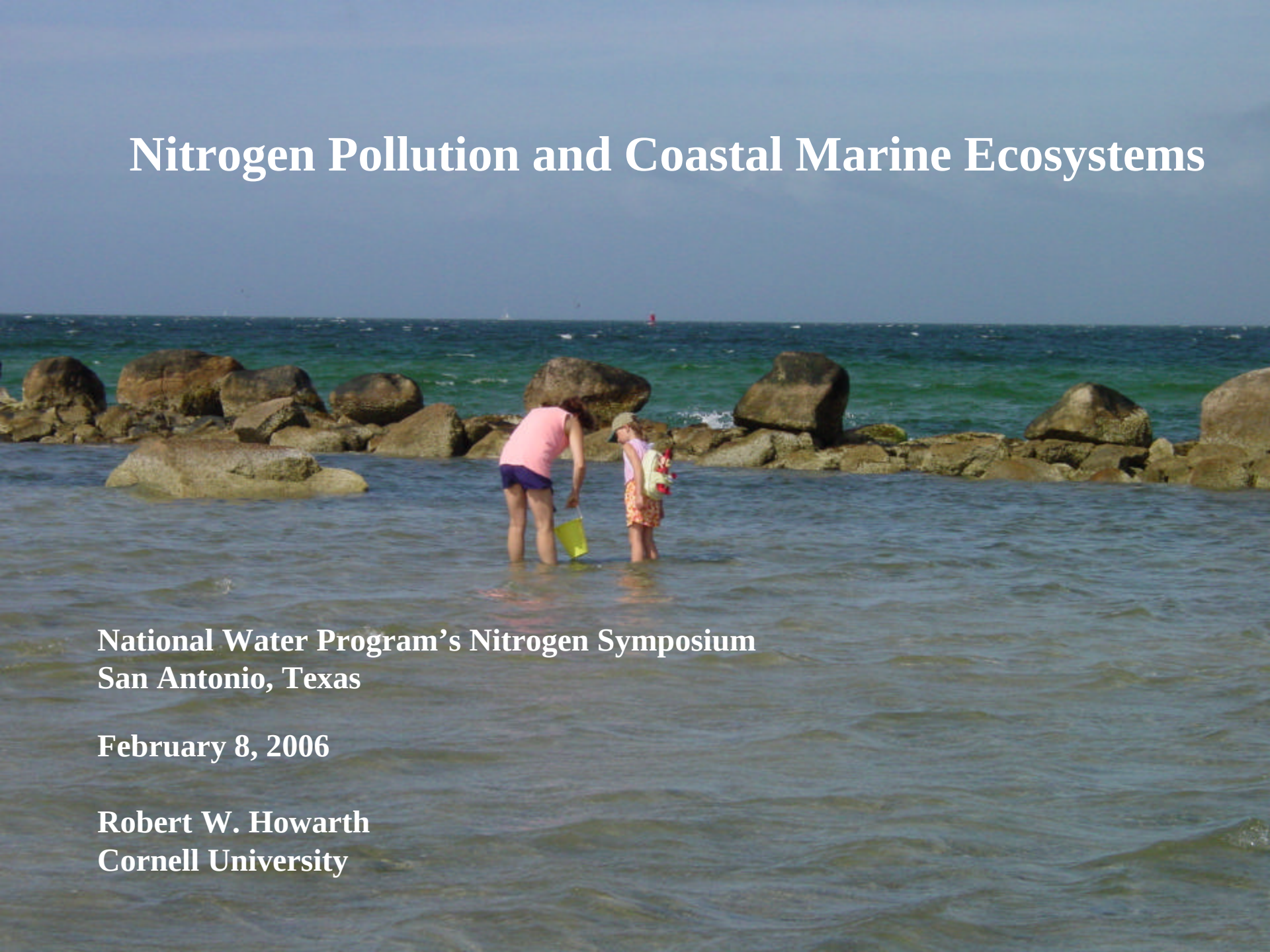
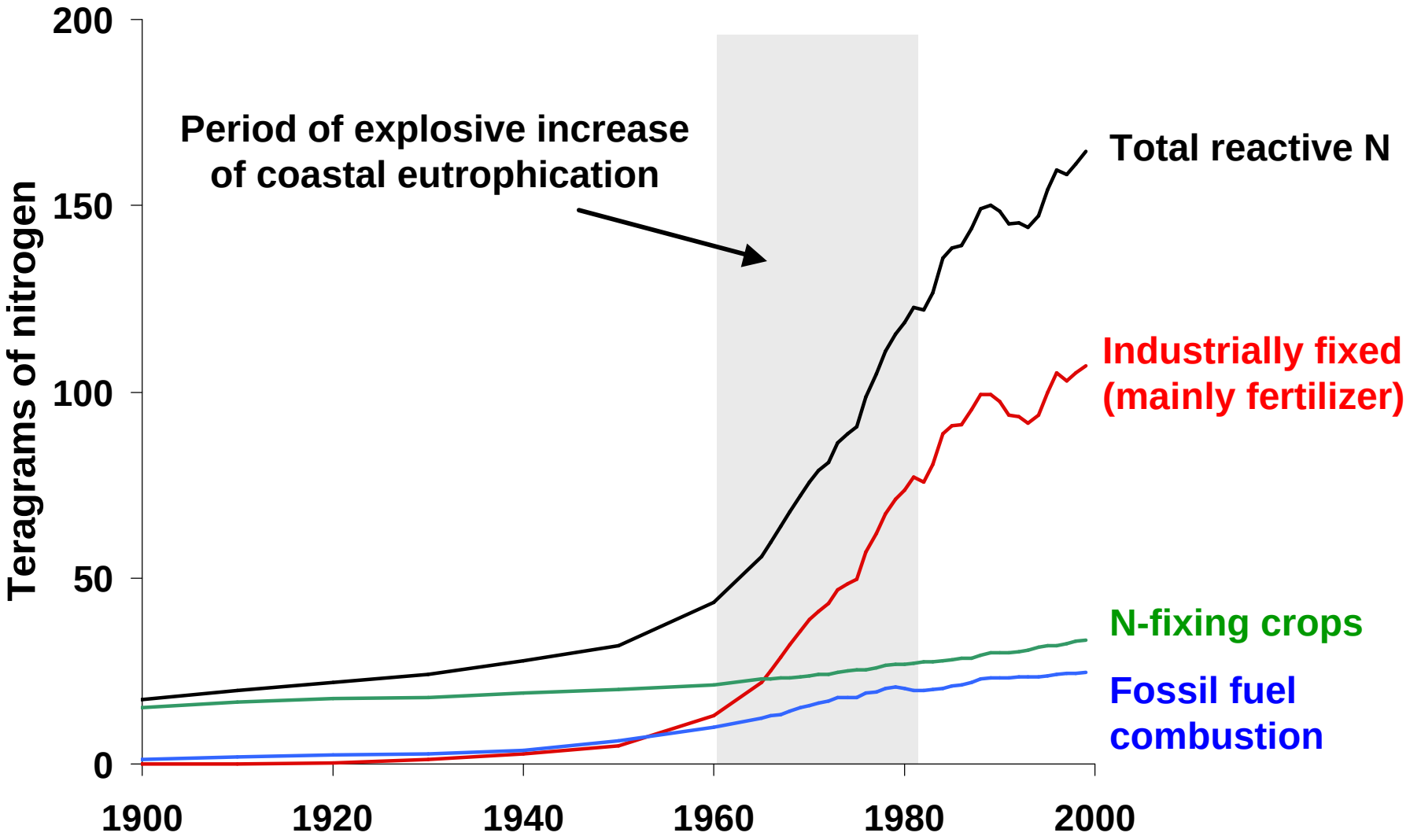
# Nitrogen Pollution and Coastal Marine Ecosystems



National Water Program's Nitrogen Symposium
San Antonio, Texas

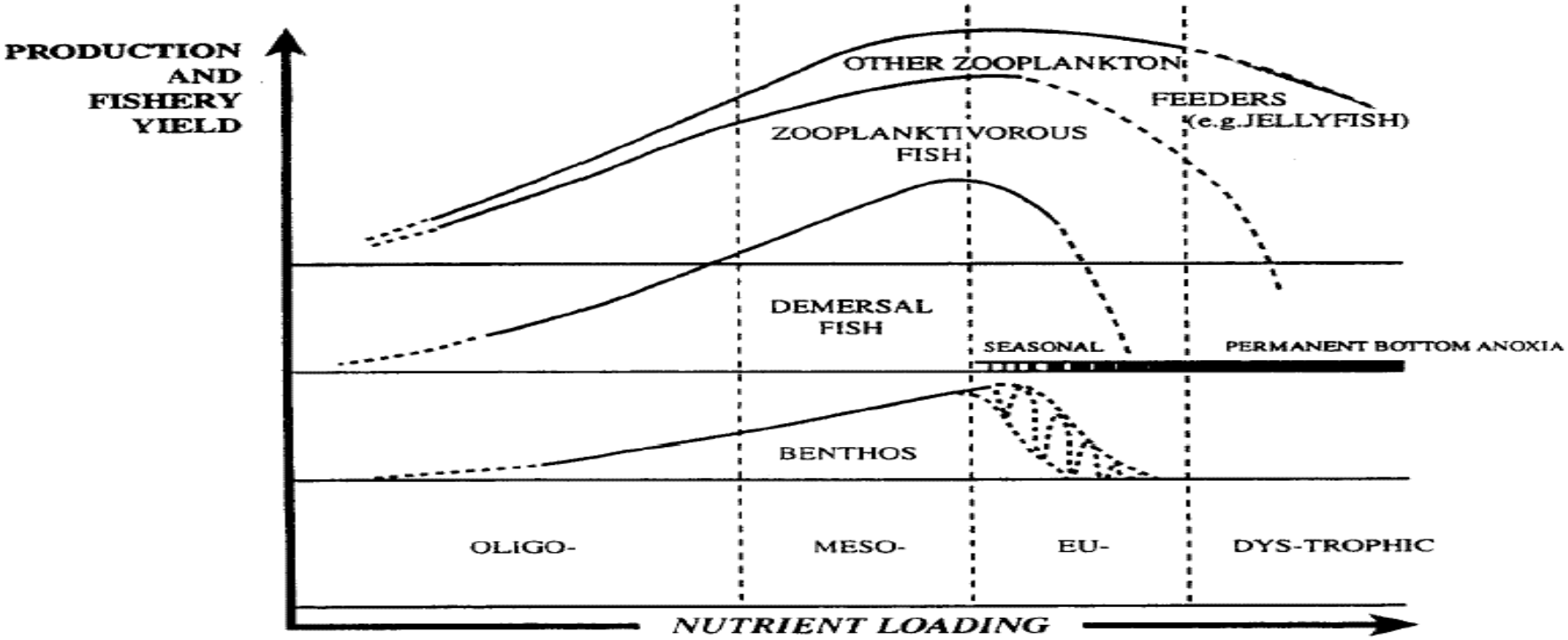
February 8, 2006

Robert W. Howarth
Cornell University

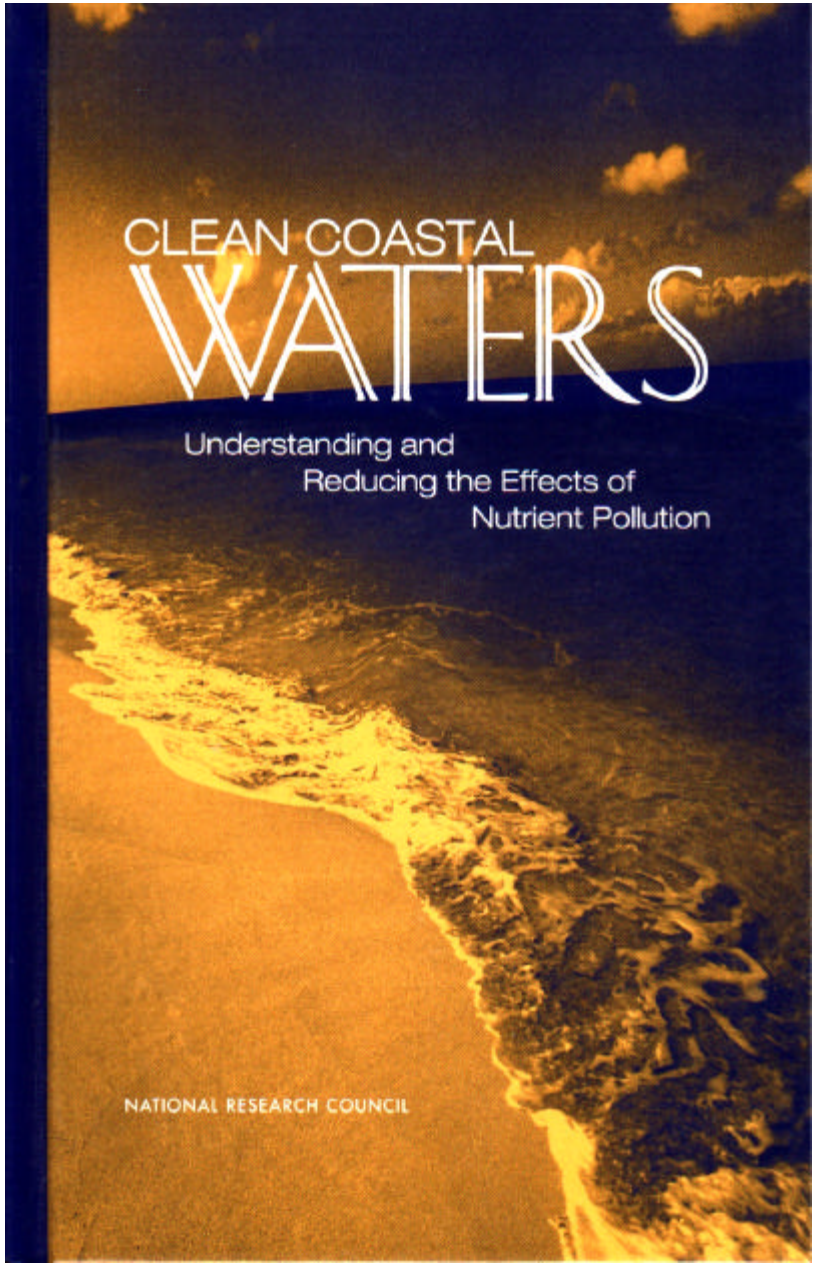



(Boesch 2002; Galloway et al., 2004)

# More Nutrients = More Production = More Fish To a Point, Then .....




(Caddy, 1993)




# NRC 2000:

**Nitrogen is now the largest pollution problem in the coastal waters of the United States.**

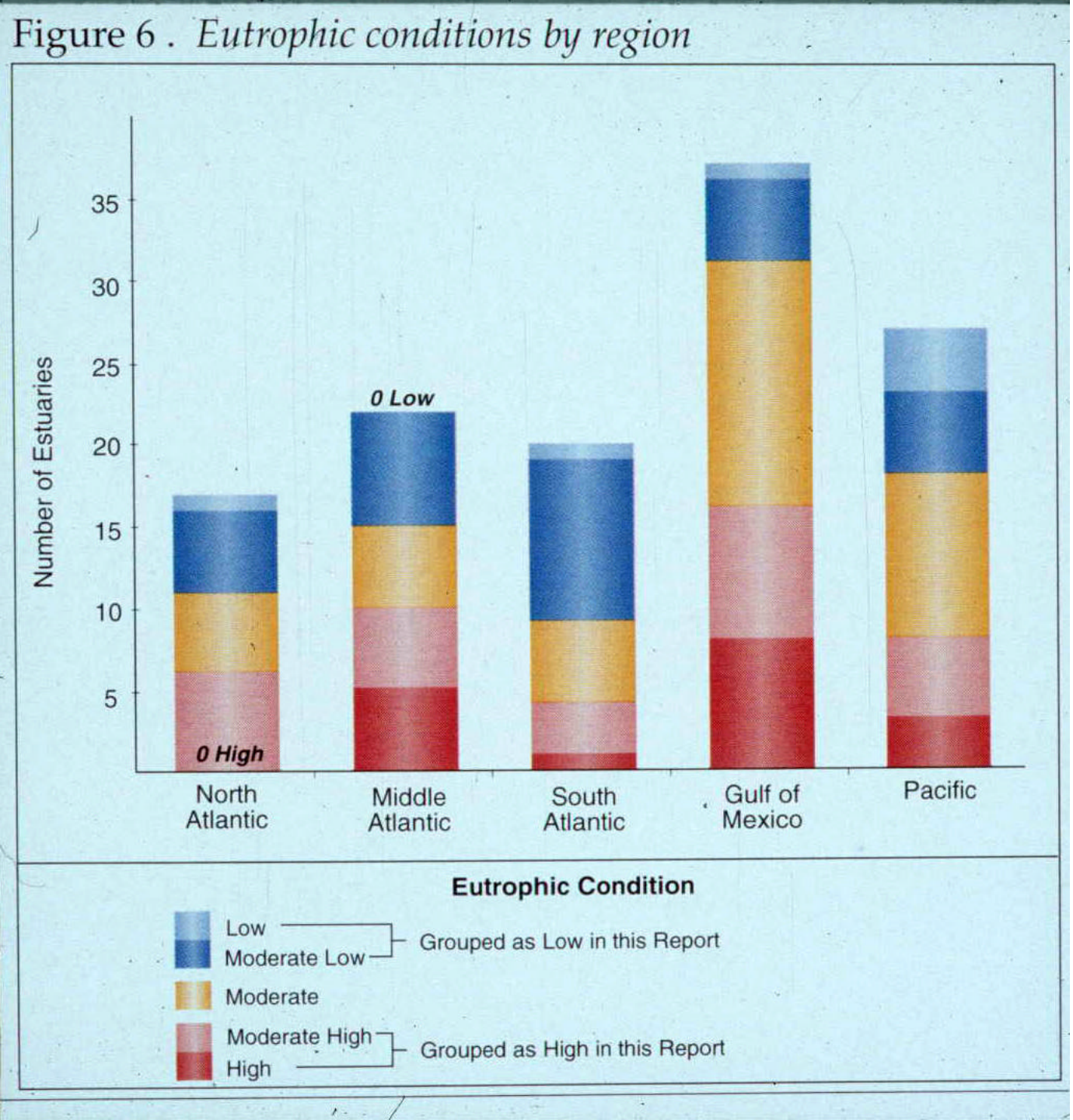
**Two thirds of coastal rivers and bays are moderately to severely degraded from nitrogen pollution.**

Yellowstone River
Missouri River
Mississippi River
Platte River
Illinois R.
Ohio River
Arkansas River
St Louis
Tennessee River
Red River
Mississippi River
New Orleans
0 200 KILOMETERS
0 200 MILES

# Impact on Gulf of Mexico Fin Fish

| Species | Water Column Distribution | Relative CPUE 1933 | | Relative CPUE 1989 |
|---|---|---|---|---|
| Bay anchovy | Pelagic | 29.9 | ↑ | 55.7 |
| Gulf menhaden | Pelagic | 14.1 | ↑ | 26.9 |
| Sand seatrout | Demersal | 25.1 | ↓ | 17.7 |
| Atlantic croaker | Demersal | 207.4 | ↓ | 16 |
| Sea catfish | Demersal | 15.1 | ↓ | 10.6 |
| Spot | Demersal | 8.3 | ↓ | 4.4 |
| Atlantic bumper | Pelagic | 1.1 | ↑ | 3.5 |

Chesney & Baltz 2000




**National assessment by NOAA of extent and severity of coastal nutrient pollution in USA.**

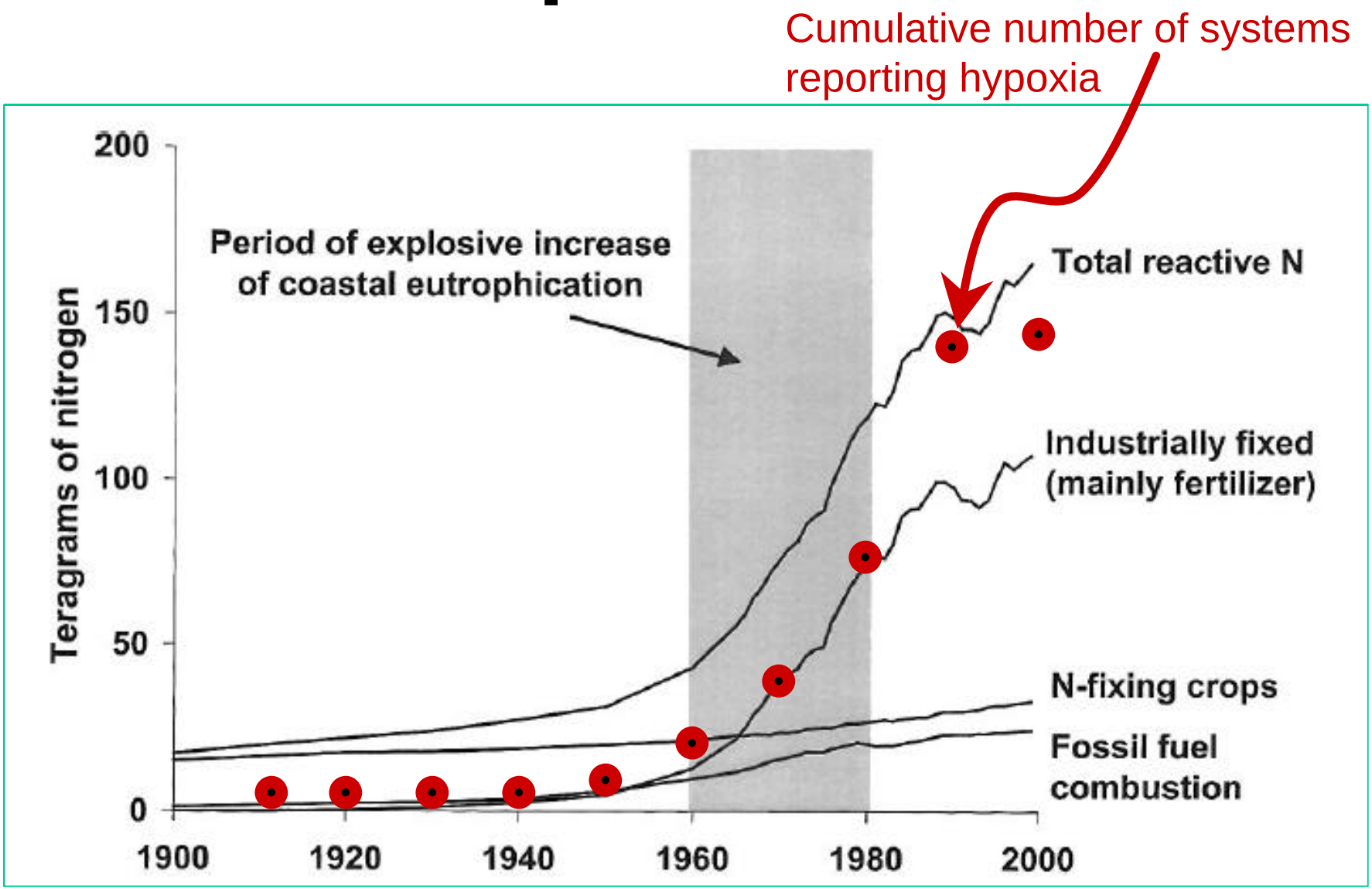
**All coastlines affected.**

**2/3rds of coastal rivers and bays degraded.**

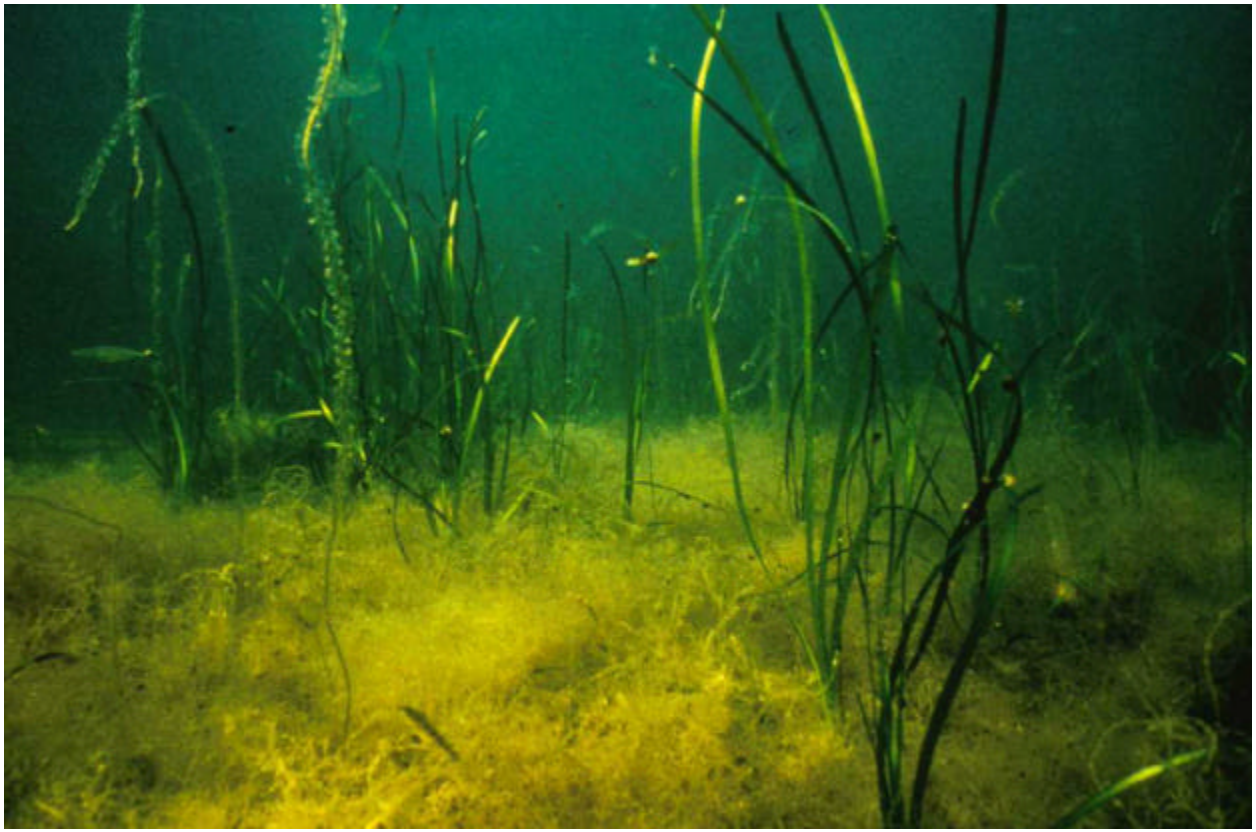
*(Bricker et al. 1999)*

# “Dead zones,” or hypoxic areas – major global problem (UNEP, March 2004)

# Global Impacts

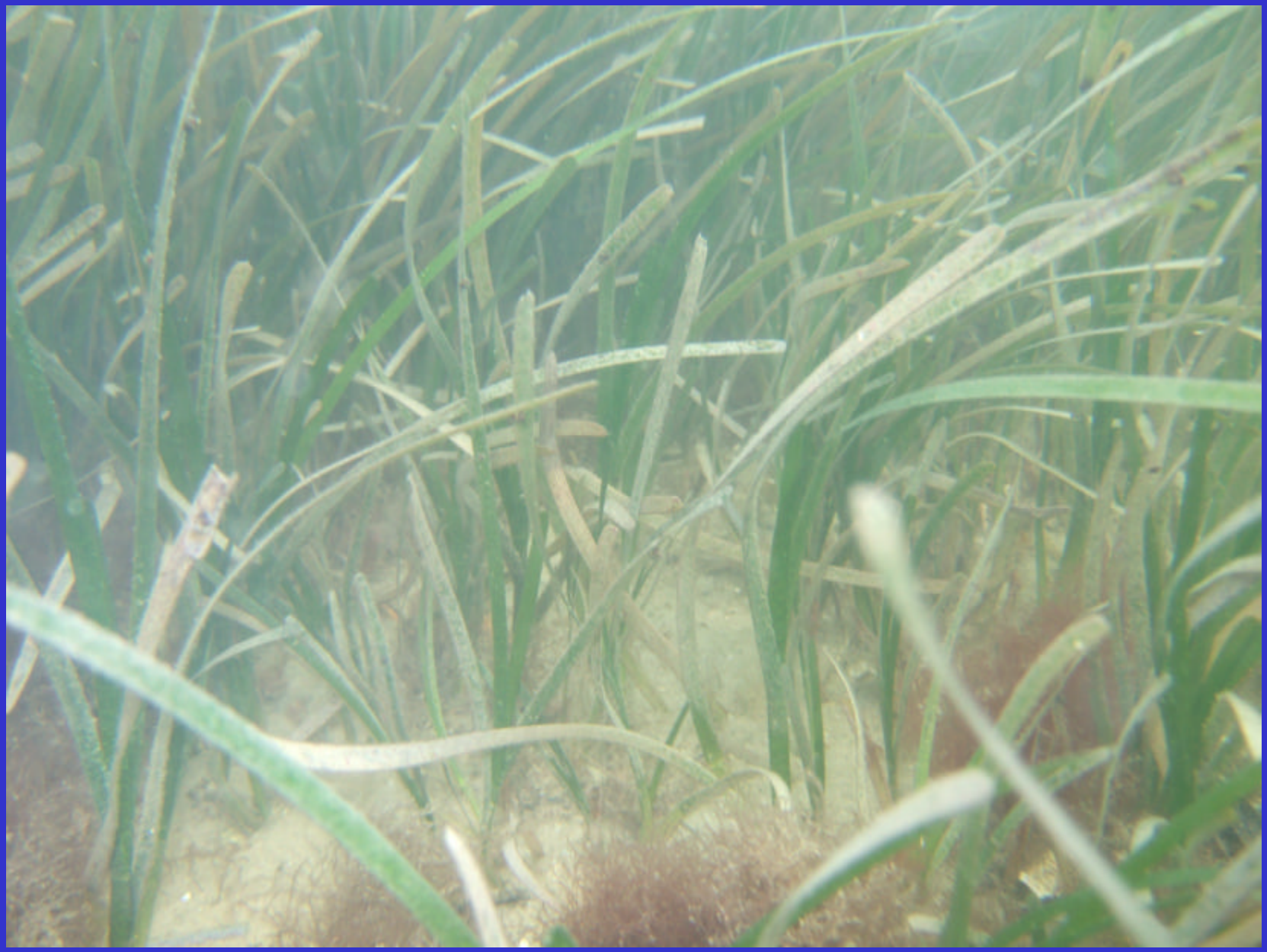



Modified from R. Diaz



**Nitrogen effects beyond hypoxia & anoxia ("dead zones"):**

- **habitat degradation and alteration of ecological structure, loss of diversity**
- **increased incidence and duration of harmful algal blooms**



WARNING . . .
TOXIC SHELLFISH
SHELLFISH FROM THIS AREA ARE UNSAFE TO EAT DUE TO PARALYTIC SHELLFISH TOXIN.
DO NOT EAT CLAMS, OYSTERS, MUSSELS OR SCALLOPS.
Red Tide Hotline
1-800-562-5632
TDD RELAY SERVICE
1-800-833-6388
For information call (360) 753-5982
Health

Since 1975…..

**Substantial progress in controlling P inputs to aquatic ecosystems – low-P detergents, P removal in sewage treatment, BMPs to reduce erosion.**

**Substantial improvement in water quality in many freshwater lakes, particularly Great Lakes.**

**Water quality in coastal marine ecosystems has deteriorated!**

**P regulates eutrophication lakes, but N in coastal systems.**

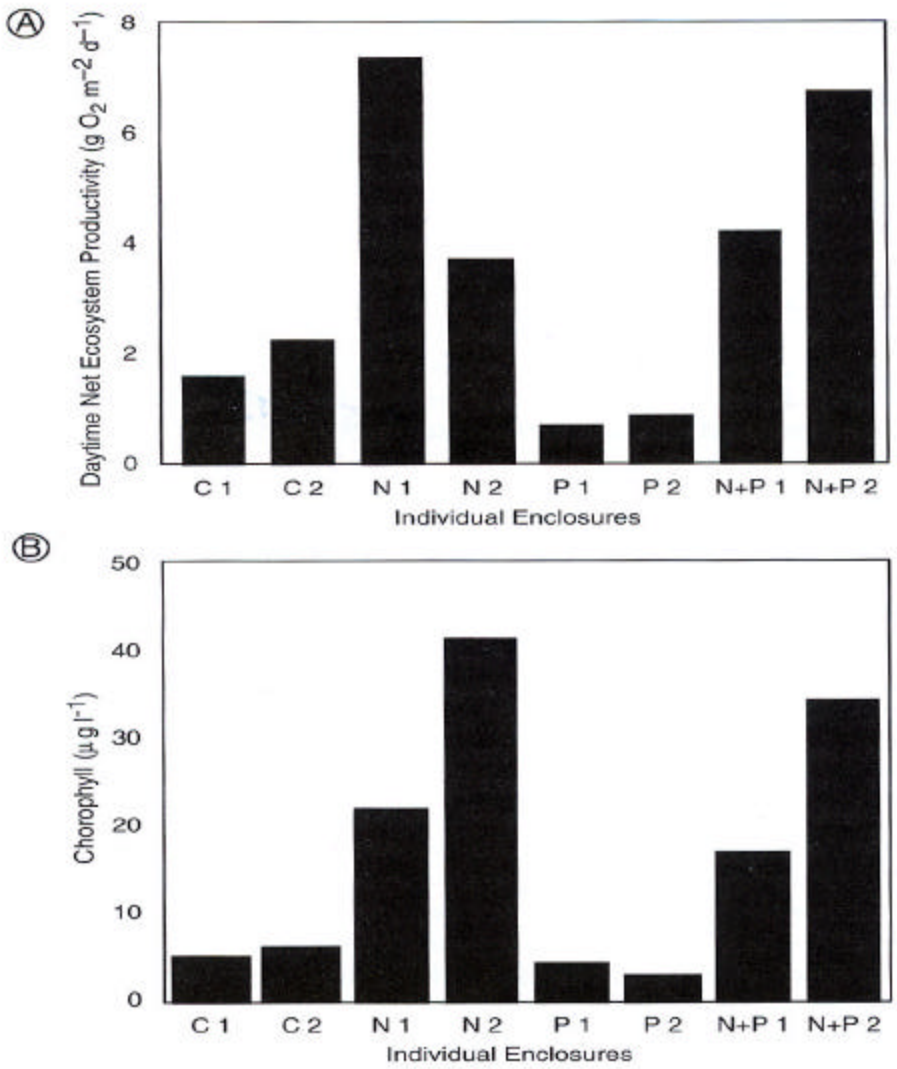
Water quality managers and engineers slow to accept N limitation in coastal systems…..discounted bioassay data. But in past 10-15 years, new types of evidence:

Mesocosm and whole –ecosystem studies in estuaries.

Improved understanding of mechanisms driving N vs P limitation in estuaries vs. lakes.

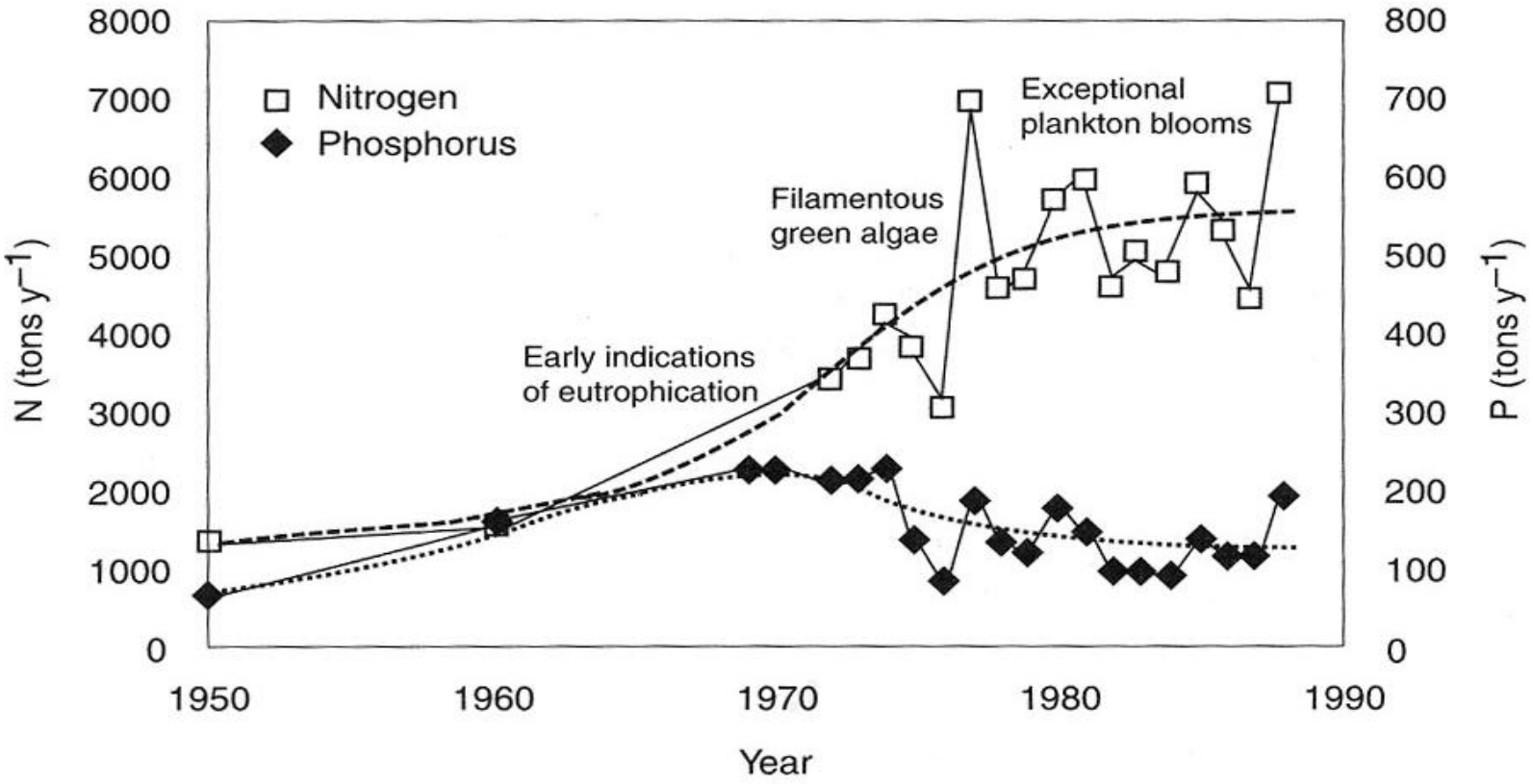
*Experimental Lakes Area (Ontario) – Lake 226*

*Marine Ecosystems Research Lab (MERL), Rhode Island*




Response of estuarine mescosms at Narragansett Bay, RI (MERL) to nutrient enrichment (Oviatt et al. 1995).

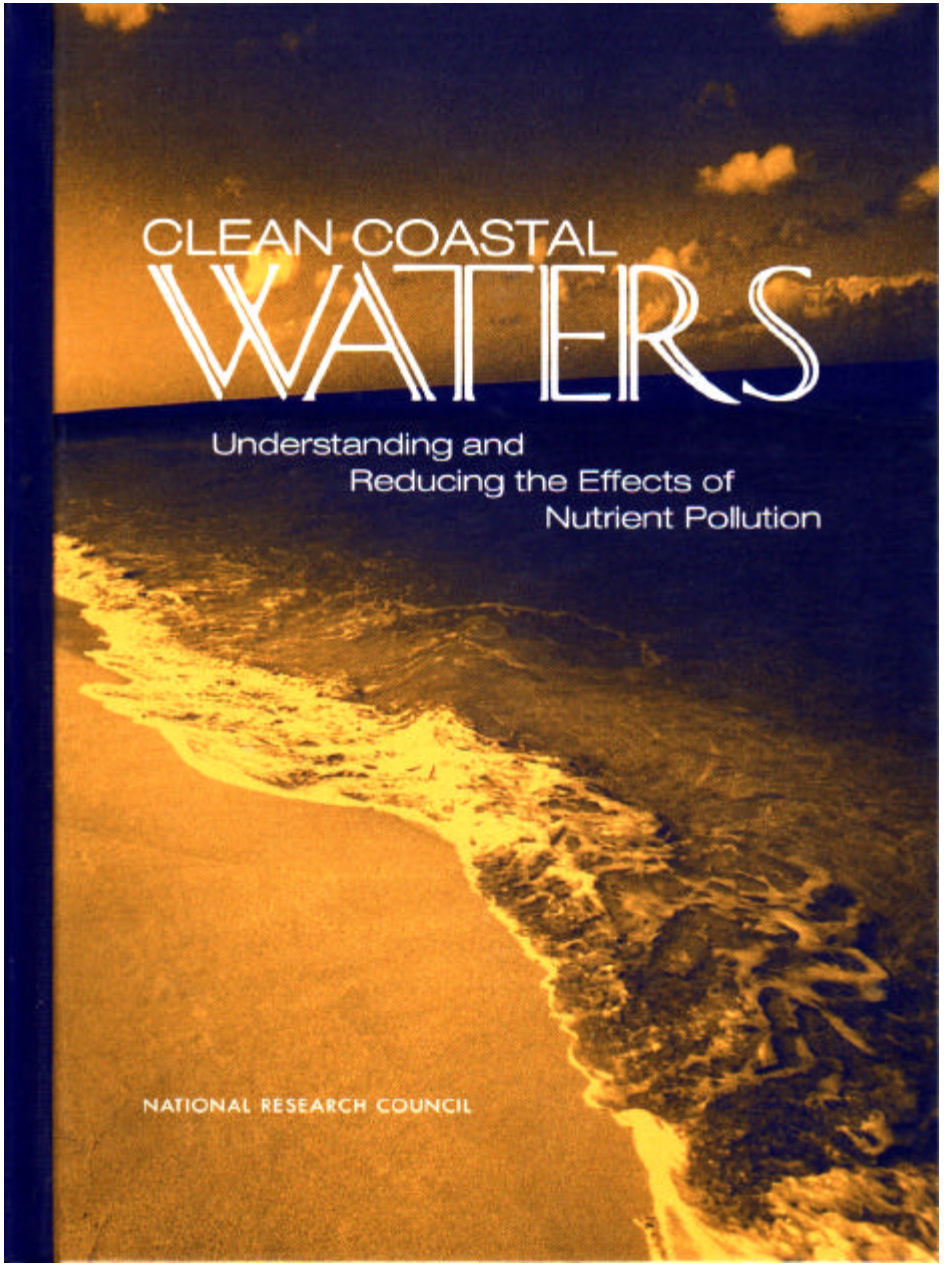
# Time Trend of Nutrient Enrichment in Laholm Bay, SW Sweden (Rosenberg et al. 1990)



# Mechanisms that differ between lakes and coastal marine ecosystems?

- greater P availability in coastal systems than in freshwater lakes (desorption of phosphate from riverine particles; less adsorption in sediments, due to abundance of $FeS_2$)

- little or no planktonic nitrogen fixation in coastal marine ecosystems




**Inputs of both nitrogen and phosphorus should be better controlled, but <u>nitrogen</u> is central.**

**Best management practices for phosphorus do not necessarily work well for nitrogen!**

**Example: no-till agriculture.**

**Nitrogen far more mobile in groundwater, and through atmosphere.**

**What about Lousiana continental shelf ("Dead Zone")?**

**EPA region 4 (Atlanta, GA): *The Role of Nitrogen/Phosphorus in Causing or Contributing to Hypoxia in the Northern Gulf* (August 2004 DRAFT).**

**Widely reported in press; Farm Bureau presentation to Congressmen.**

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**If true, according to this un-authored report, then should focus attention on P reductions from wastewater treatment plants, not N reductions from agriculture.**

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# "Phosphorus, not nitrogen, major culprit!"

**Evidence?**

- **Some bioassay measurements in low salinity plume;**
- **inference from N:P ratio of Mississippi River water (relative to Redfield ratio of 16:1).**

**EPA Region 4 draft report considered only inorganic N and P (ratio in Mississippi = ~ 30:1)**

**This ignores P adsorbed to sediments in Mississippi, which desorbs when it hits saltwater.**

**Therefore, should consider ratio of N and P in Mississippi that is potentially available in Gulf of Mexico = ~ 10:1**

**Also, preferential loss of N compared to P during benthic recycling on continental shelf underlying Dead Zone as water moves along shore to the West with prevailing currents.**

# Nitrogen has caused the “Dead Zone.”

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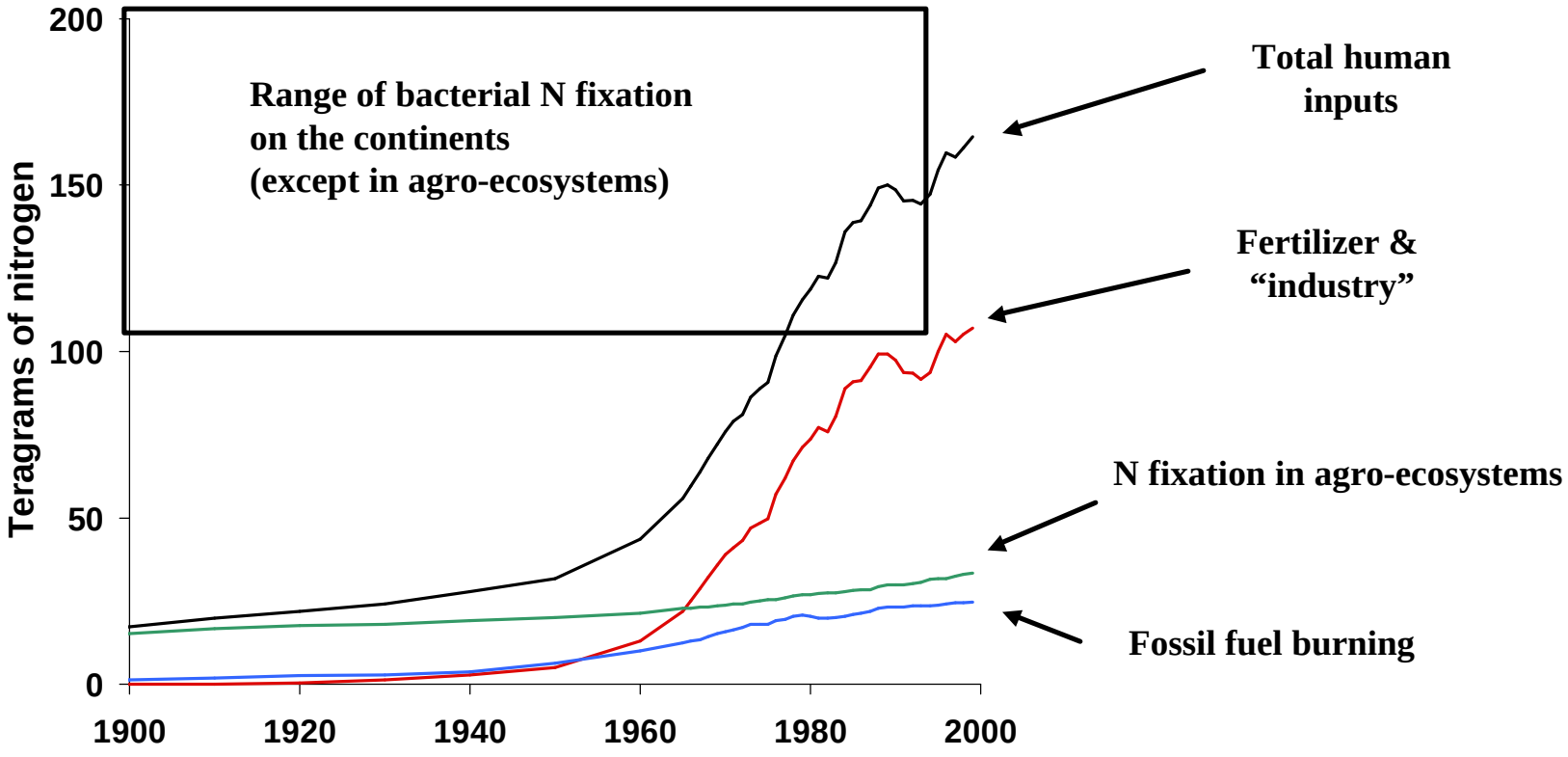
**Phosphorus may well be contributing to the problem, particularly as nitrogen load has grown larger. Phosphorus also important in trapping silica upriver.**

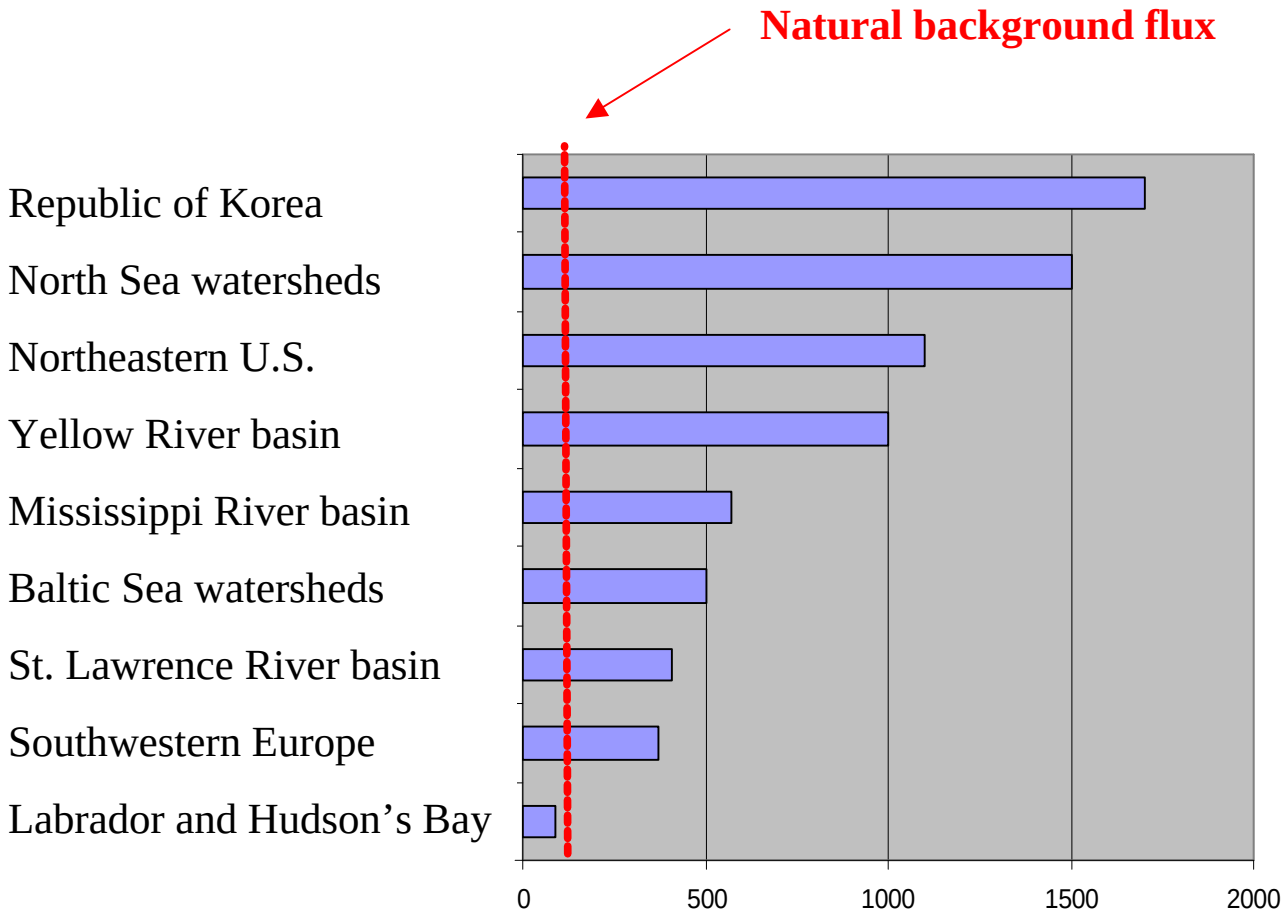
**But, need to control sediment-bound P from agriculture, and not just wastewater dissolved phosphorus.**

## Nitrogen inputs to coastal waters:

# What are the sources?

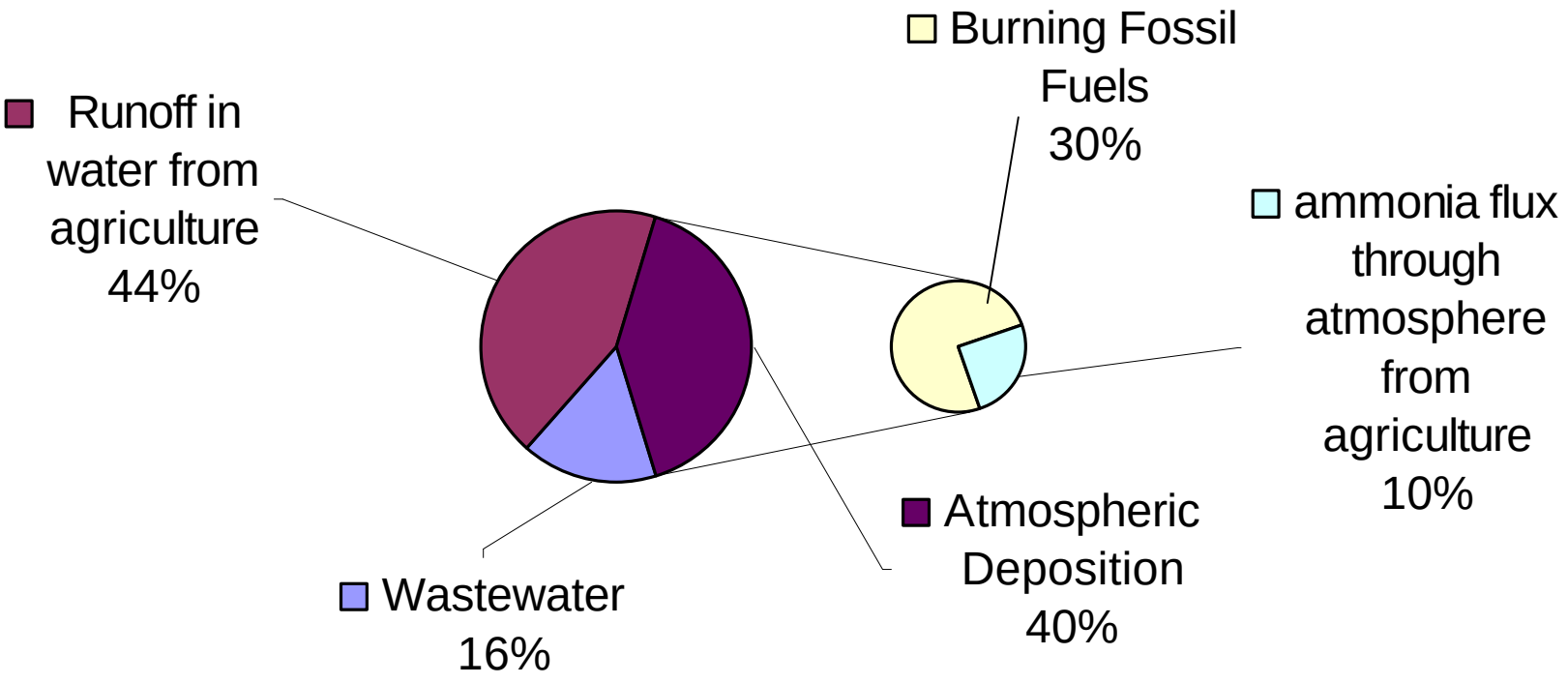
Globally, the drivers major drivers are agriculture (principally synthetic N fertilizer) and the inadvertent creation of nitrogen when fossil fuels are burned ("the acid rain" component").





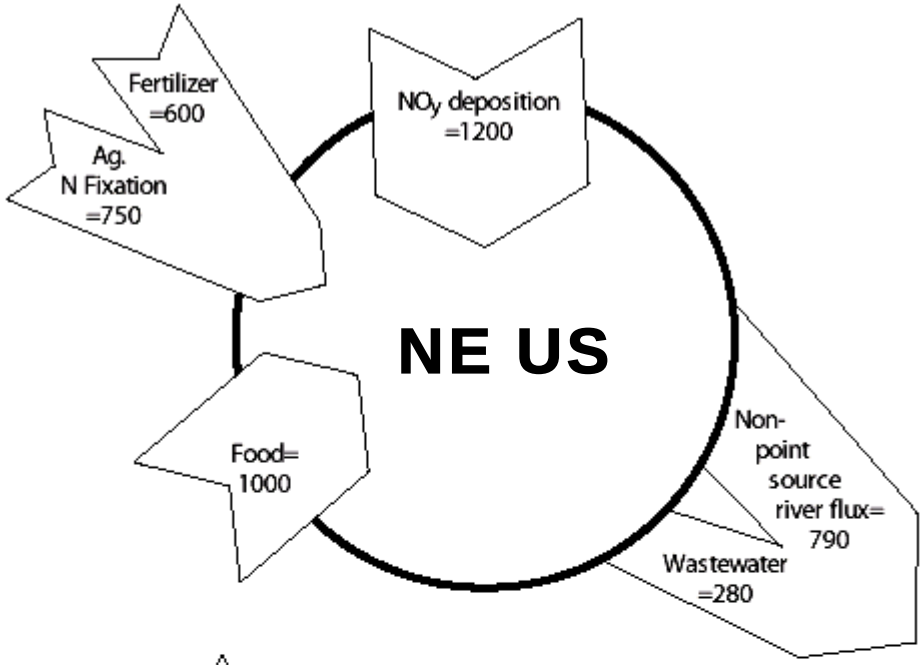

***Flux of nitrogen from the landscape to coastal oceans in rivers for contrasting regions of the world in the temperate zone (kg per km2 of watershed area per year; from Howarth et al. 1996, 2002; Bashkin et al. 2002).***

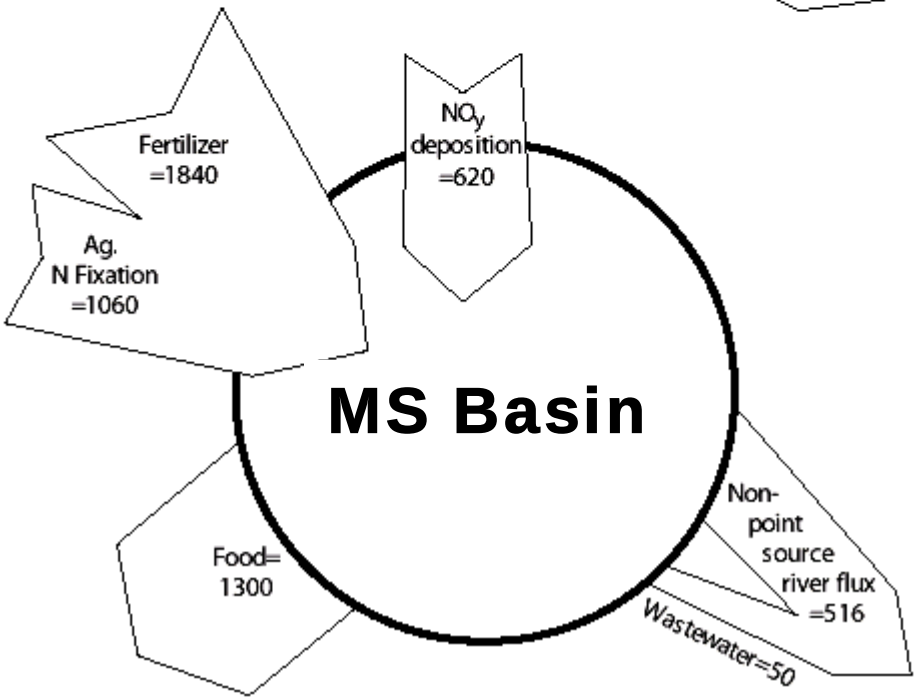
# Sources of Nitrogen Pollution to Coastal Rivers and Bays in the US on Average



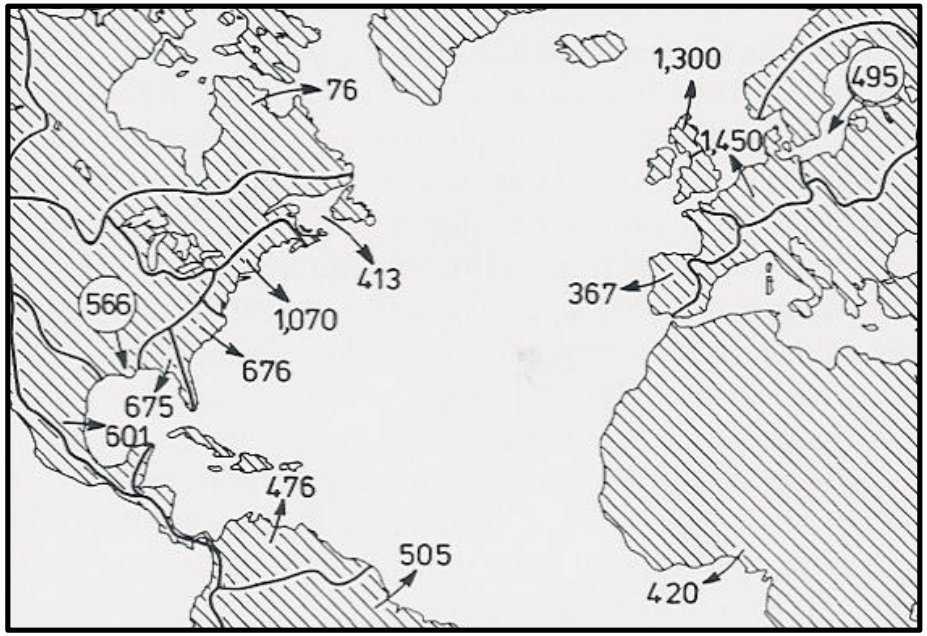

Howarth and Rielinger 2003

# Regional Differences



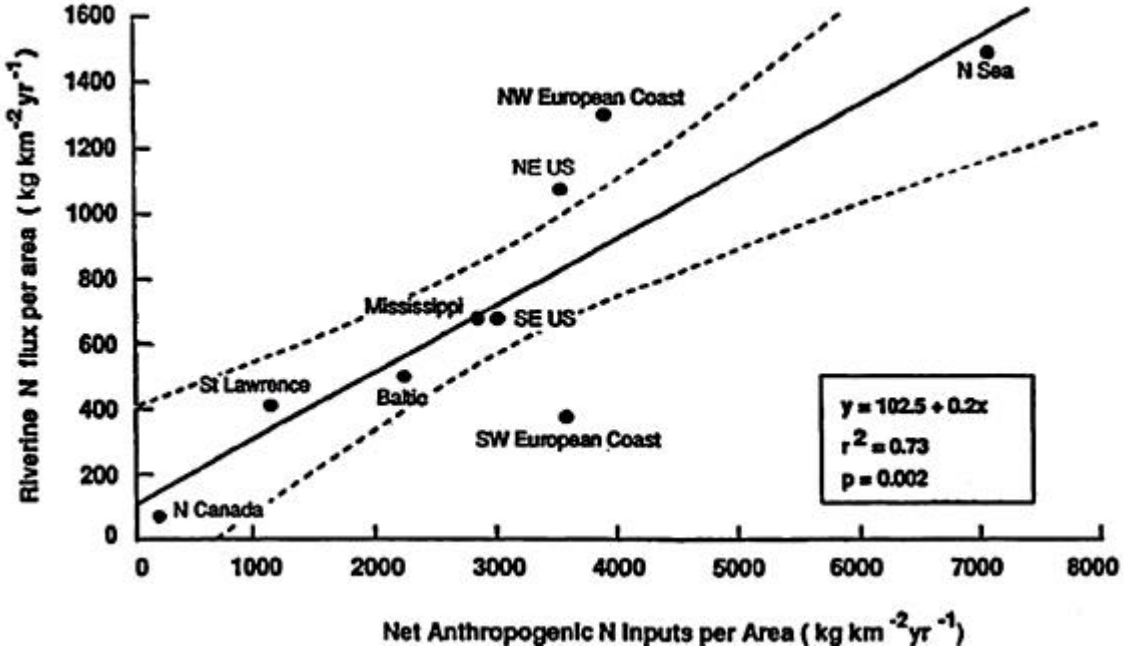




Howarth et al. 2003



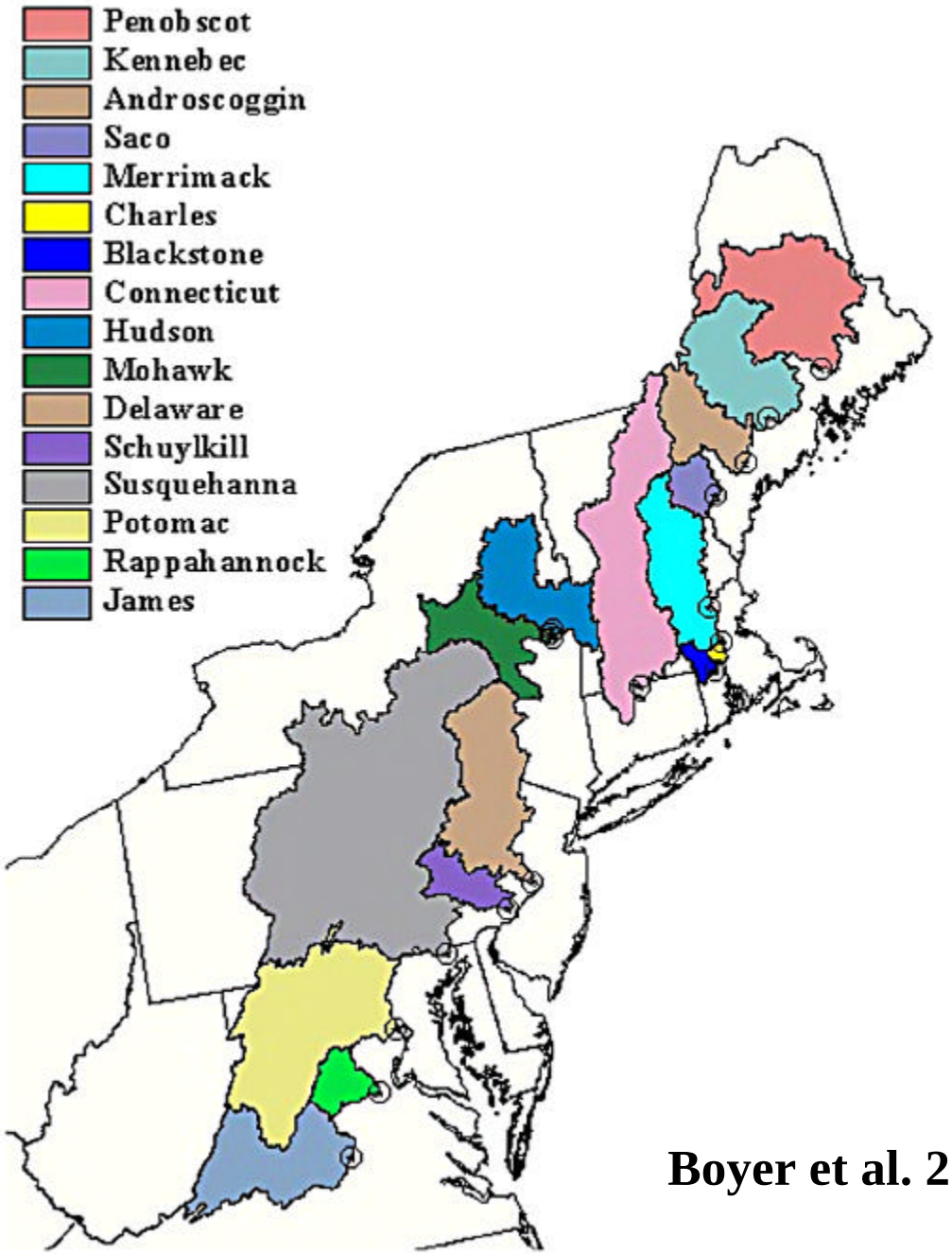

Only 20% of net inputs are exported…. What are the sinks for the 80% of inputs?

Kg N km$^{-2}$ year$^{-1}$



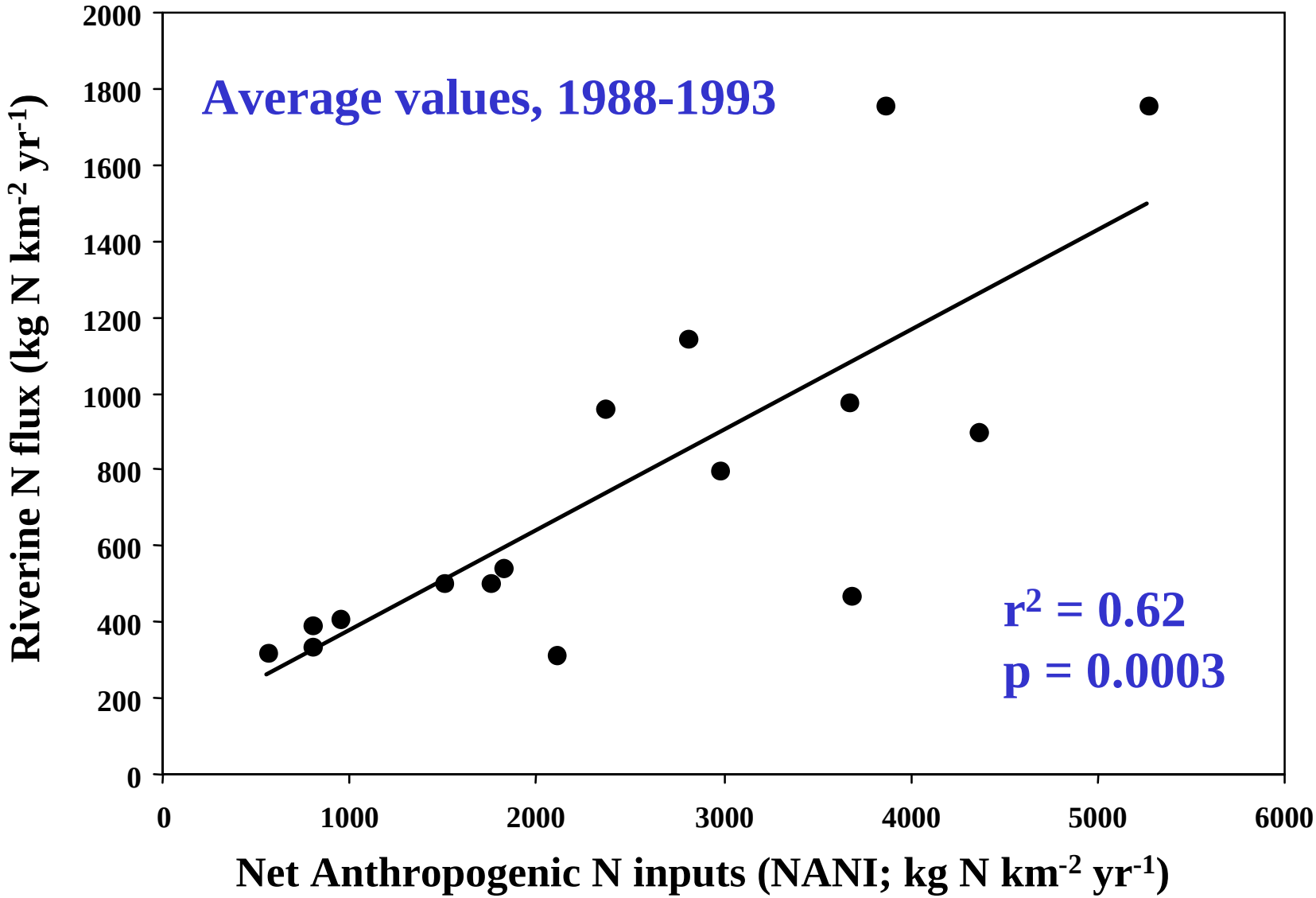

(Howarth et al. 1996)

# Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA




Boyer et al. 2002

# Approximately 25% of nitrogen inputs are exported in rivers.

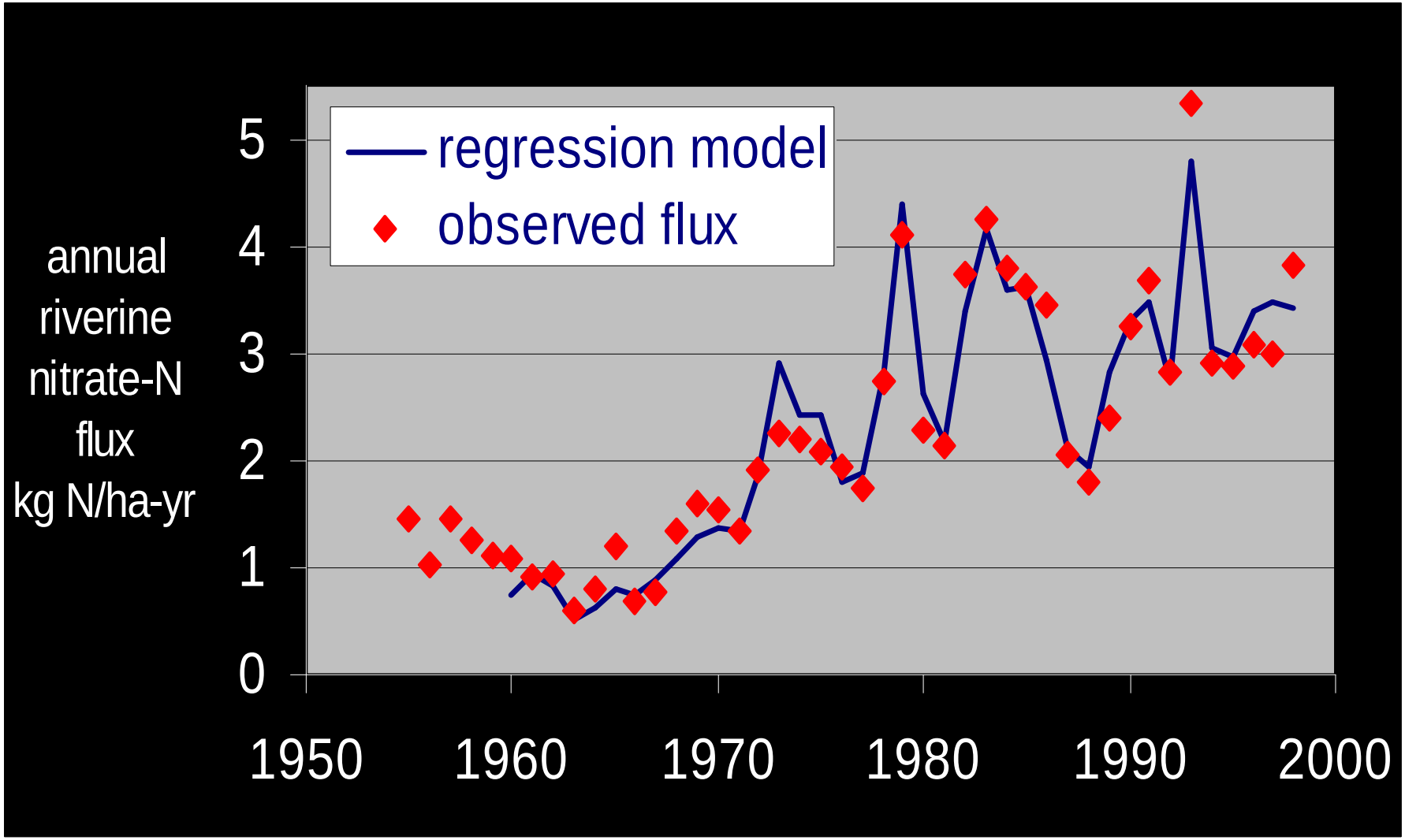



(Howarth et al. 2006, based on Boyer et al. 2002)

# N fluxes are governed by sources and sinks

**N fluxes are governed by sources and sinks –**
**<u>at the time scale of ~ 5 years or more</u>.**

Mississippi River nitrate flux: observed and modeled using annual water yield and net N input for the Mississippi Basin (McIsaac et al. 2001)



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**But clearly a climate influence at shorter time scales, with nitrogen temporarily stored in soils and aquifers in dry years and flushed out in wet years.**

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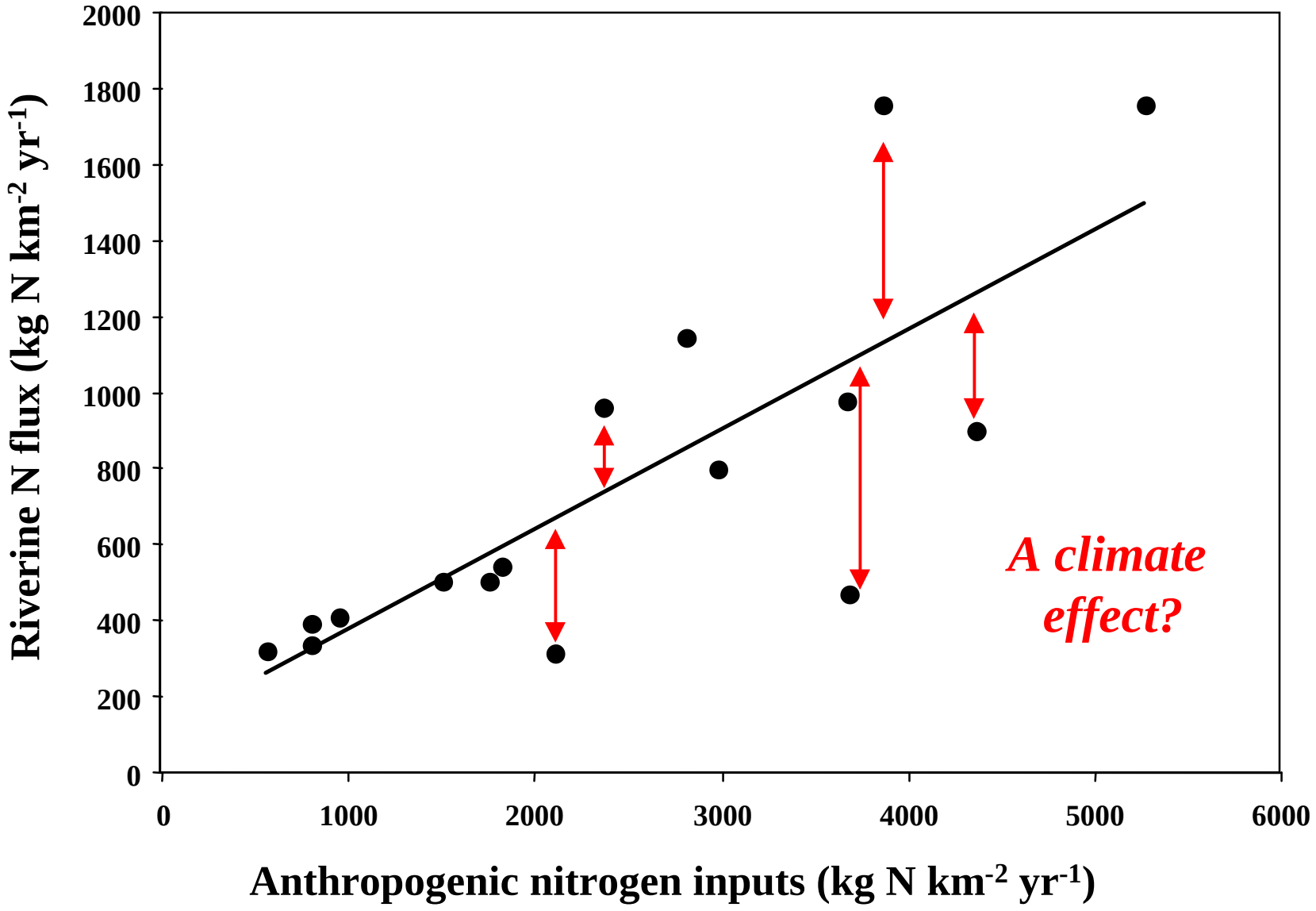
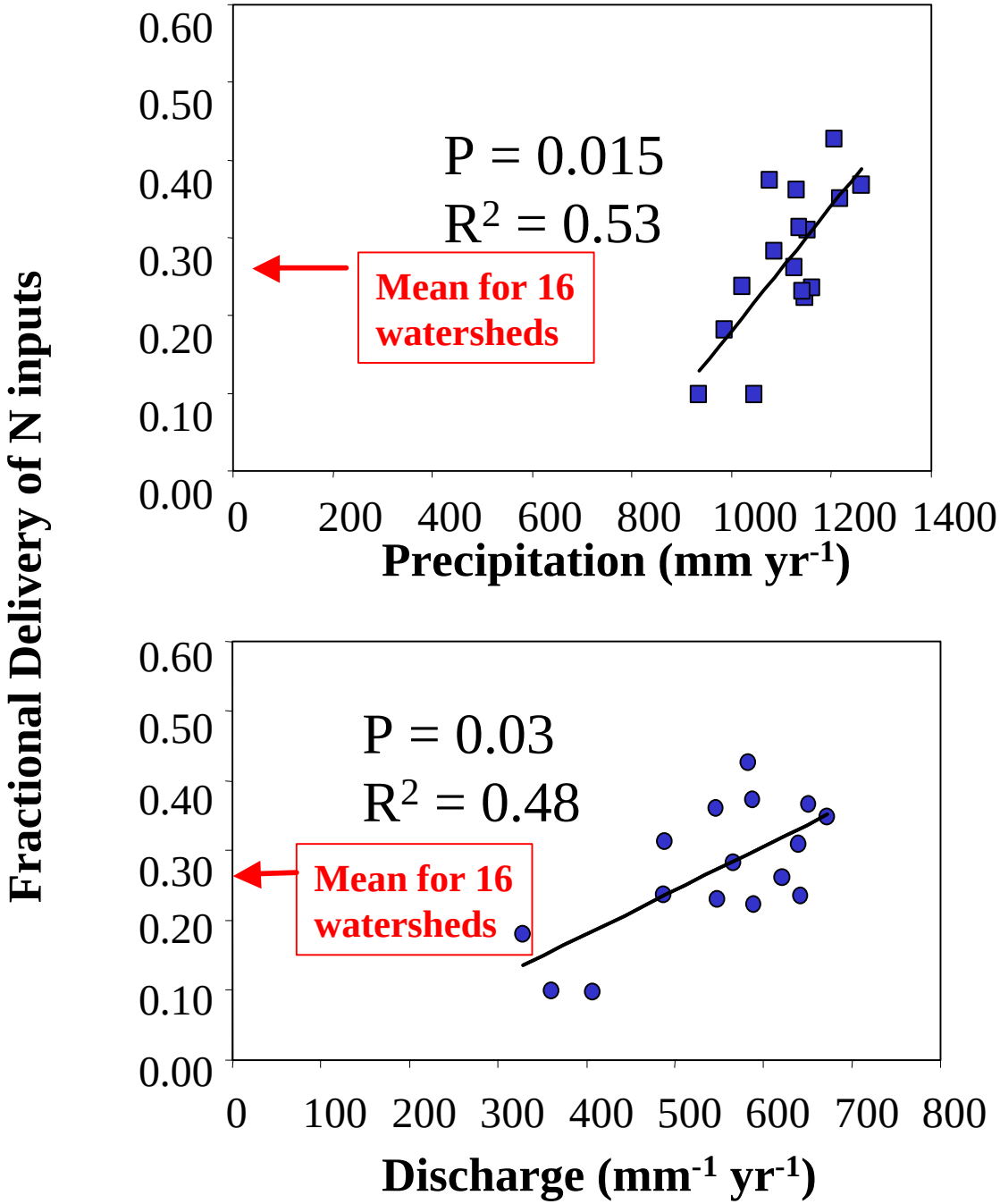
**But clearly a climate influence at shorter time scales, with nitrogen temporarily stored in soils and aquifers in dry years and flushed out in wet years.**

**Is there also a climate effect over longer time scales? That is, does climate influence long-term sinks of nitrogen in the landscape (denitrification or storage in soils or biomass)?**


Riverine N flux (kg N km-2 yr-1)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
1000
2000
3000
4000
5000
6000
Anthropogenic nitrogen inputs (kg N km-2 yr-1)
A climate effect?




(Howarth et al. 2006)

Under long-term steady state conditions, watersheds with wetter climates export a higher percentage of the nitrogen inputs.

(10% export in watersheds with less discharge; 40% export in watersheds with greater precipitation).

**The influence of climate must be on nitrogen sinks in the landscape : <u>probably less denitrification in wetter watersheds!!</u>**

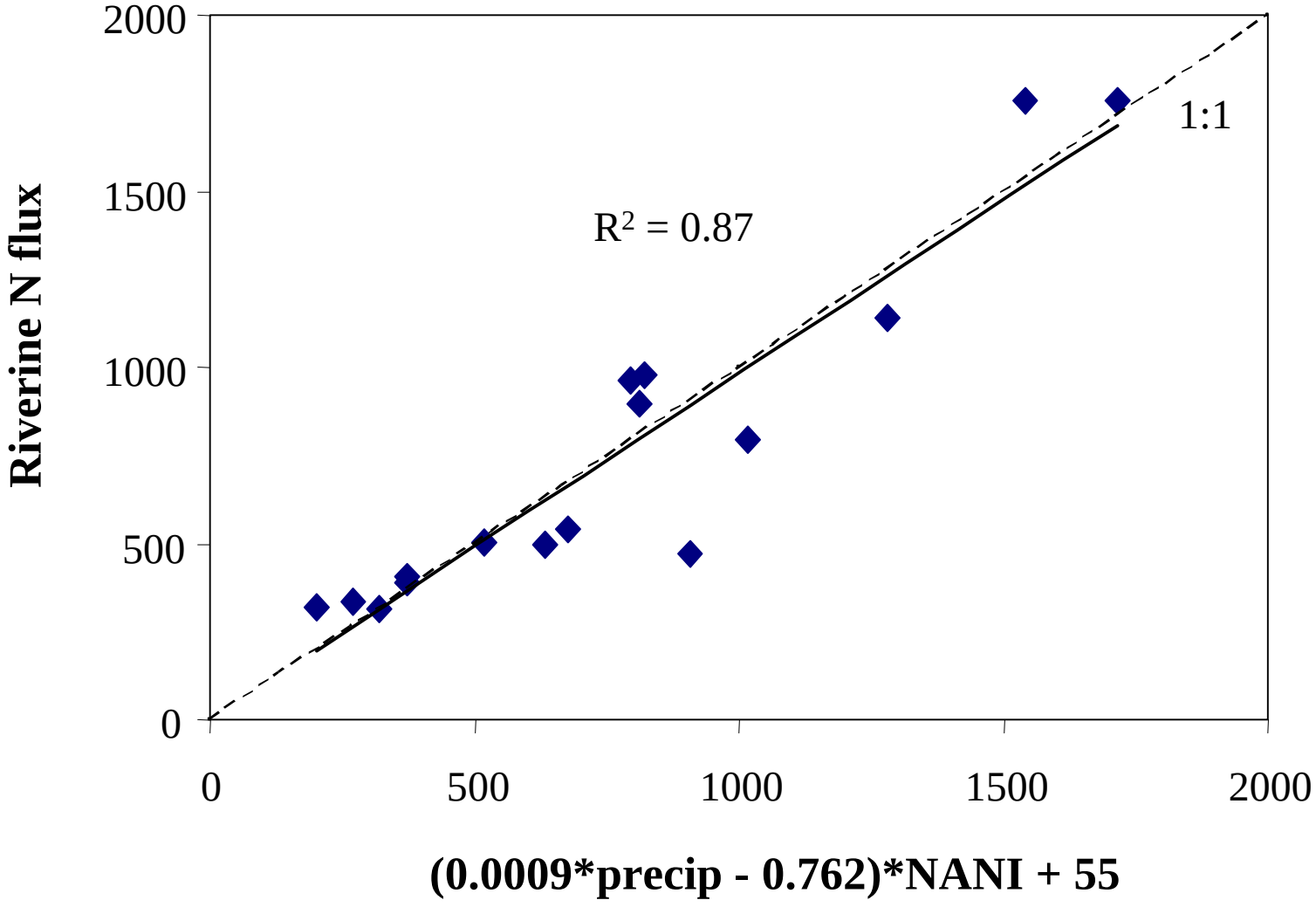
**Predictive equation for river nitrogen flux (R) as a function of nitrogen inputs ($N_i$) and fractional delivery of these inputs, based on precipitation (P).**

$$R = \underbrace{(0.00095 * P - 0.762)}_{\text{fractional delivery term}} * N_i + 55$$

**<u>Summary statistics</u>:**

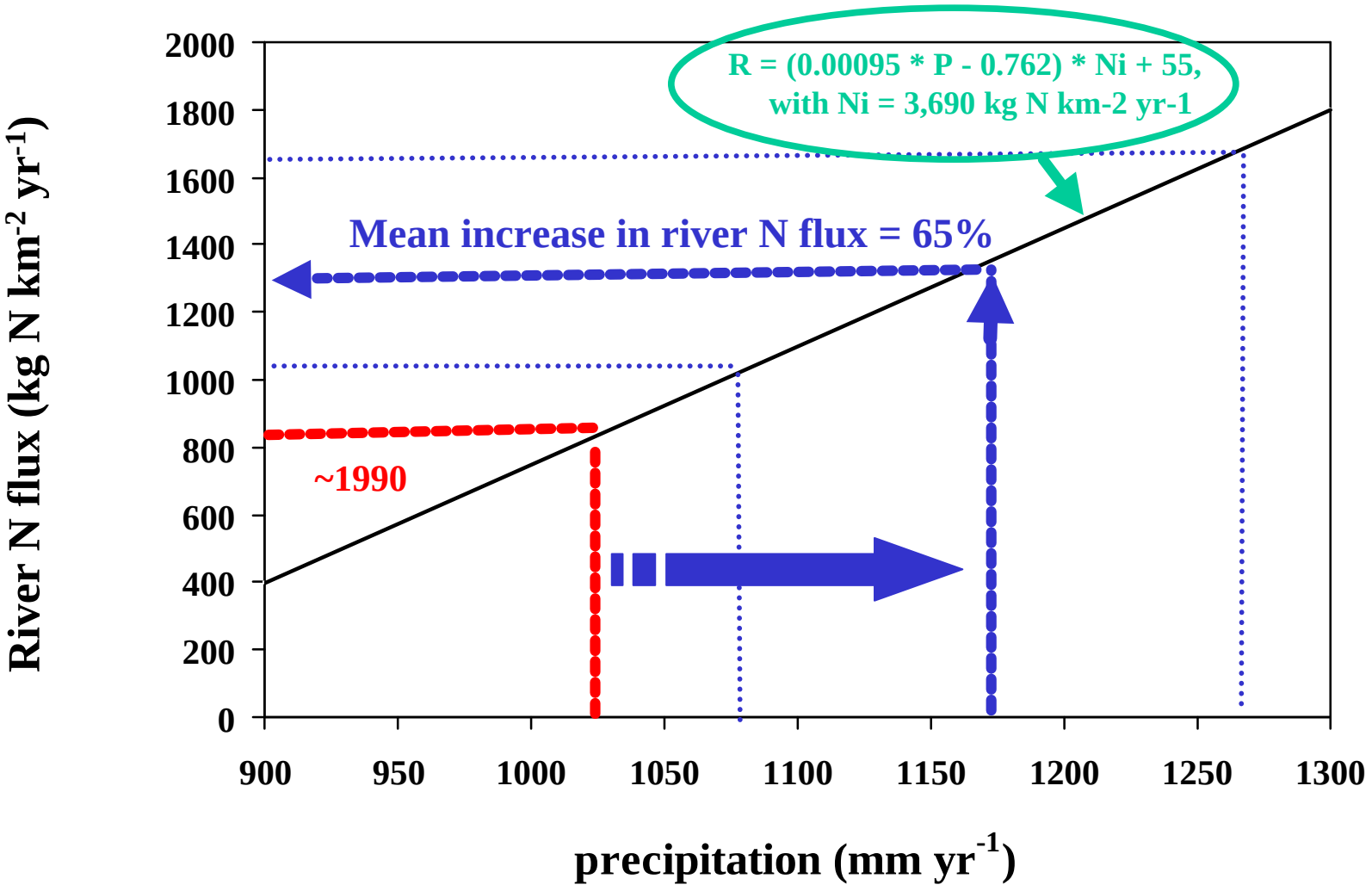
**Adjusted $r^2 = 0.87$**
**$p < 0.000001$**

**Both $N_i$ and $(N_i)(P)$ terms are highly significant ($p = 0.002$ and $0.0002$, respectively)**




Howarth et al. 2006

## Susquehanna River: Estimated change by 2095 (mean and range), Based on climate-change predictions of Naijar et al. (2000).



# Concluding thoughts….

- Nitrogen pollution is the largest pollution problem in coastal marine ecosystems; creates low-oxygen “dead” zones, aggravates harmful algal blooms, degrades seagrass beds and other habitat, and lowers biodiversity.

- Phosphorus, and not nitrogen, causes eutrophication in freshwater lakes, and society has been slow to recognize this difference and respond to the nitrogen problem.

- Large regional variation in nitrogen cycling, with > 15-fold increases in riverine nitrogen fluxes in some regions. These differences are driven by differences in nitrogen use in the regions.

- Non-point sources dominate nitrogen fluxes in all regions. Agriculture is the largest source globally, and in many watersheds (including the Mississippi basin).

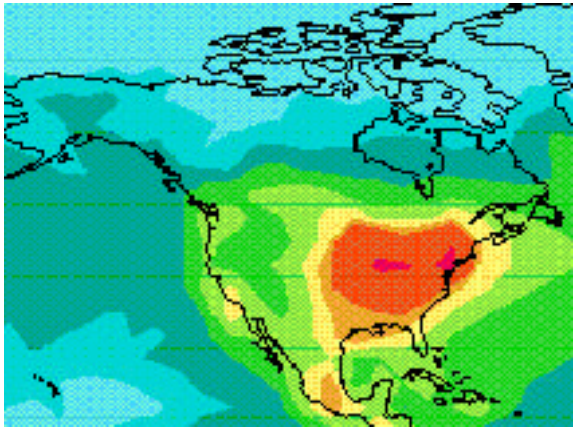
- Climate influences the average export of nitrogen over time (~10% of NANI in drier watersheds; ~ 40% of NANI in wetter ones). The effect is probably due to <u>less</u> denitrification in wetter watersheds.

**Grant # R830882**

# *Thanks to EPA STAR Program!*

***Also, NOAA Coastal Ocean Program,***

***and USDA CSREES (Agricultural Ecosystems Program at Cornell).***



# North American Nitrogen Center

**One of 5 regional centers of the International Nitrogen Initiative, established by the International Council of Science in 2003 (through SCOPE and the IGBP).**

**www.eeb.cornell.edu/biogeo/nanc.nanc.htm**

**nitrogen@cornell.edu**