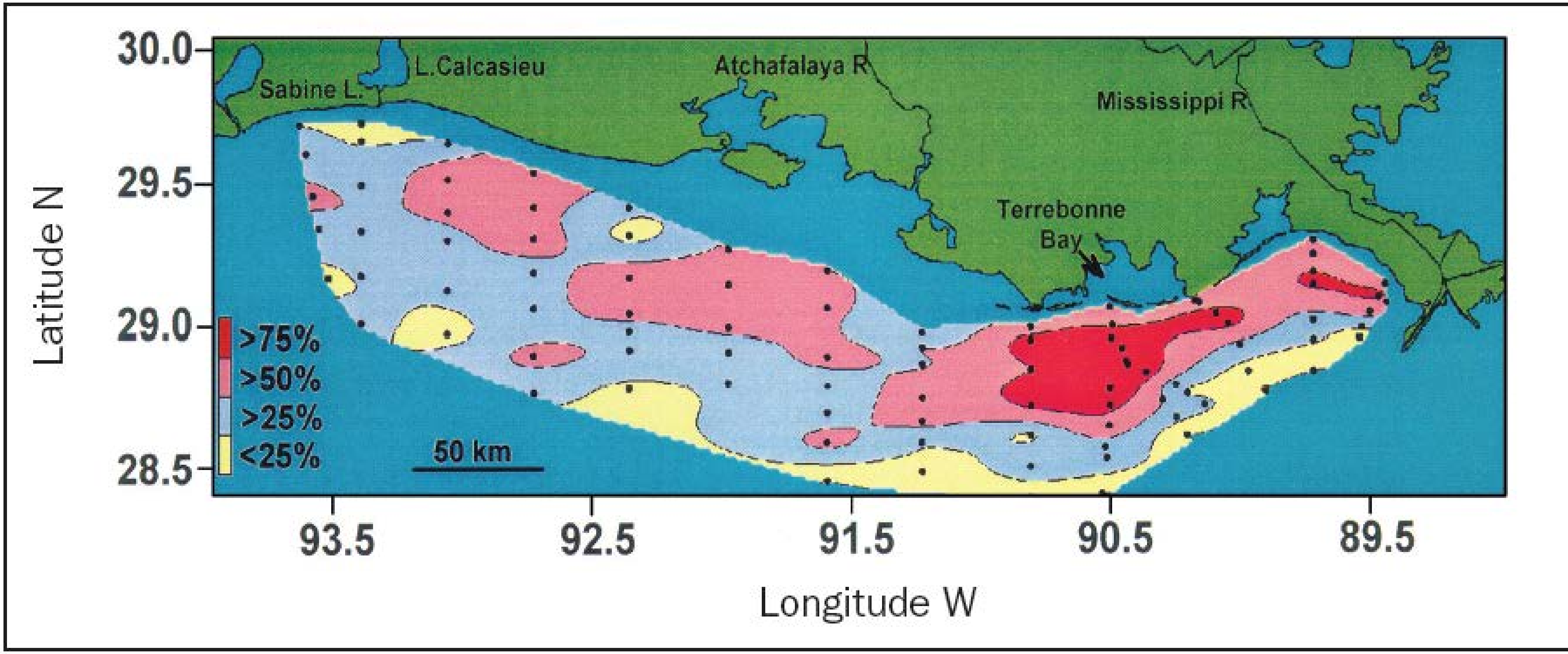


Figure 4. Frequency of occurrence of midsummer hypoxia over the 60–80-station grid, 1985–2001. Modified from Rabalais and Turner 2001a.

From: Rbalais, Turner & Scavia. 2002. Bioscience 52:129-142.

What can we do about it?

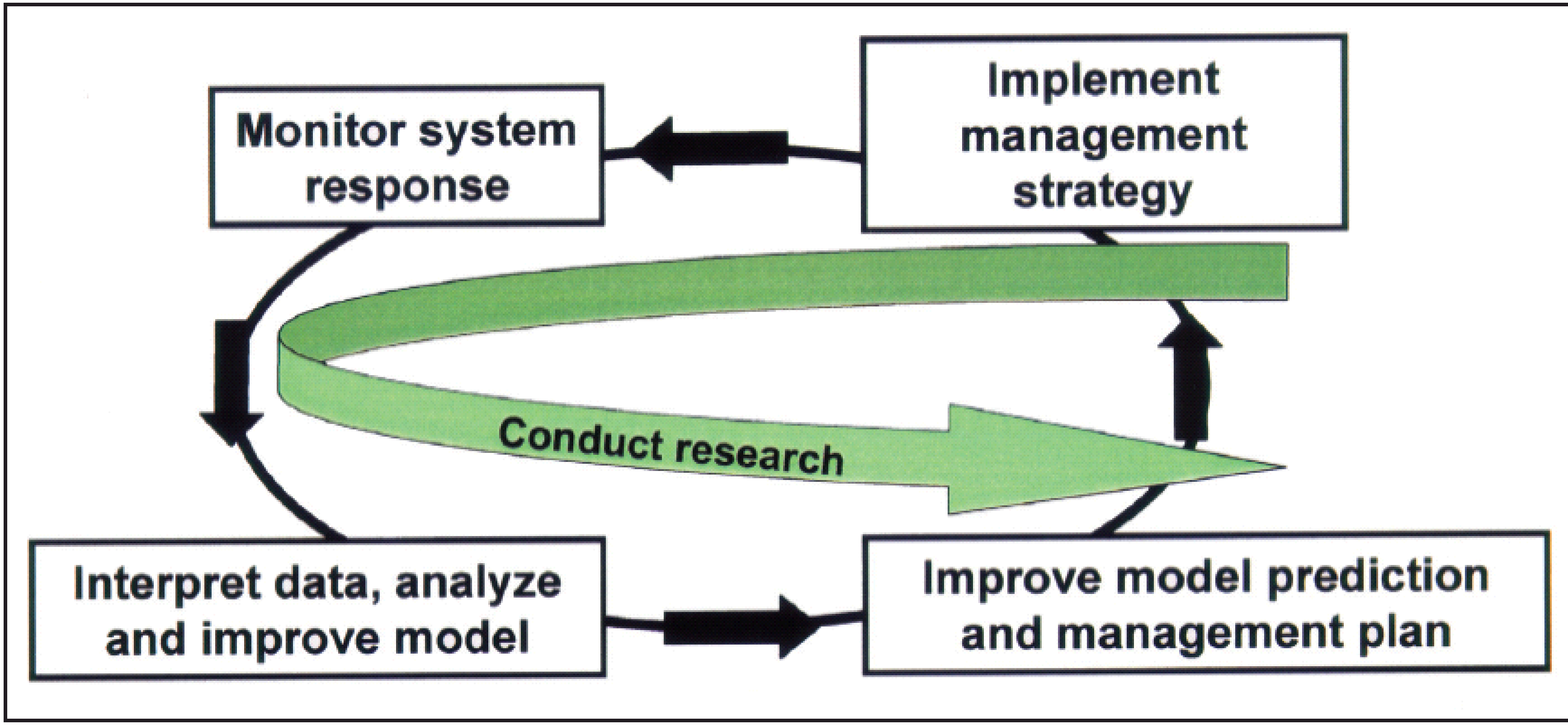


Figure 8. Adaptive management framework that connects monitoring, analysis, and management actions with continuous feedback for improvement. New understandings from research should be interwoven throughout the process (Herb Buxton, US Geological Survey, in Congressional Committee on Environment and Natural Resources 2000).

(Rbalais, Turner & Scavia. 2002. Bioscience 52:129-142)

How to reduce the nutrient load?

1. Science and Technology
2. Policy changes
3. Societal changes
4. Be patient (time lags)!

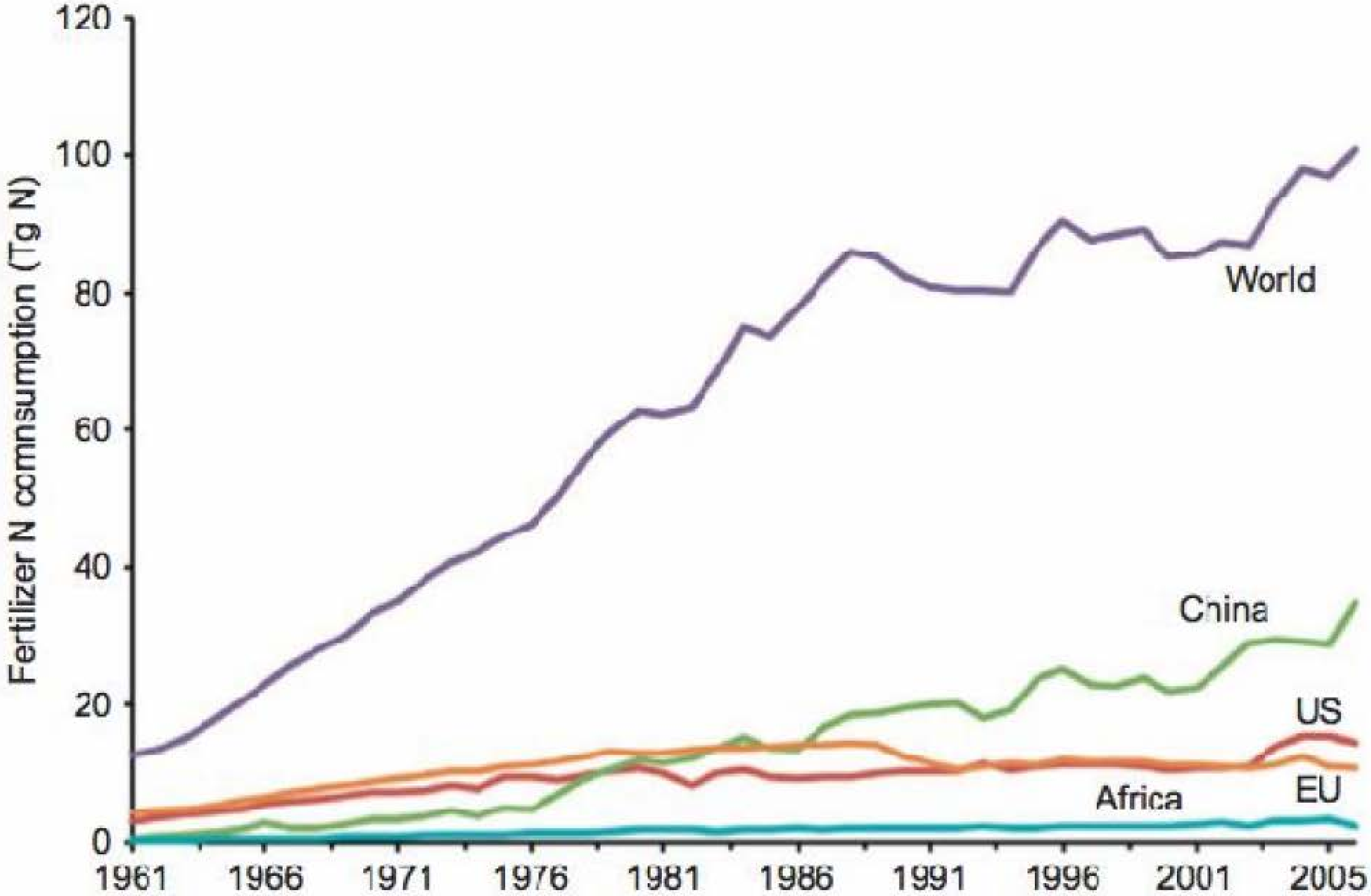
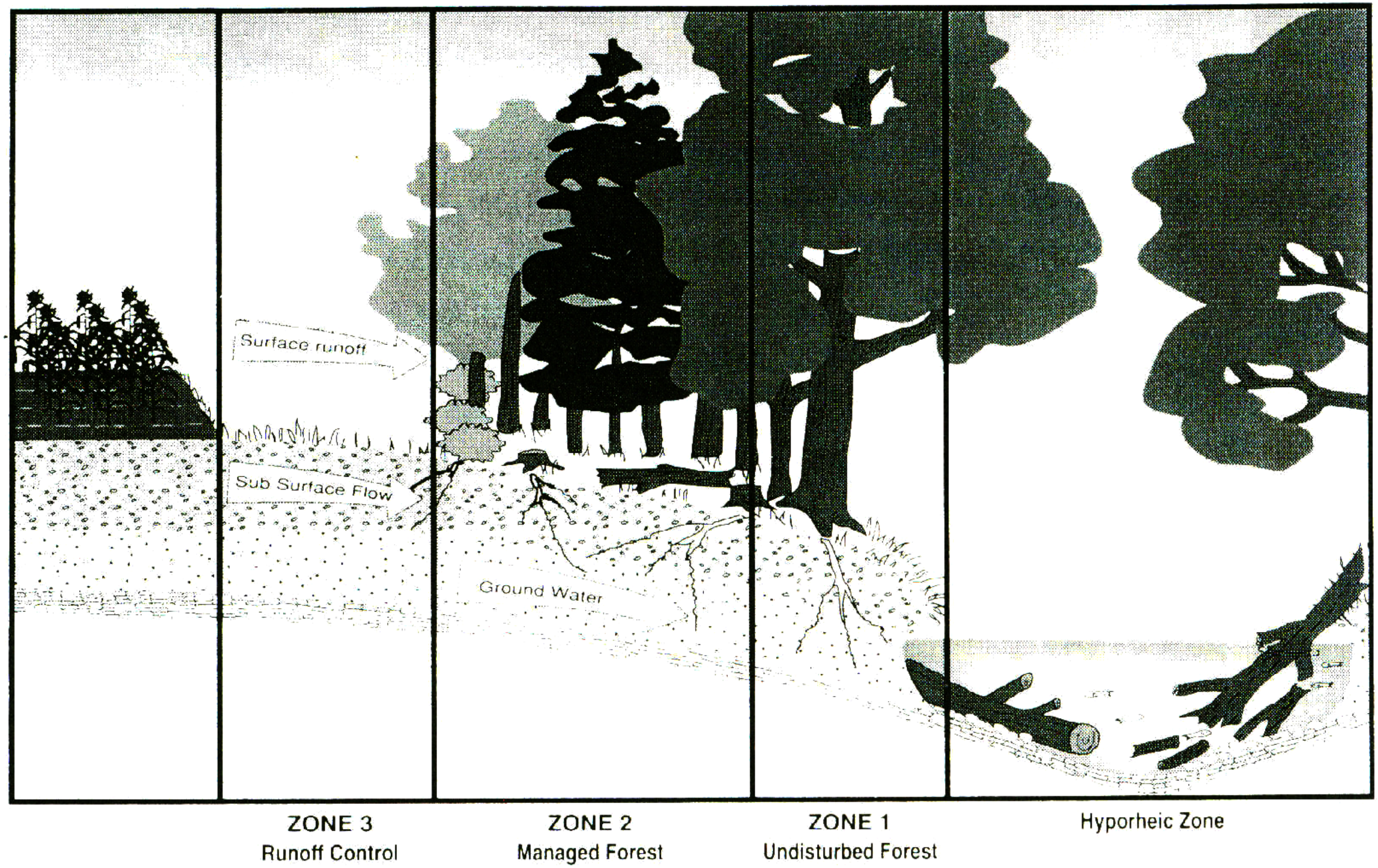


FIGURE 12.5 The production history of nitrogen fertilizer. *Source: From Robertson et al. (2009). Used with permission of the Annual Review.*

An example of a riparian buffer zone



From: Lowrance 1998. Successes, Limitations, and Frontiers in Ecosystem Science. Pace & Groffman eds. Springer

TABLE 5.1. Difference in nitrogen forms entering the riparian ecosystem in shallow groundwater and leaving in streamflow.[1]

	Groundwater Input	Streamflow Output	Difference (Input-Output)
NO_3^--N	10,153	1,000	9,153
NH_4^+-N	990	112	878
Organic N	2,325	4,470	−2,145

[1] All units are kg per year for the entire riparian zone (from Lowrance et al. 1983).

From: Lowrance 1998. Successes, Limitations, and Frontiers in Ecosystem Science. Pace & Groffman eds. Springer

Summary

1. Non-point source pollution is a difficult environmental issue.

2. Nutrient loading from nonpoint-source pollution is the main cause of the eutrophication and hypoxia/anoxia in the Gulf of Mexico.

3. Because of ecosystem holding/buffering capacity, there often is a time lag between the beginning of nutrient loading and the occurrence of eutrophication and hypoxia.

4. The adaptation of riparian buffer zone in agricultural landscapes may lessen the nutrient loading to the watershed for some regions.

5. Reduction of nutrient loading will ultimately require actions from all sectors of the society.

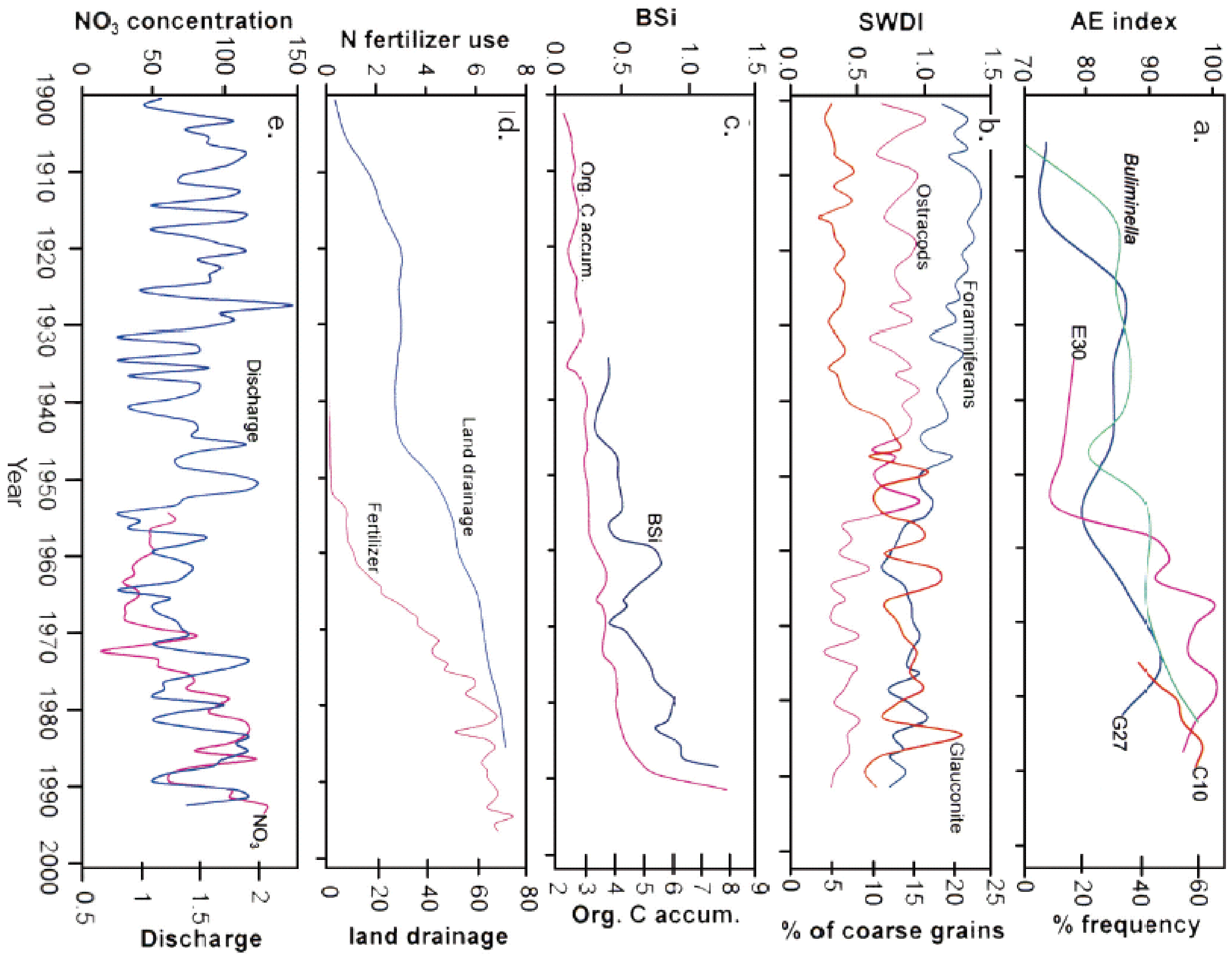


Figure 5. Changes since the beginning of the 20th century in indicators of Gulf of Mexico productivity and oxygen stress and Mississippi River basin landscape use and riverine fluxes. Panel a, A-E index for cores C10 (3-year running average), E30, and G27 (Sen Gupta et al. 1996); percentage frequency of Buliminella in core G27 (Rabalais et al. 1996). Panel b, SWDI (Shannon-Wiener Diversity Index) for foraminiferans and ostracods (Nelsen et al. 1994; TA Nelsen [National Oceanic and Atmospheric Administration,Miami, Florida], personal communication, 1999); percentage of glauconite in coarse-grain sediment (Nelsen et al. 1994). Panel c, BSi (biologically bound silica, frequency) for core E30 (Turner and Rabalais 1994); organic carbon accumulation (mg · m–2 · yr –1) (Eadie et al. 1994). Panel d, nitrogen fertilizer use in the Mississippi River basin (millions of metric tons per year) (Goolsby et al. 1999); land drainage (millions of acres) (Mitsch et al. 2001). Panel e, nitrate concentration (∝M) in the lower Mississippi River (Turner et al. 1998a); lower Mississippi River discharge (10,000 m3 per second; Bratkovich et al. 1994).