
Nutrients and the food web
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"Ammonium is a paradoxical nutrient"

Ammonium is a preferred form of nitrogen for phytoplankton under some conditions

Ammonium can be inhibitory or even toxic under some conditions and to some species

"Sensitivity to NH_4^+ may be a universal biological phenomenon"

Britto and Kronzucker 2002

There is no controversy or uncertainty regarding the effects of ammonium on plants (including algae) and animals (including humans)

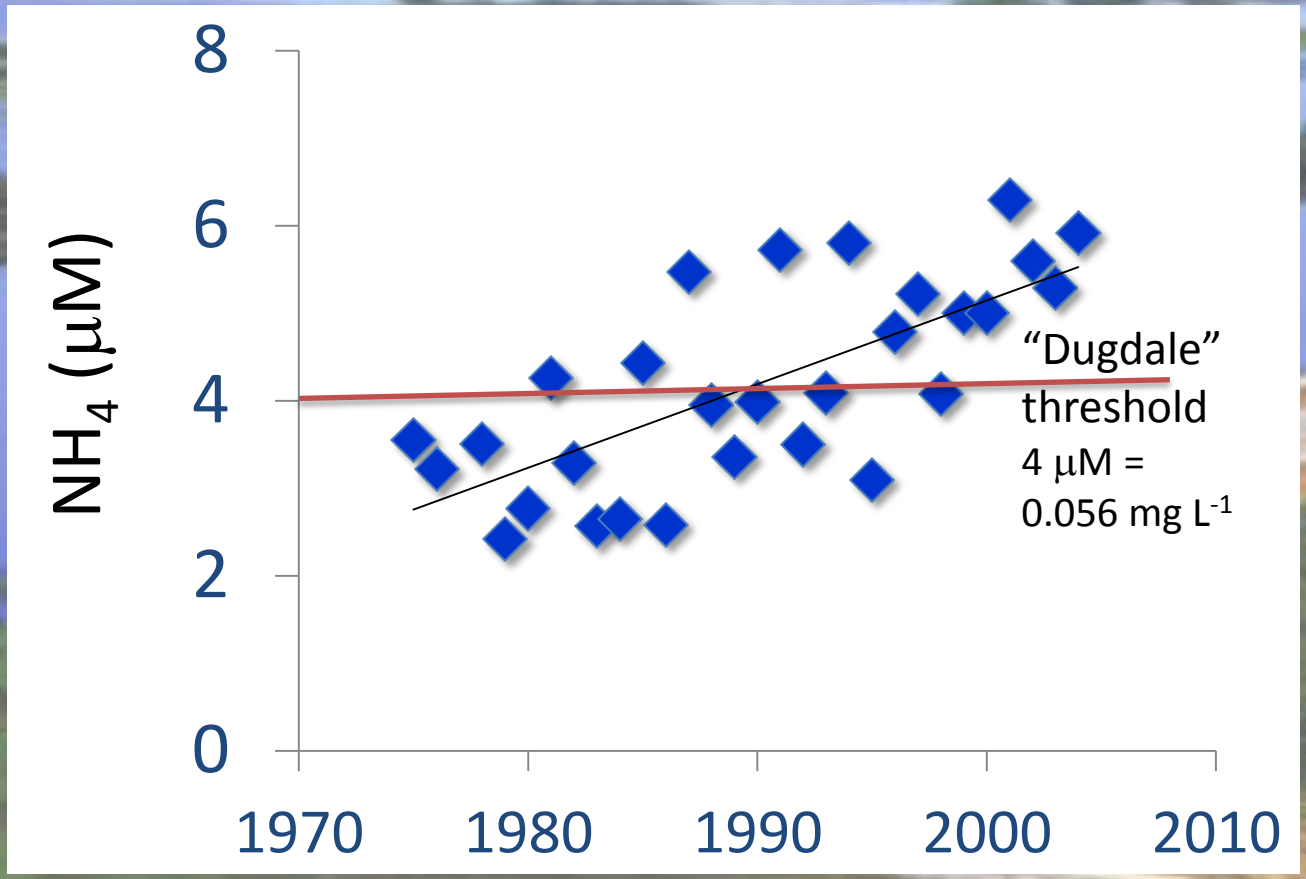
"… but the threshold at which symptoms of toxicity become manifested differs…"

Concentrations at which ammonium has been shown to inhibit the uptake of nitrate by phytoplankton range from 1 μM or less to >20 μm

"the extent and threshold concentrations involved depend on the species under study, its physiological status, and the environmental conditions to which this particular species or the natural assemblage has been exposed"

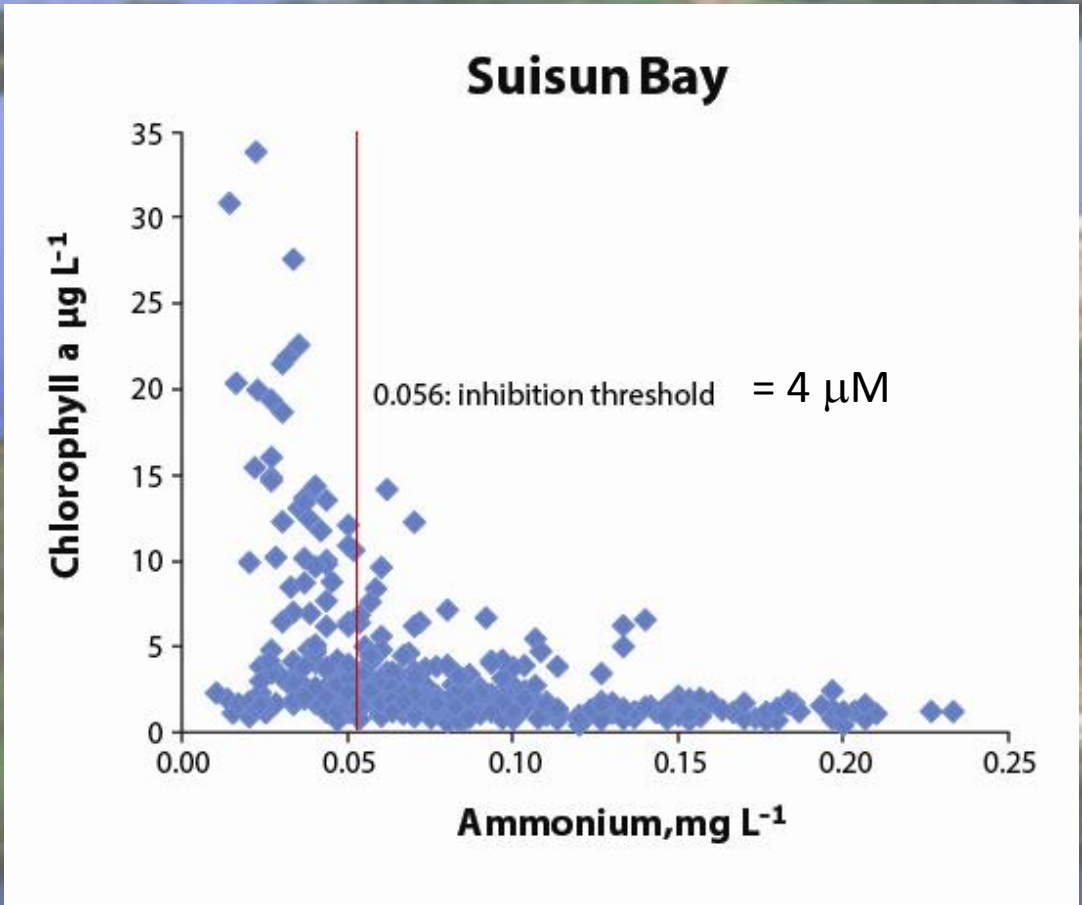
(Varela and Harrison 1999)

Ammonium in San Francisco Bay Delta: increasing over time

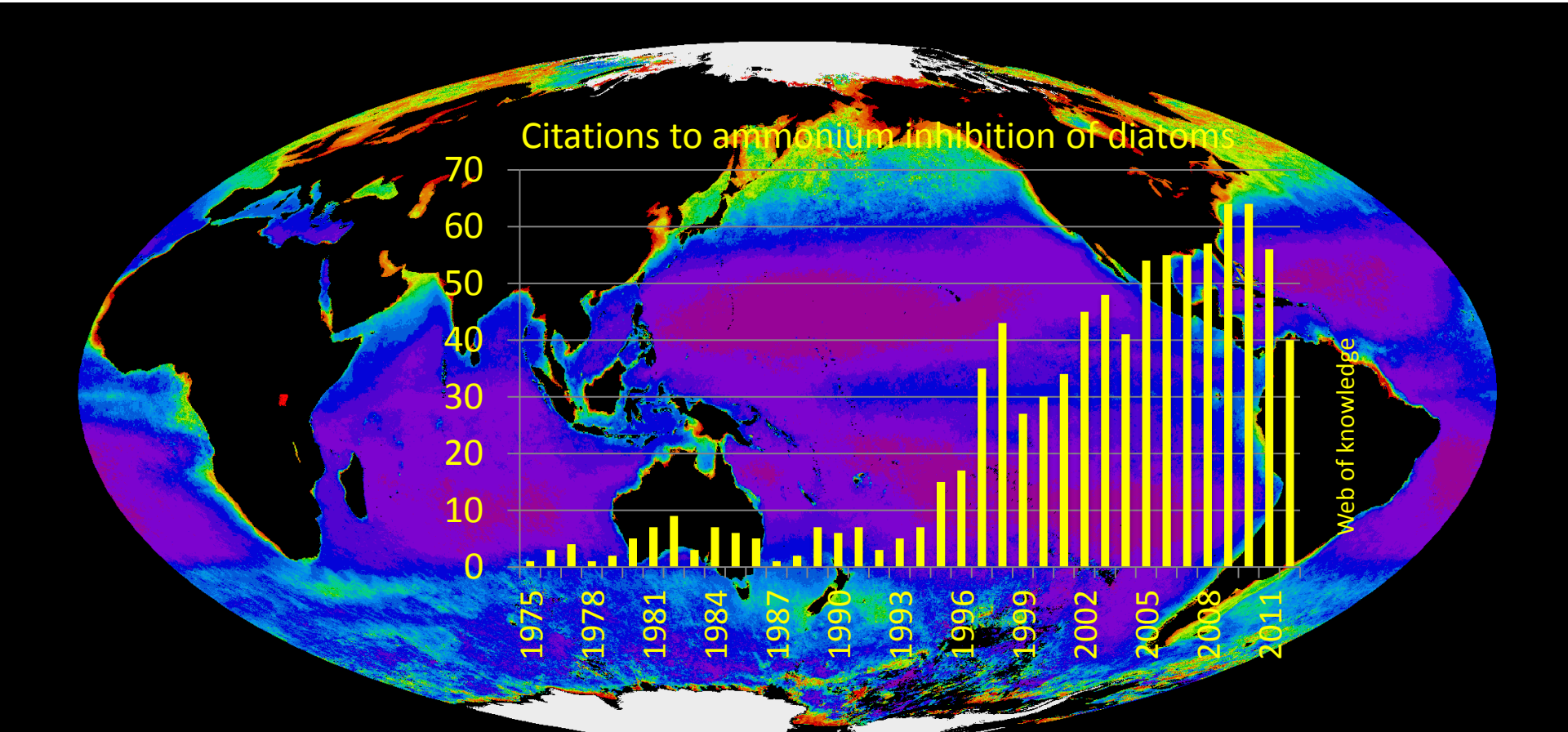


Glibert et al., 2011

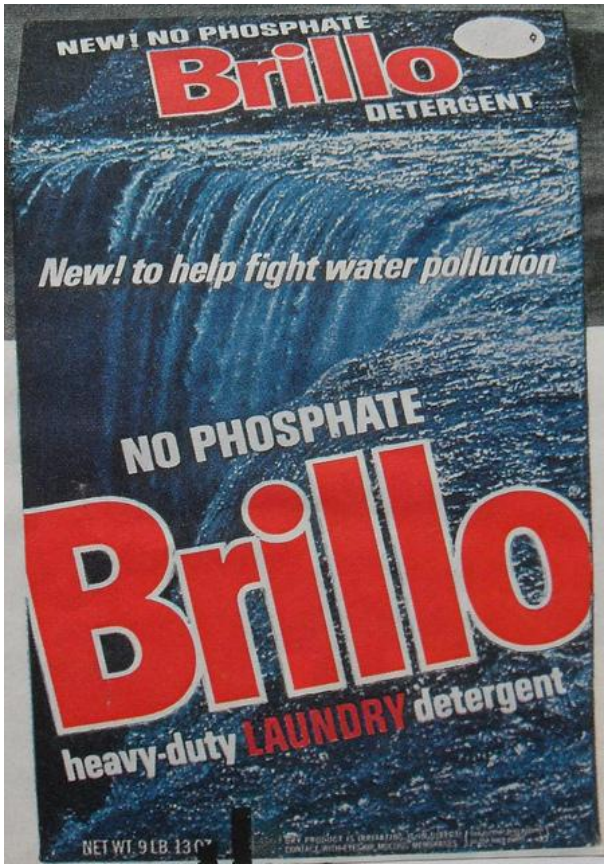
Overall, long-term ammonium data show strong negative relationship with chlorophyll in the water column



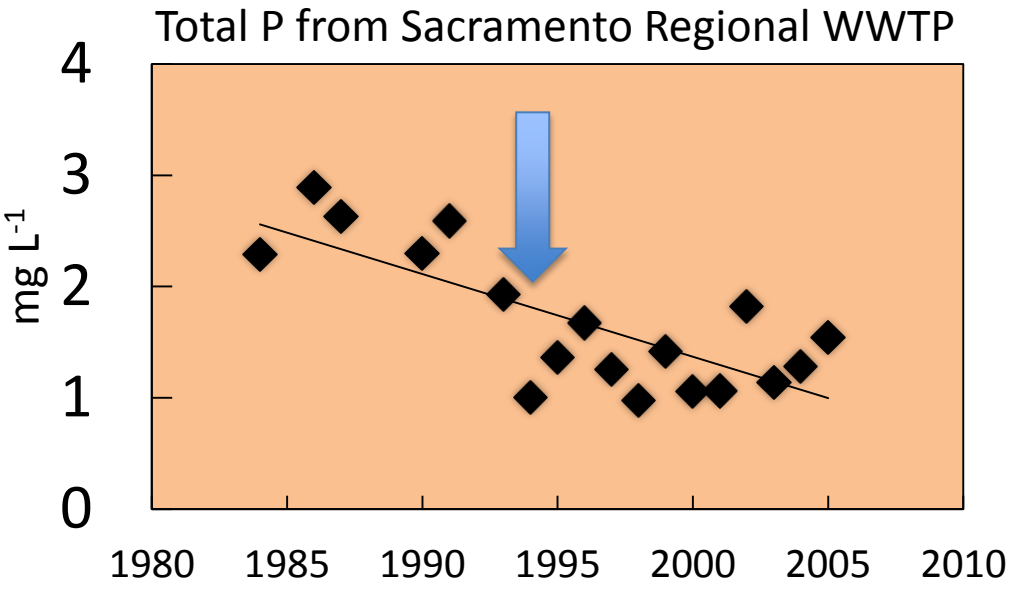
Inhibition of diatoms by ammonium is being increasingly recognized – and included in ecosystem models of ocean productivity



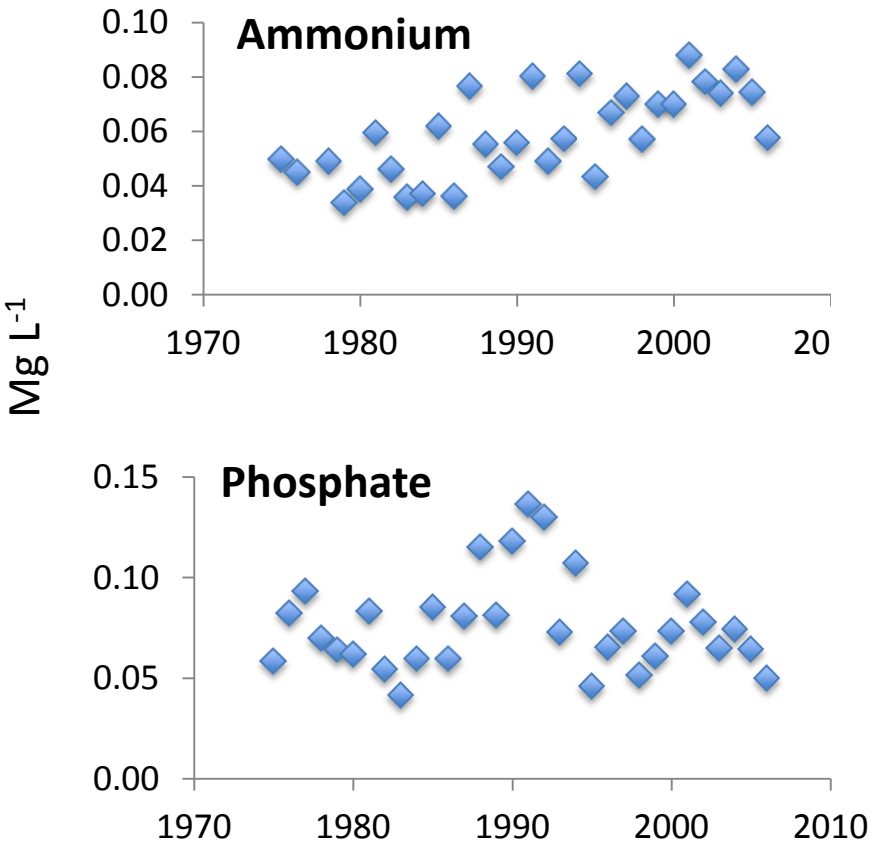
Ammonium is not the only nutrient that has changed

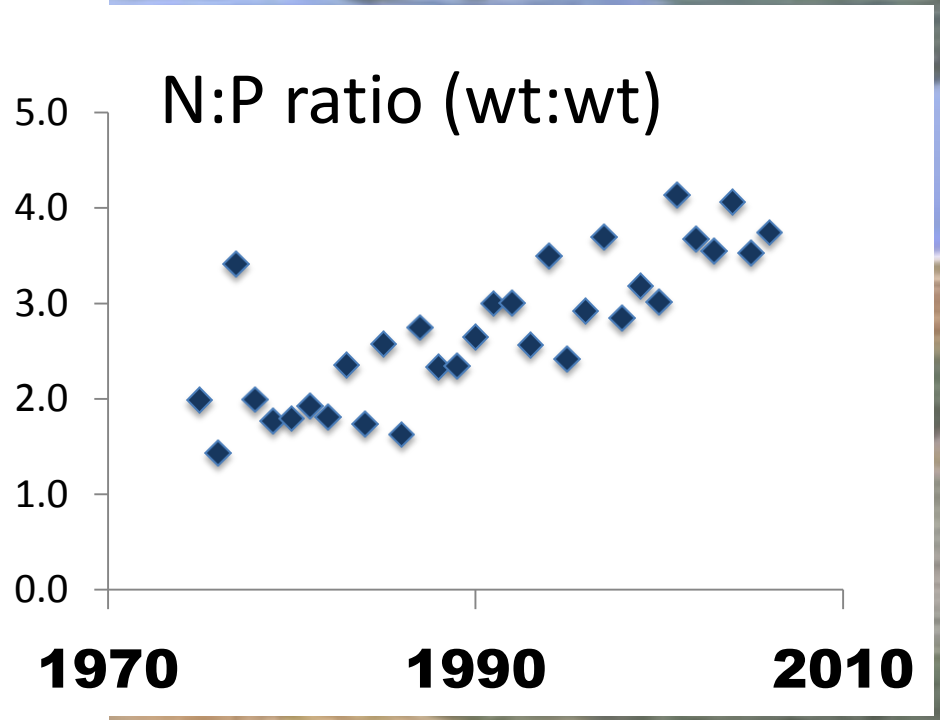


By the mid 1990s the switch to non-P detergents had occurred throughout the US and Europe. The manufacturers made the switch regardless of state (or country) laws to avoid region-by-region formulations



Nitrogen: Phosphorus ratios have increased

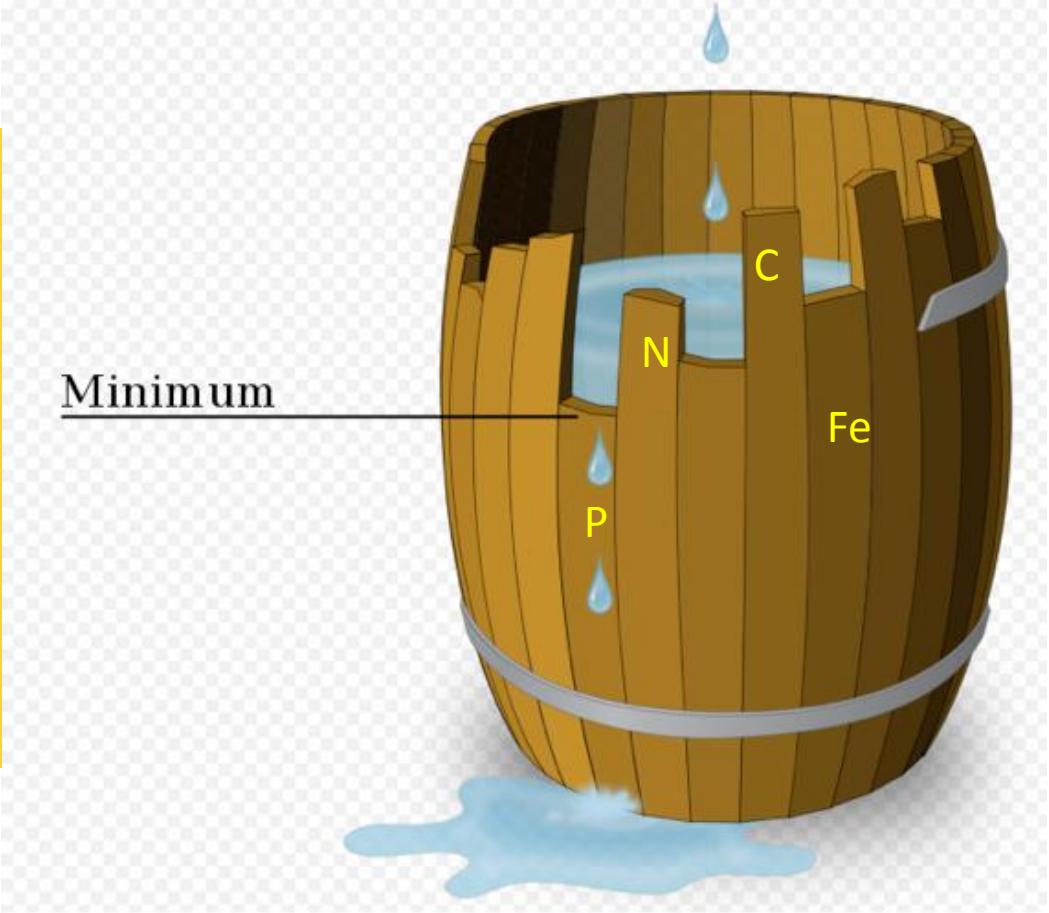




Liebig' Law of the minimum

Growth is limited by the nutrient that is in shortest supply relative to the needs of the organism.

But- in this system the nutrients, including P, rarely are low enough to be considered "limiting" using simple, classic metrics (half-saturations constants)



Classic Dogma:

"There should be no selective effect ... that might distinguish between the potential performance of any pair of planktonic algae, so long as the resource concentrations are able to saturate the growth demand..." Reynolds 1999

i.e., if nutrients are 'sufficient" they should not regulate the species composition of the algae

Contemporary Perspective:

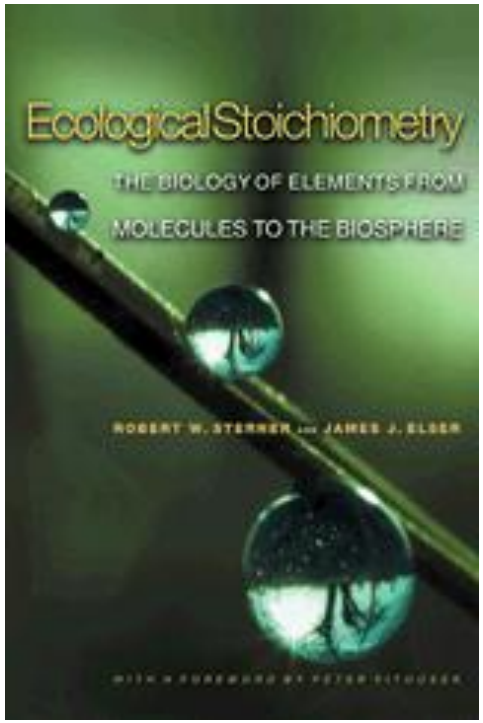
While total nutrient load sets the total amount of productivity/biomass of an ecosystem,

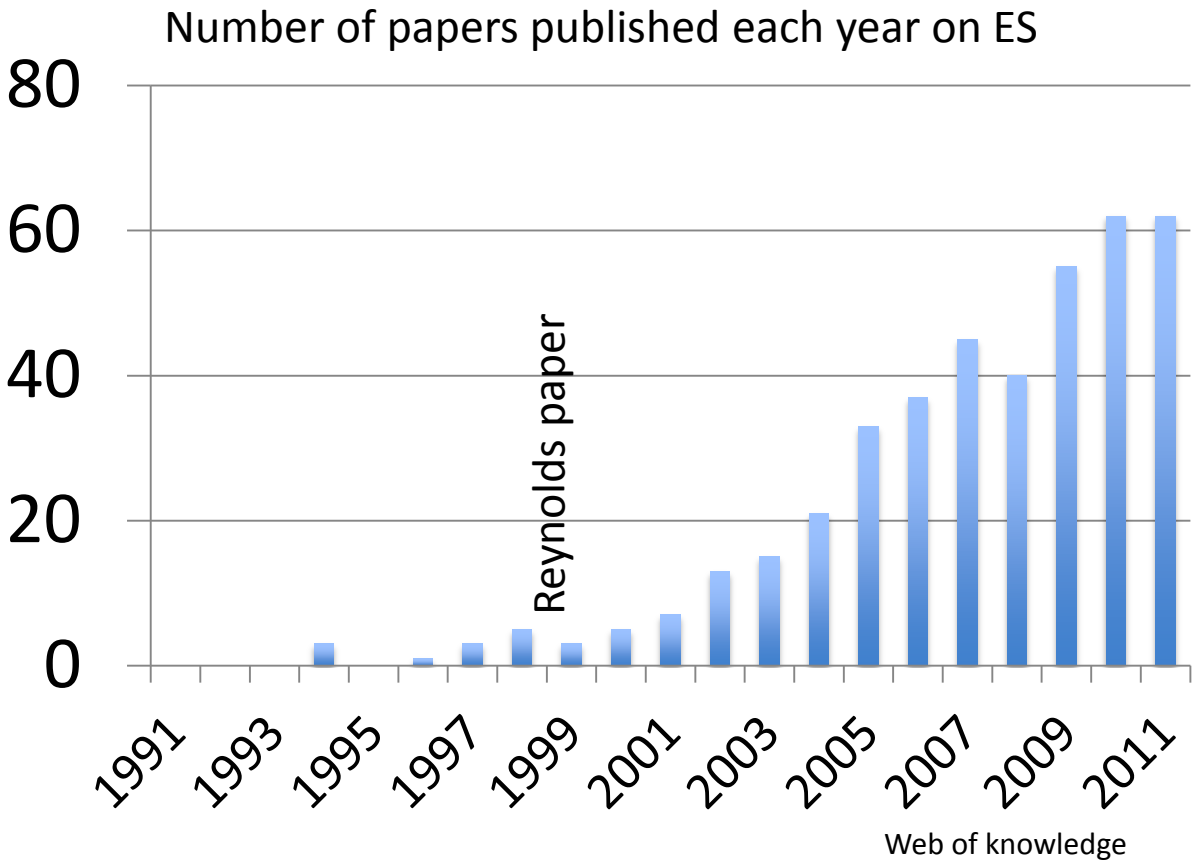
The relative proportions of nutrients sets the QUALITY

(who is there and how they are doing)

- The balance of chemical resources and their interactions;
- Match/mis-match between organismal requirement for nutrients and their availability

This concept formalized as Ecological Stoichiometry





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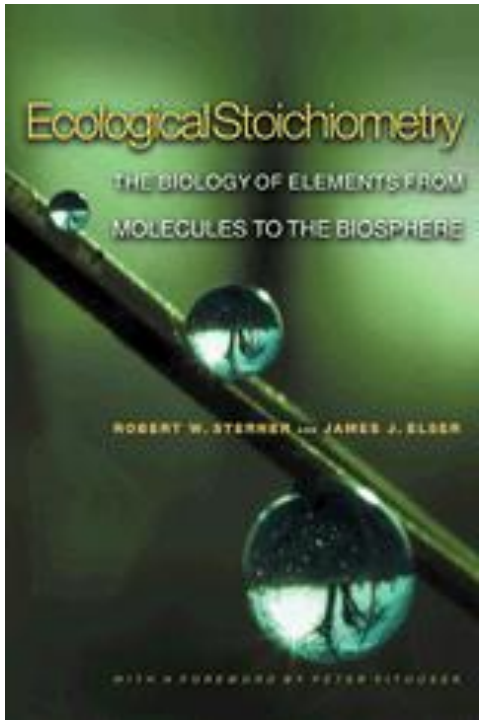
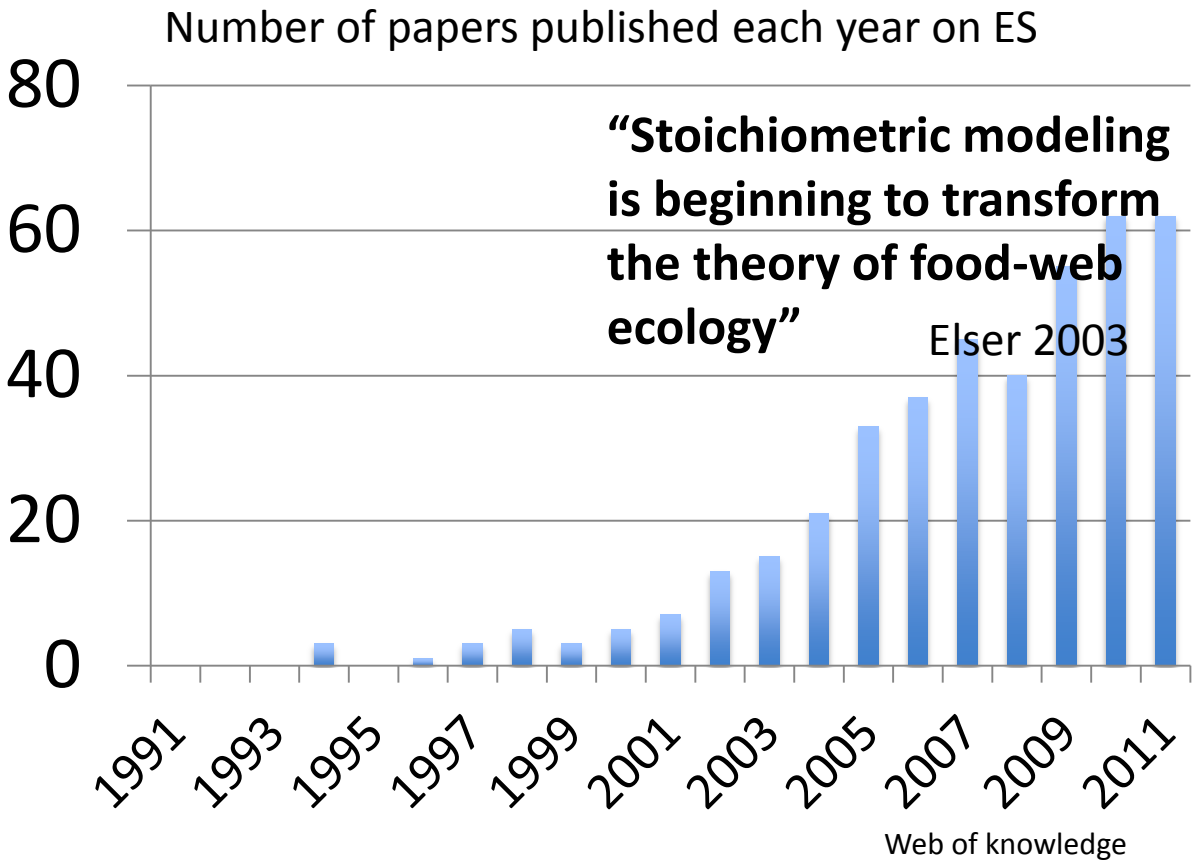
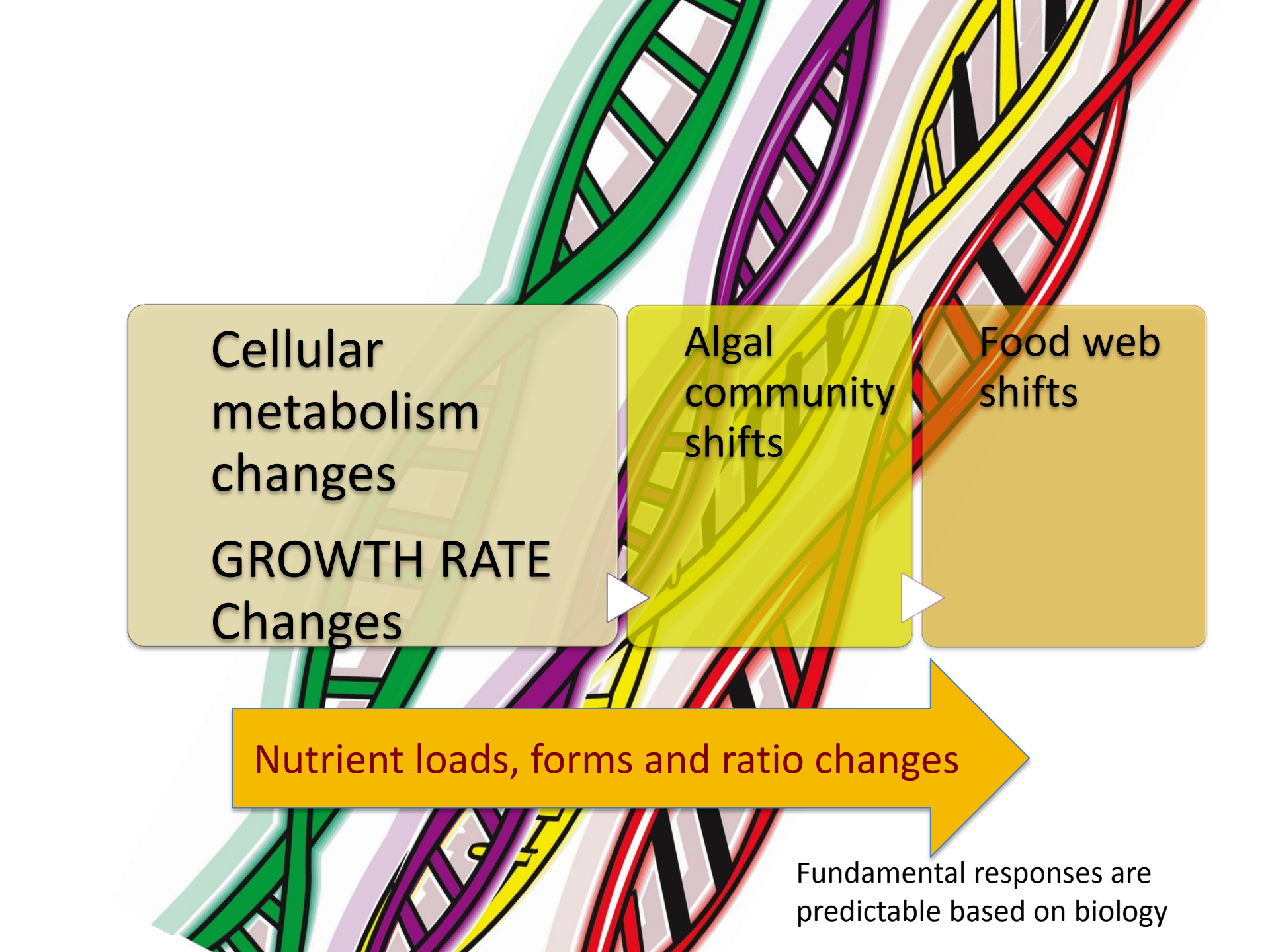




Nutrient composition regulates organism metabolism at concentrations well above those that are limiting

- *It's a balancing act.*
- Organisms sequester what they need and dissipate the rest.
- Too much presents metabolic costs as does too little
- Organisms have different needs for, and different strategies to regulate their nutrients

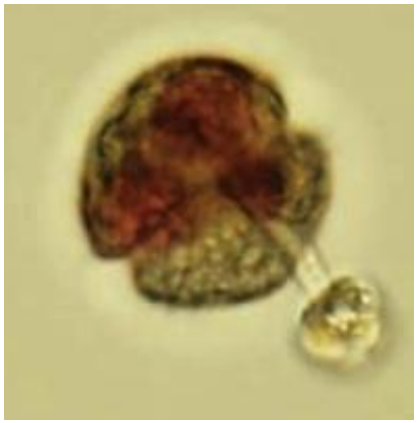

Cellular metabolism changes
GROWTH RATE Changes
Algal community shifts
Food web shifts
Nutrient loads, forms and ratio changes
Fundamental responses are predictable based on biology

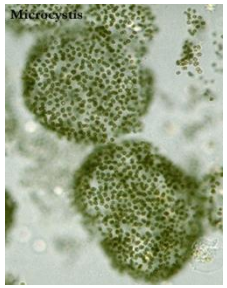
Ecological stoichiometry at the base of the Food Web

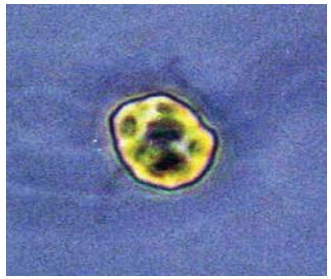
- Algae generally follow a

"*you are what you eat*" strategy

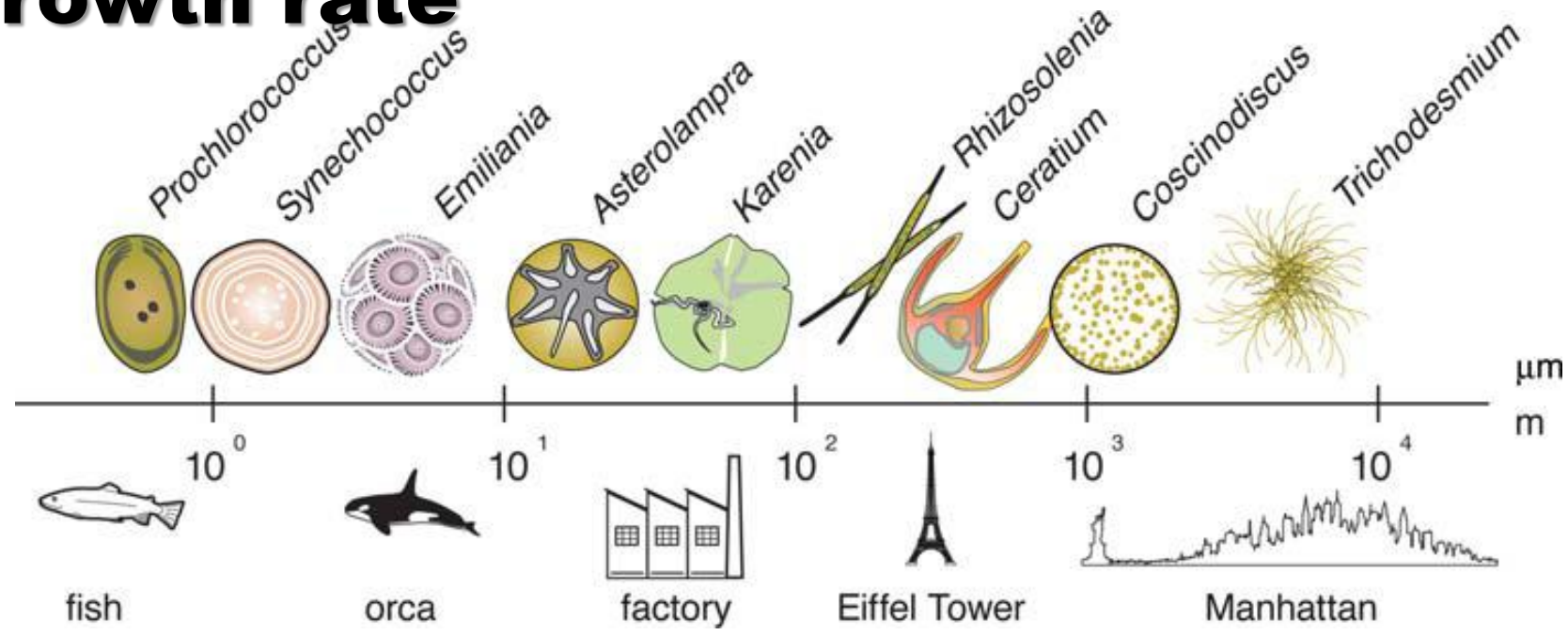
- They have limited capability to regulate their nutrient content





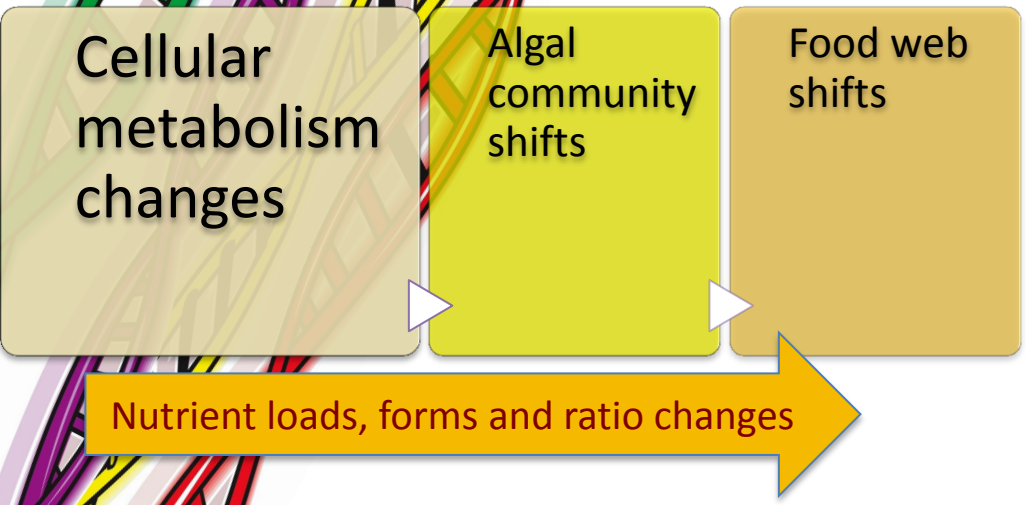


Across species there is a great diversity in size, composition and growth rate



Organism	Cell Size	C:P
Synechococcus	10^0 µm^3	~100
Diatoms	10^2- 10^3 µm^3	~50
Cryptophytes	10^1-10^4 µm^3	~60

Data and figure from Finkel et al. 2010



Cellular physiology changes across the entire spectrum of substrate availability

Cell size

Cellular pigmentation

N:C, C:P, N:P

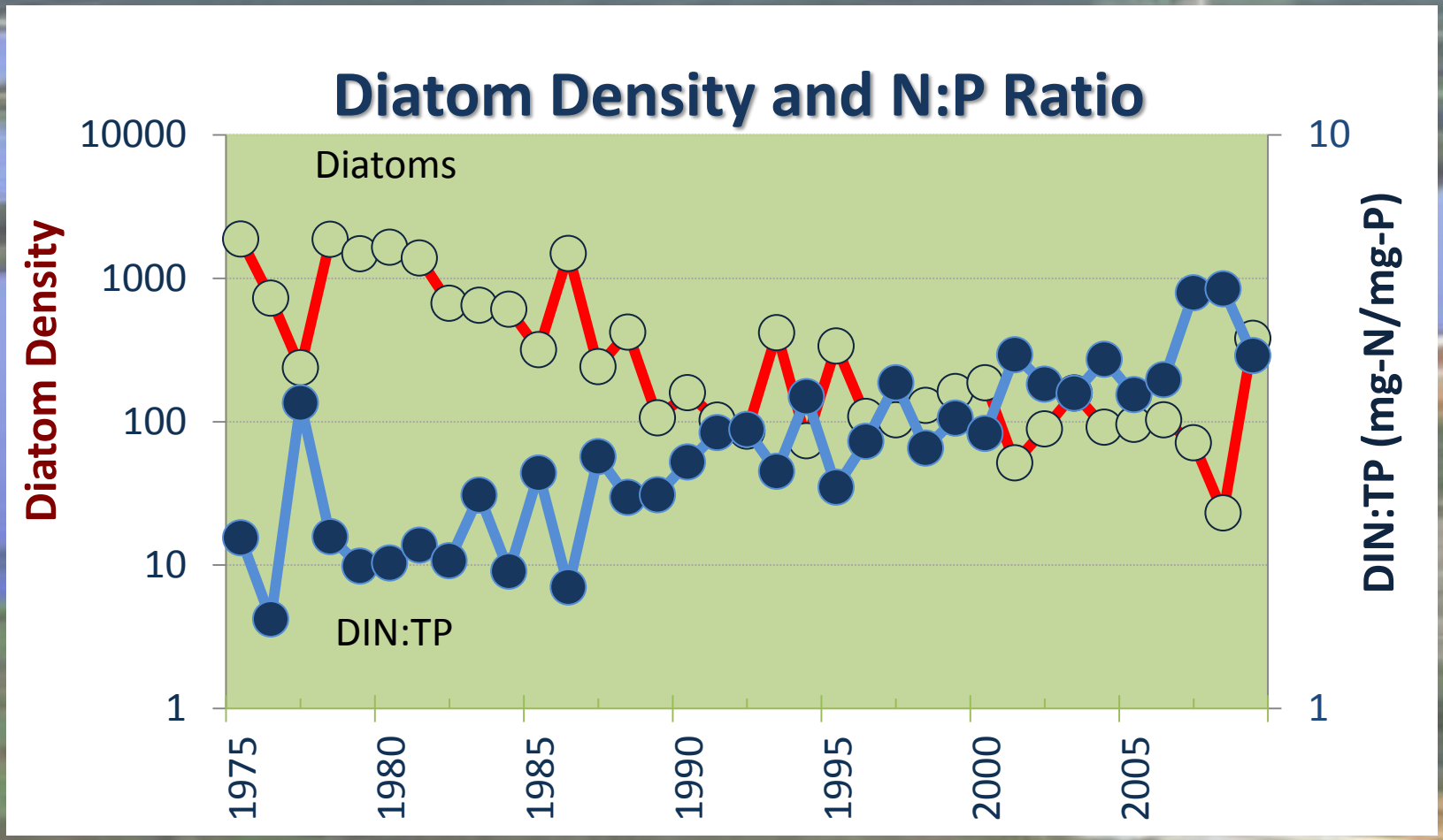
Enzyme activities

Growth rate

Toxin production

Even good food can go bad

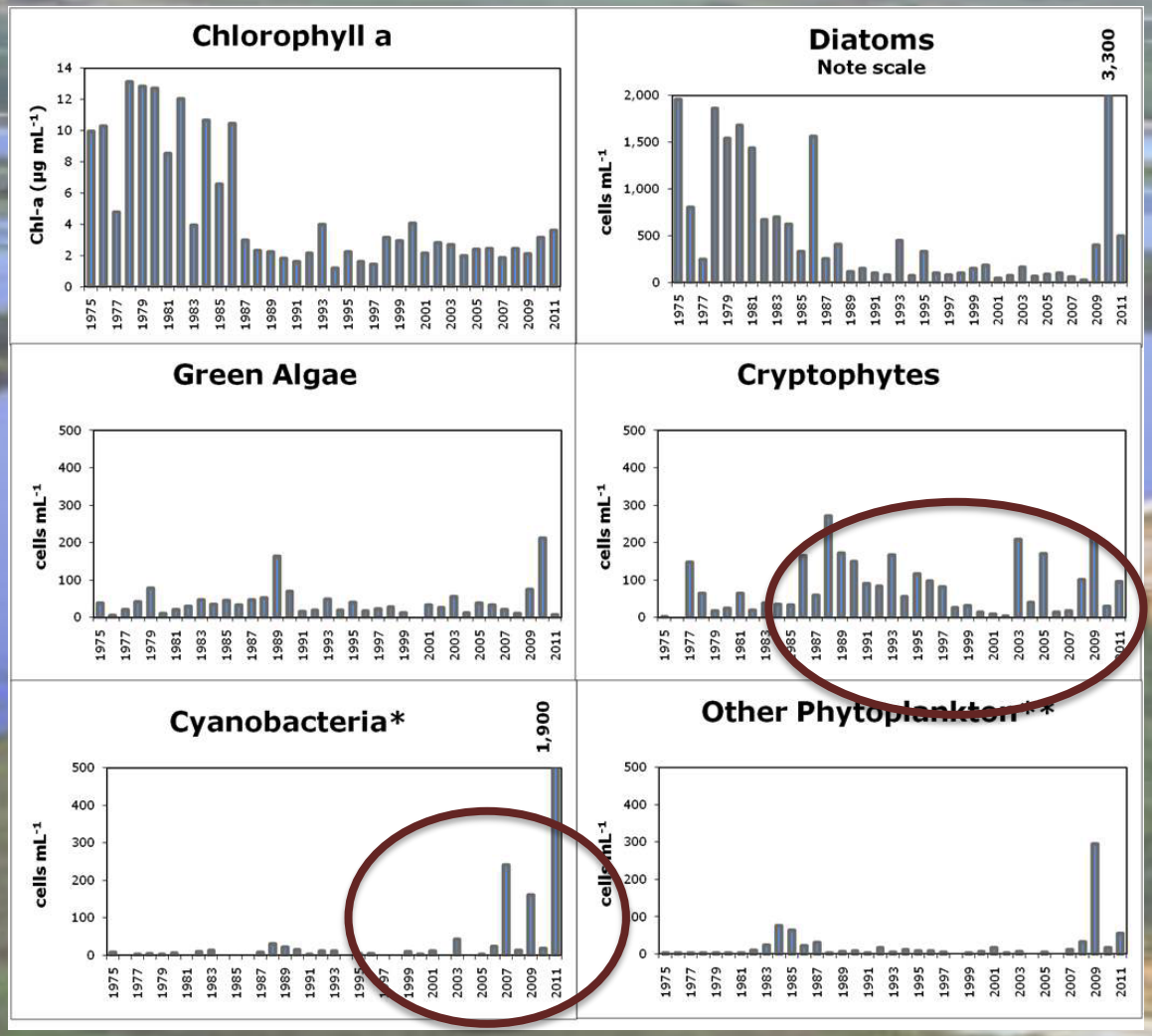
Algal community composition changes



San Francisco Bay Delta Annual averages

Glibert et al., 2011

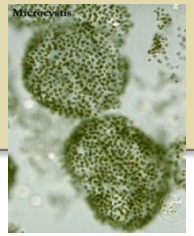
Algal community composition changes



The QUALITY of algae has changed, not just the QUANTITY

Ecological stoichiometry at higher trophic levels

Changes in the QUALITY and quantity of the algae



Grazers change in GROWTH, community shifts

Food web shifts

Nutrient loads, forms and ratio changes

Ecological stoichiometry at higher trophic levels

Changes begin at the metabolic scale
Changes in diet can affect reproduction, egg viability, and ultimately population success, ***GROWTH***

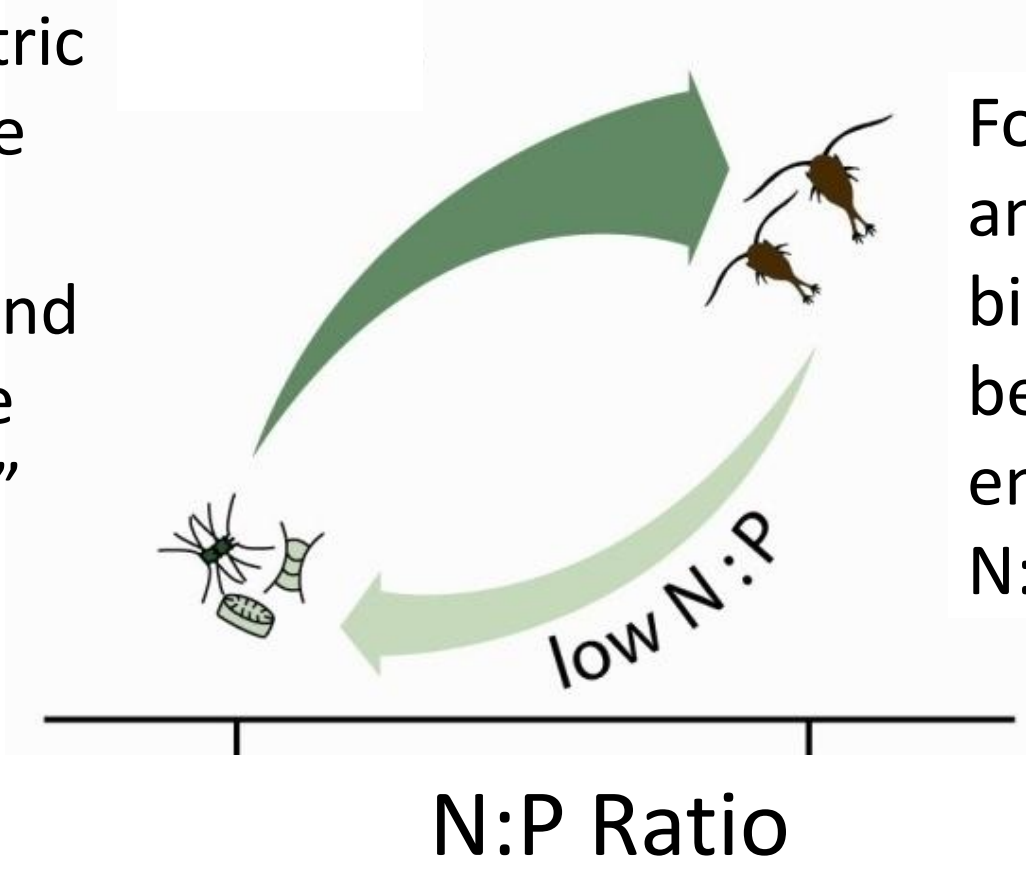
Ecological stoichiometry at higher trophic levels

"An animal's elemental composition is linked to its evolved structure and life history…

It takes a different proportion of nutrients to make skeleton and bones than it does to make muscle; Different types of organisms thrive as nutrition changes

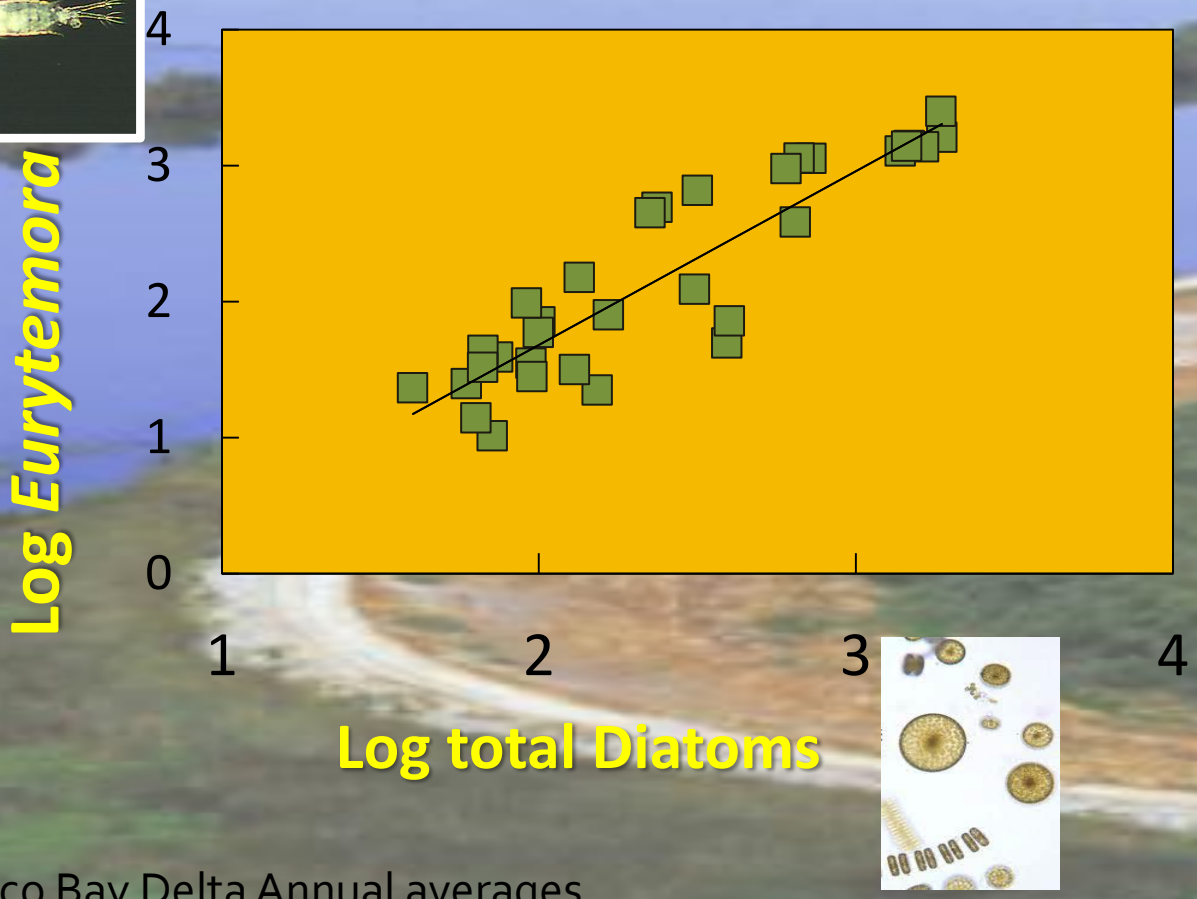
Ecological stoichiometry at higher trophic levels

Stoichiometric needs of the secondary consumer and the prey are "fine tuned"



Food biomass and grazer biomass may be at opposite ends of the N:P spectrum

Changes at the bottom of the food web alter the community at the top



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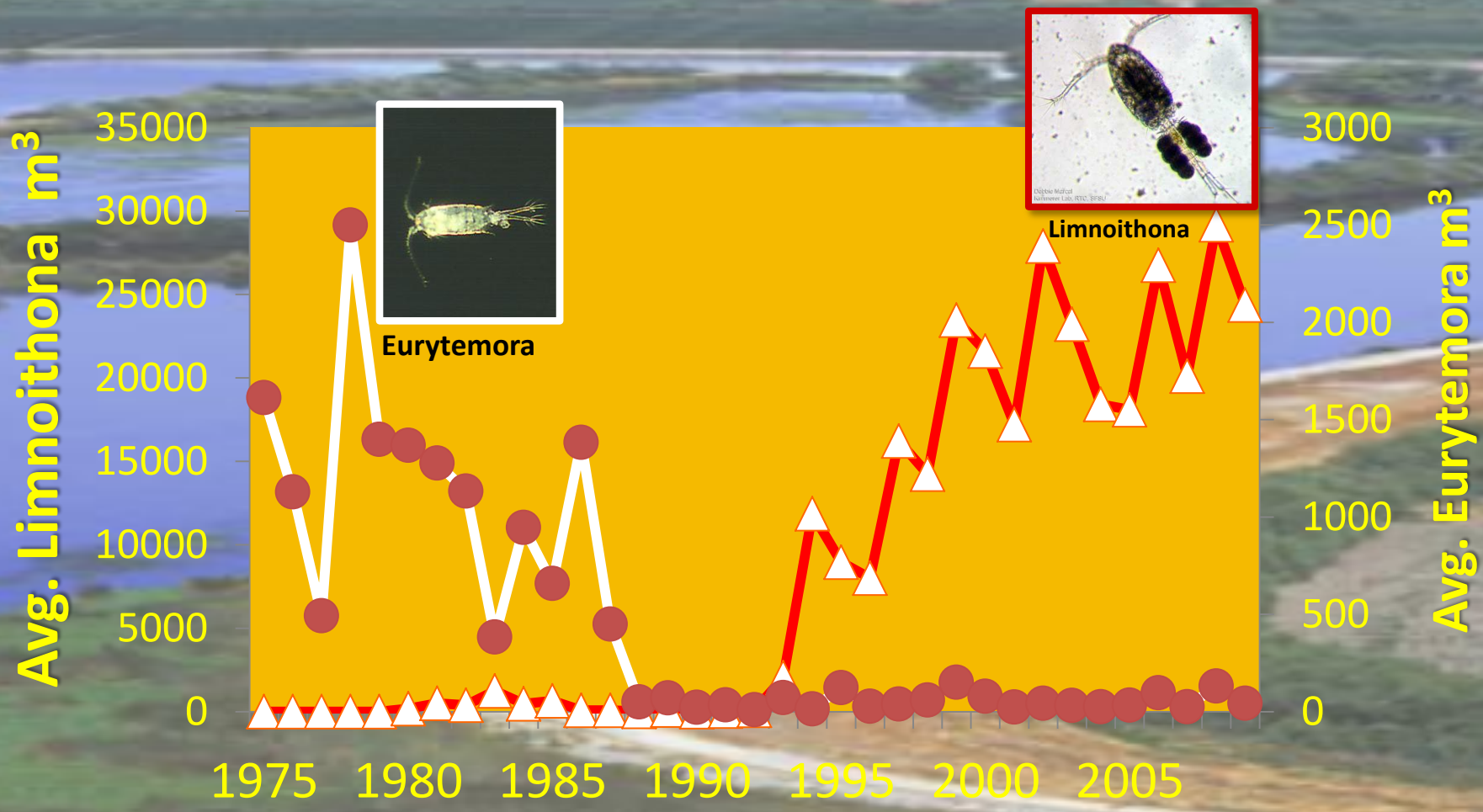

Glibert et al., 2011

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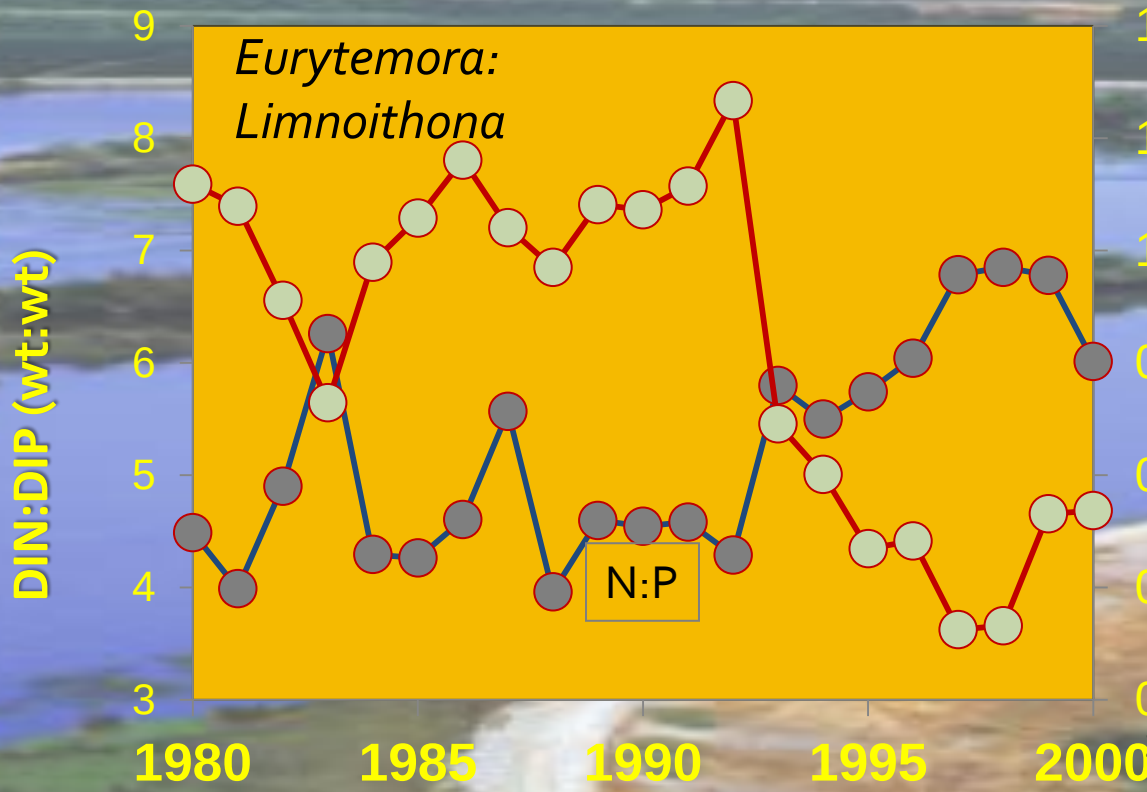

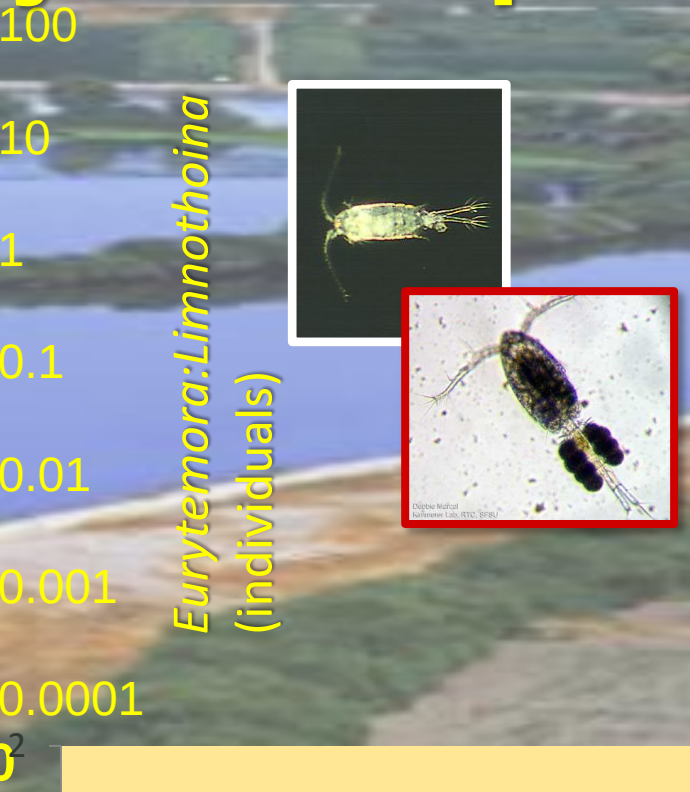

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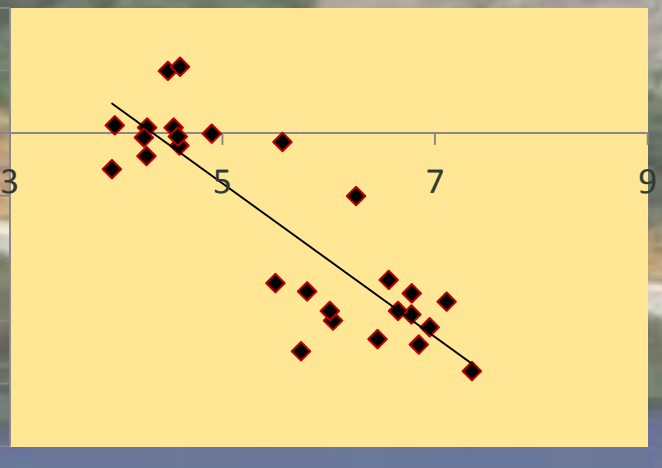

Glibert et al. 2011

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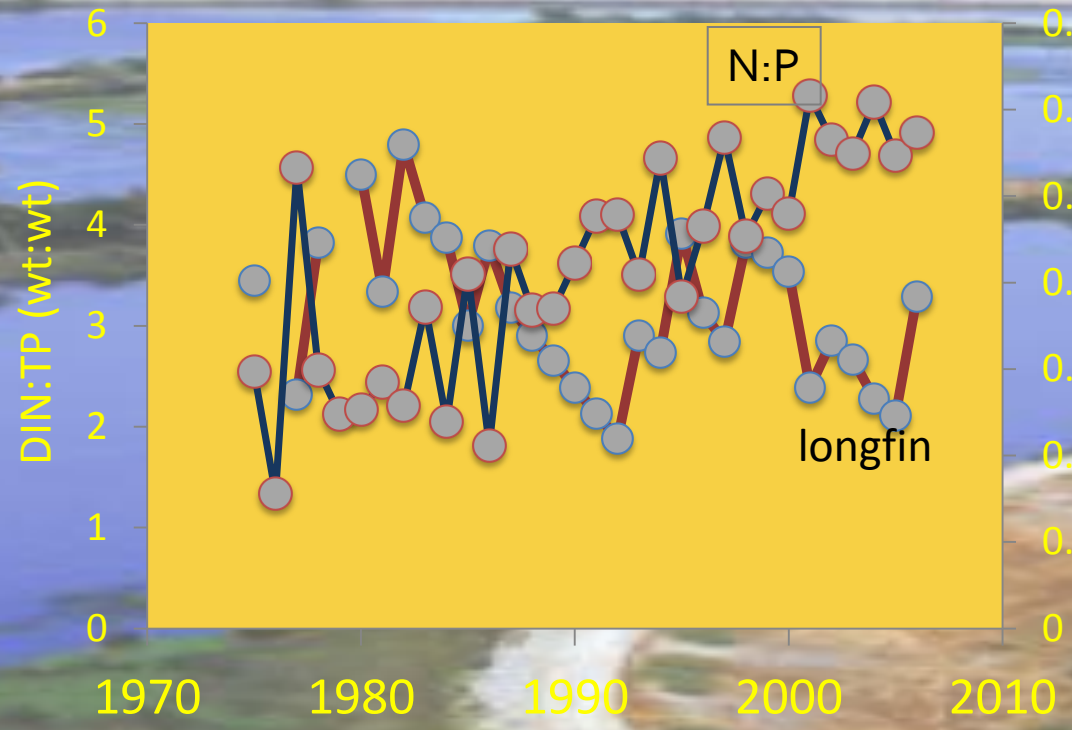

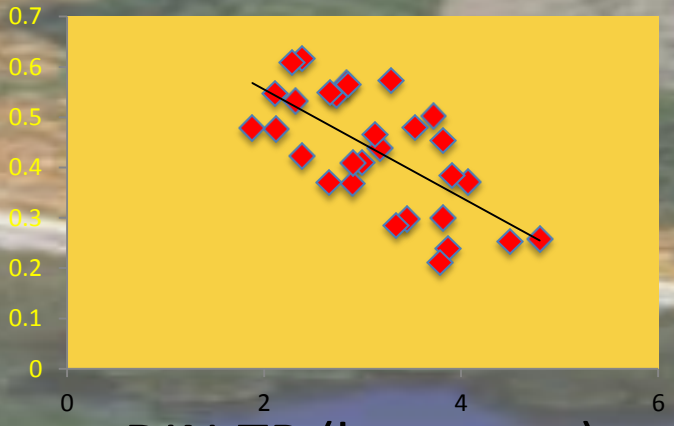

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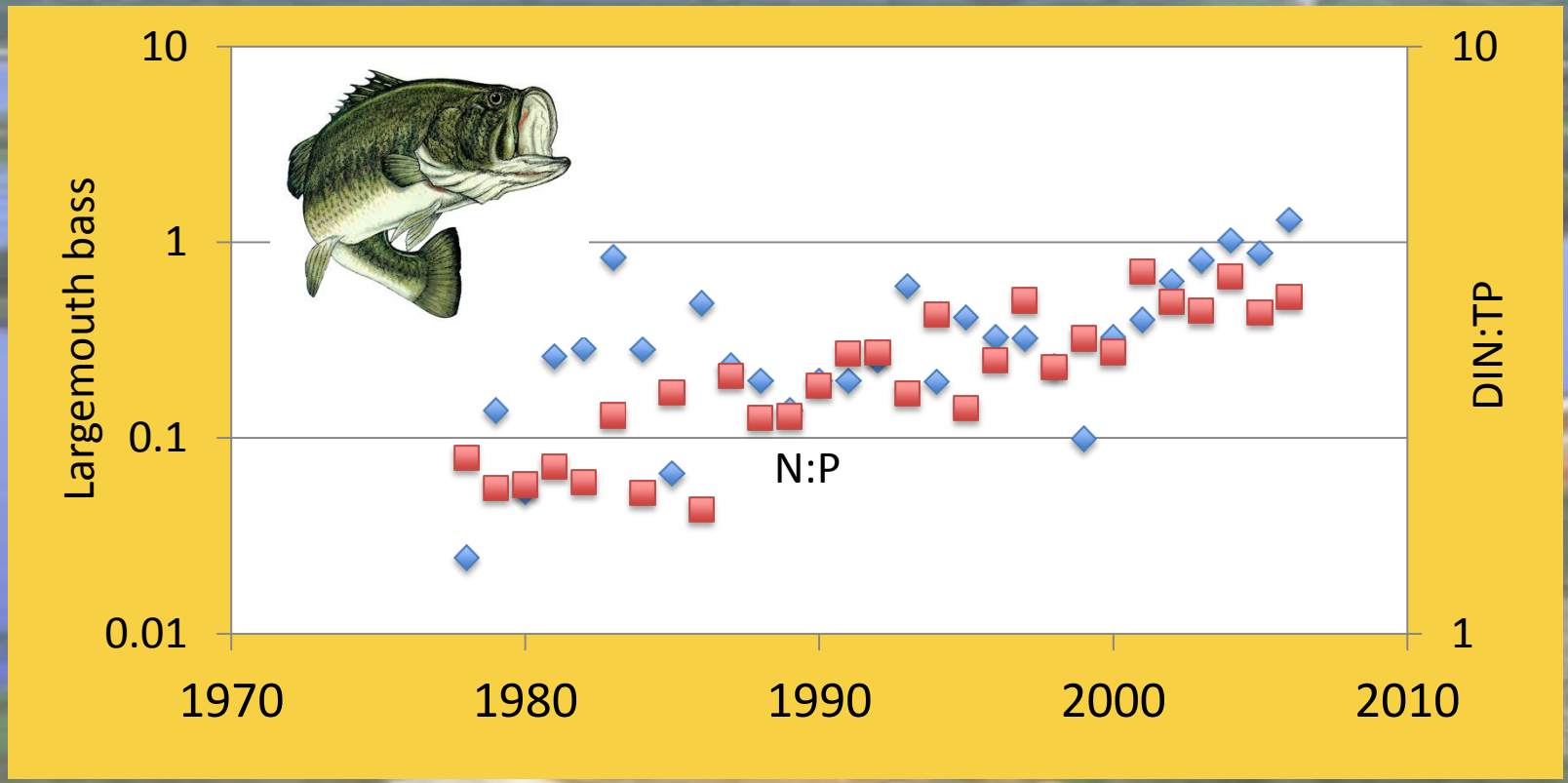
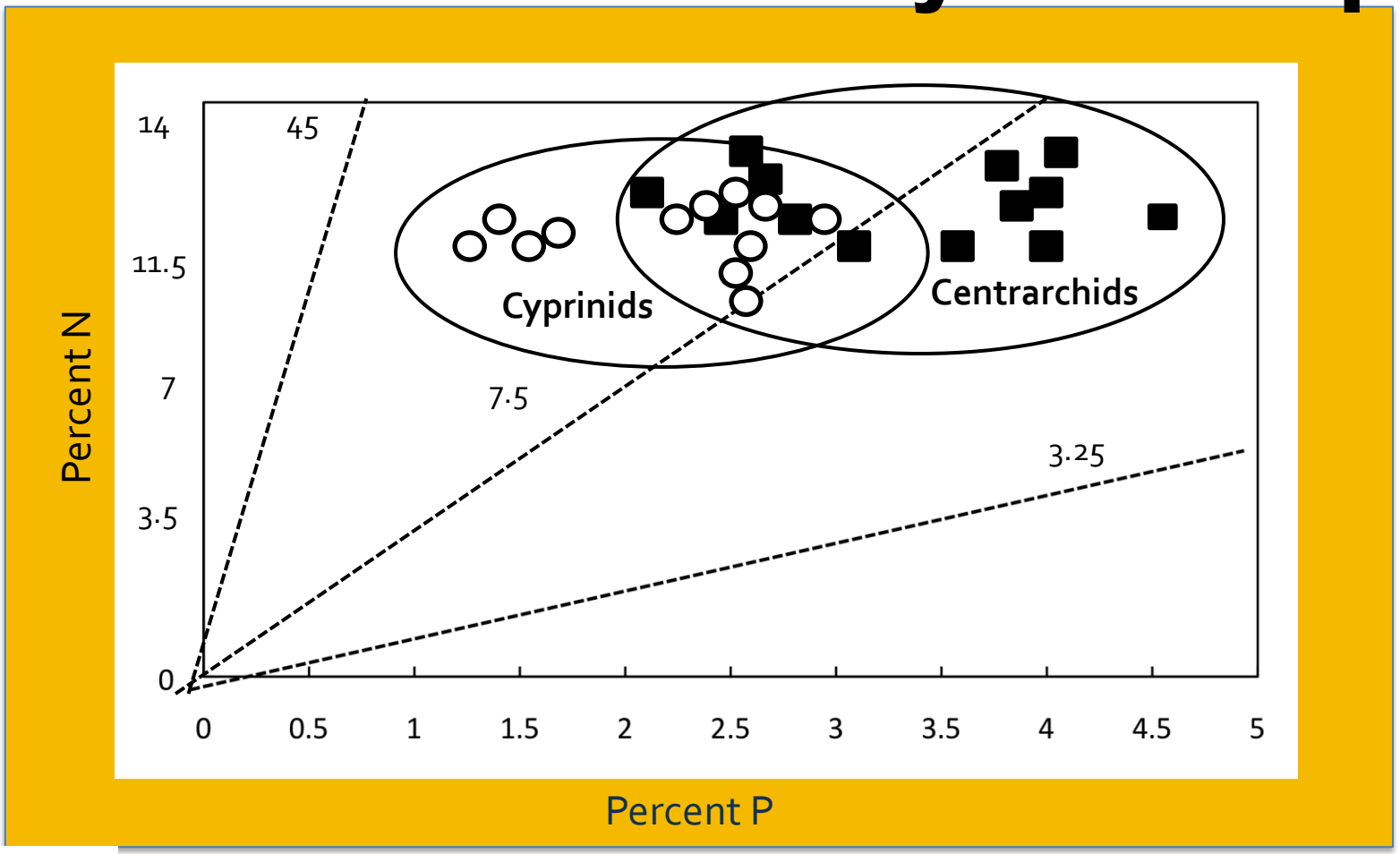


"As one ascends the pelagic food web…trophic groups grow increasingly nutrient and especially P rich…"

San Francisco Bay Delta Annual aves 1975-2005

Glibert et al., 2011

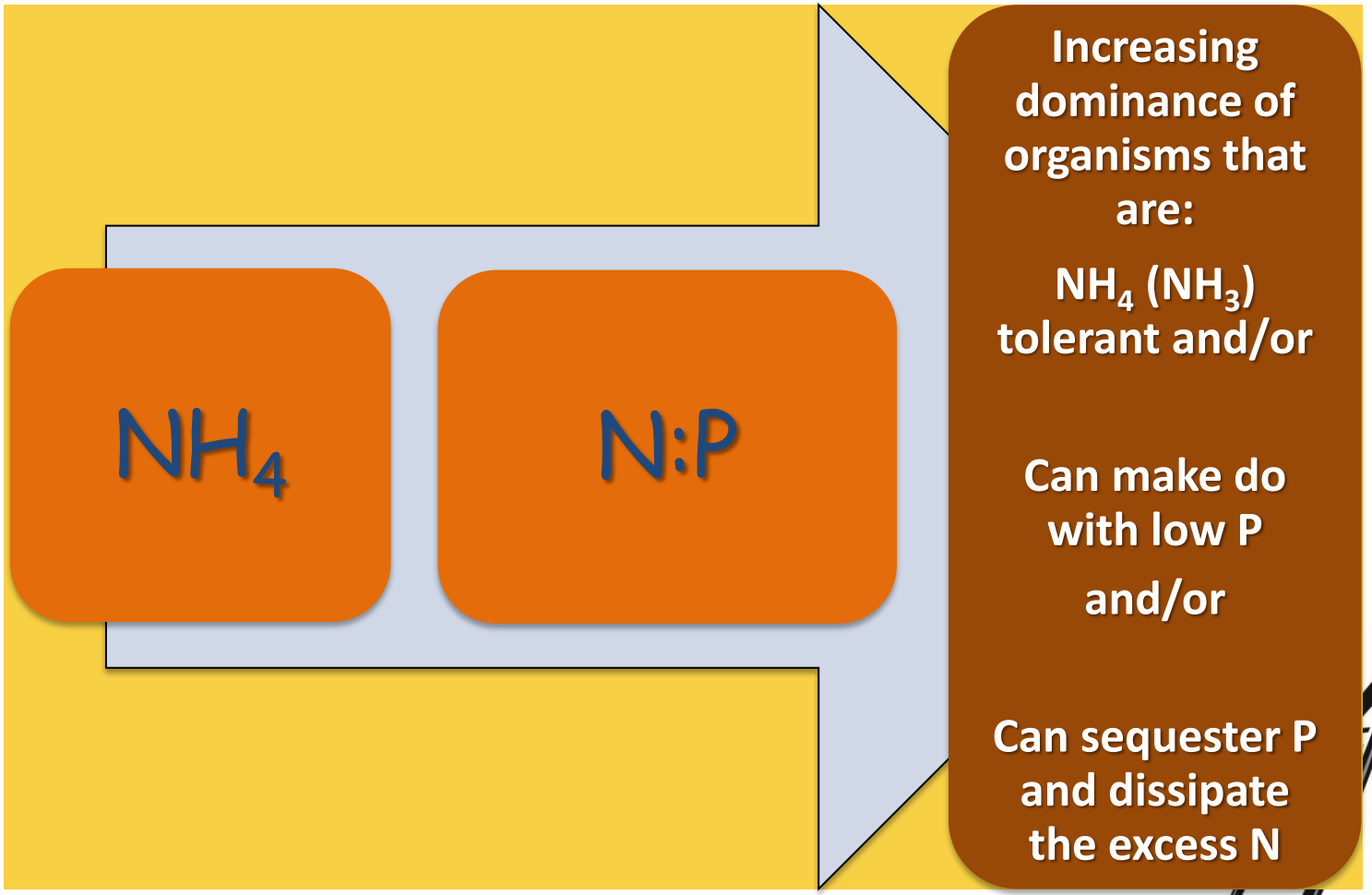
Changes at the bottom of the food web alter the community at the top



Highly evolved excretion mechanisms to help balance nutrient stoichiometry

Modified from Sterner and George 2000

Changes at the bottom of the food web alter the community at the top



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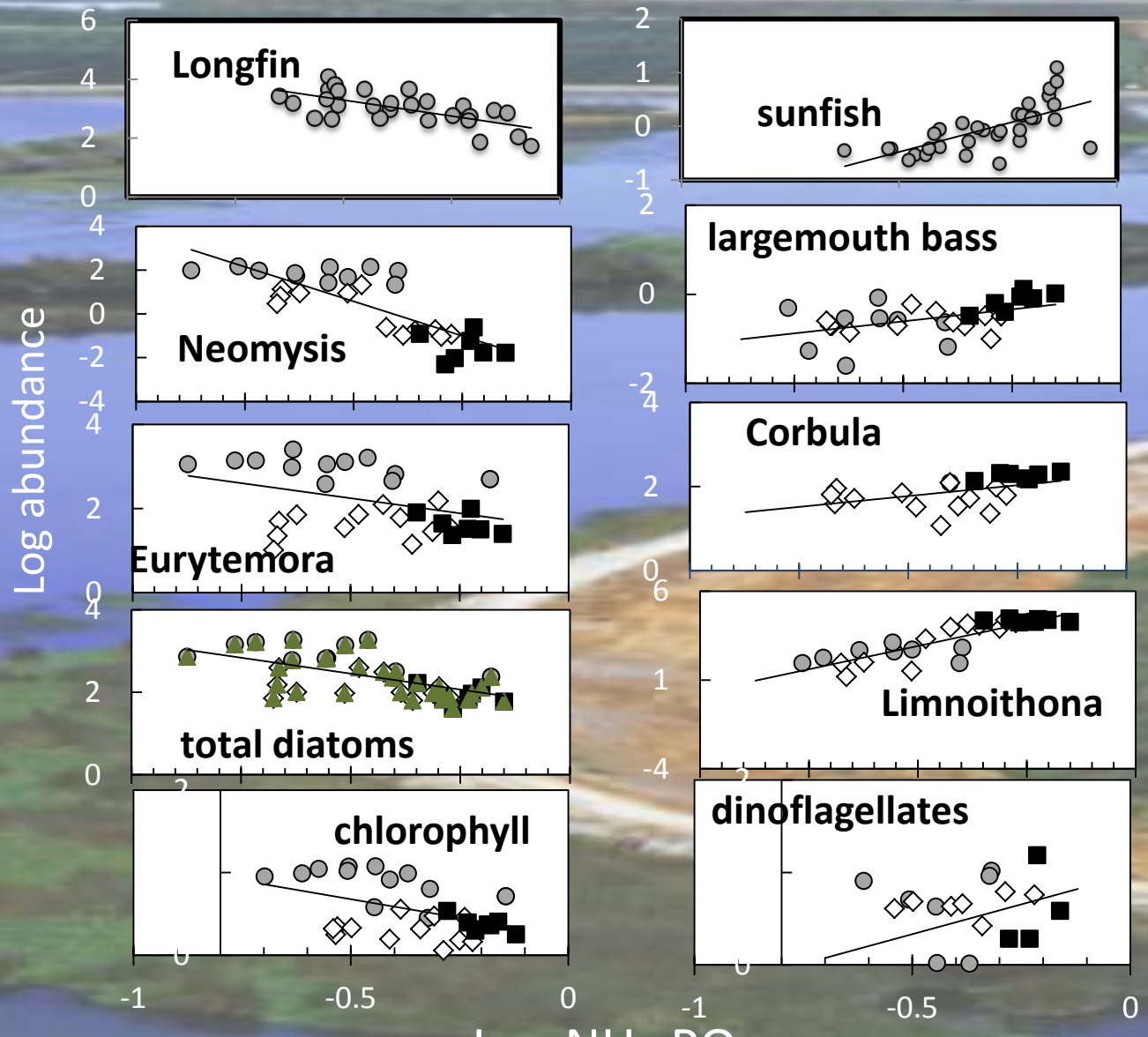
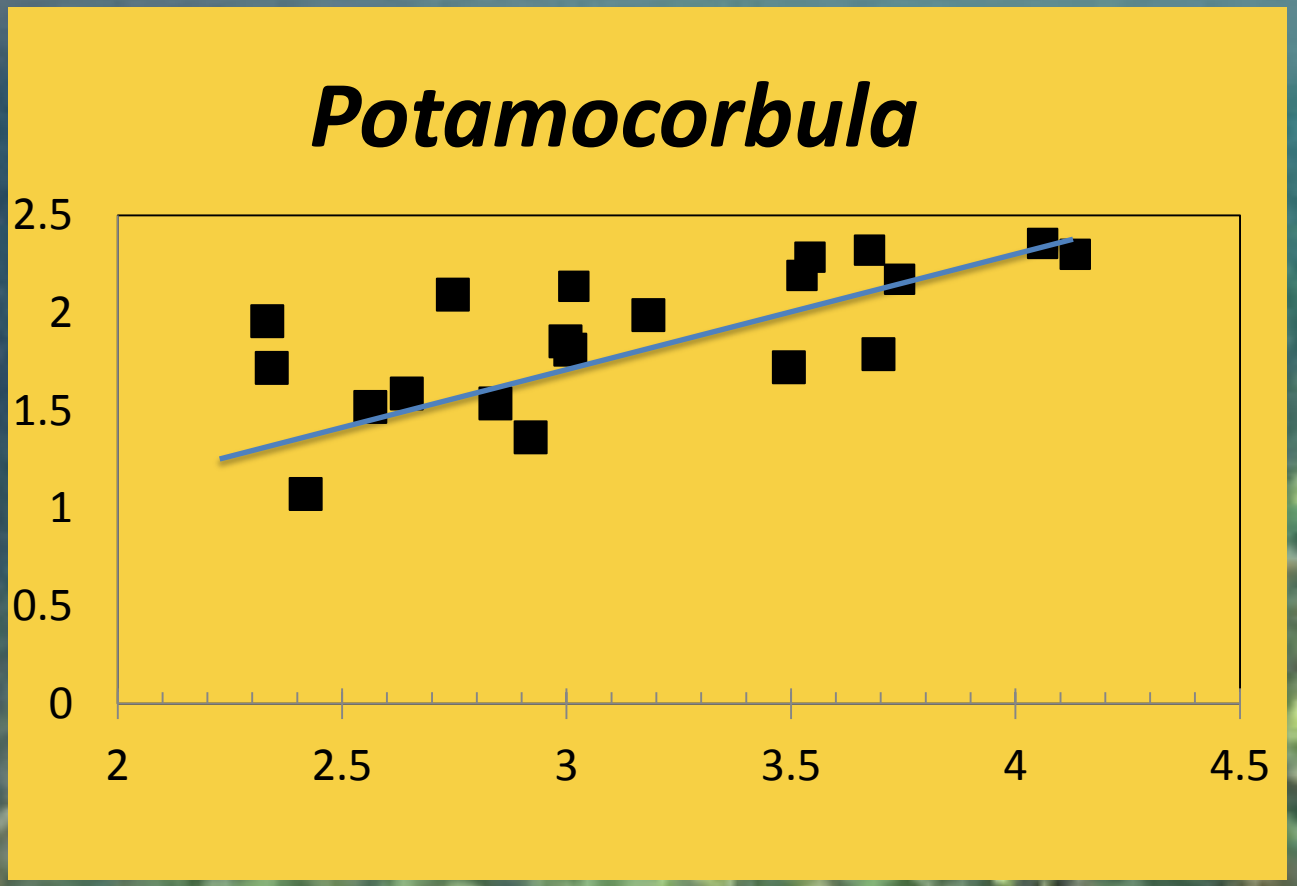


As nutrients change there are winners and losers at all levels of the food web

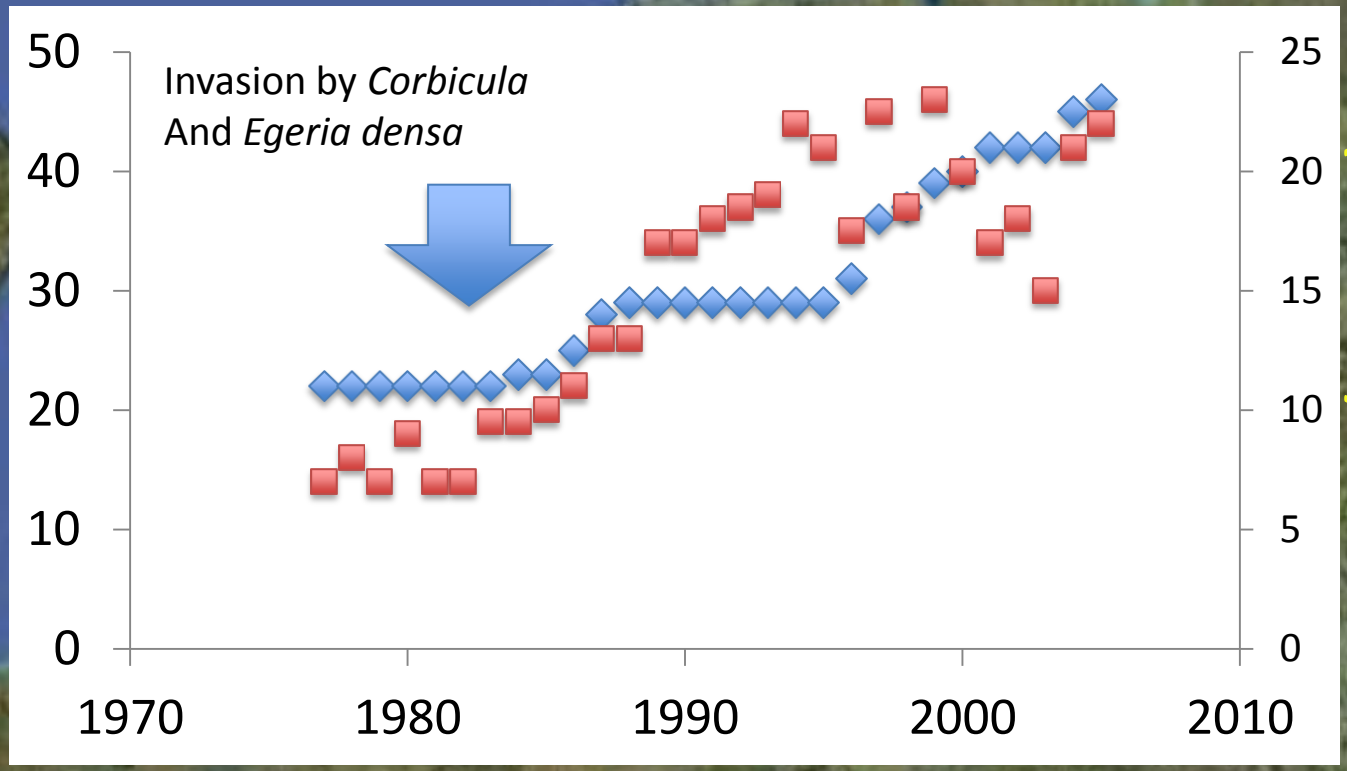
The winners and losers are predictable based on fundamental biological principles

Some of the winners are invasives



Invasive species may be as much a RESPONSE to nutrient and ecosystem change as they are a CAUSE of ecosystem change

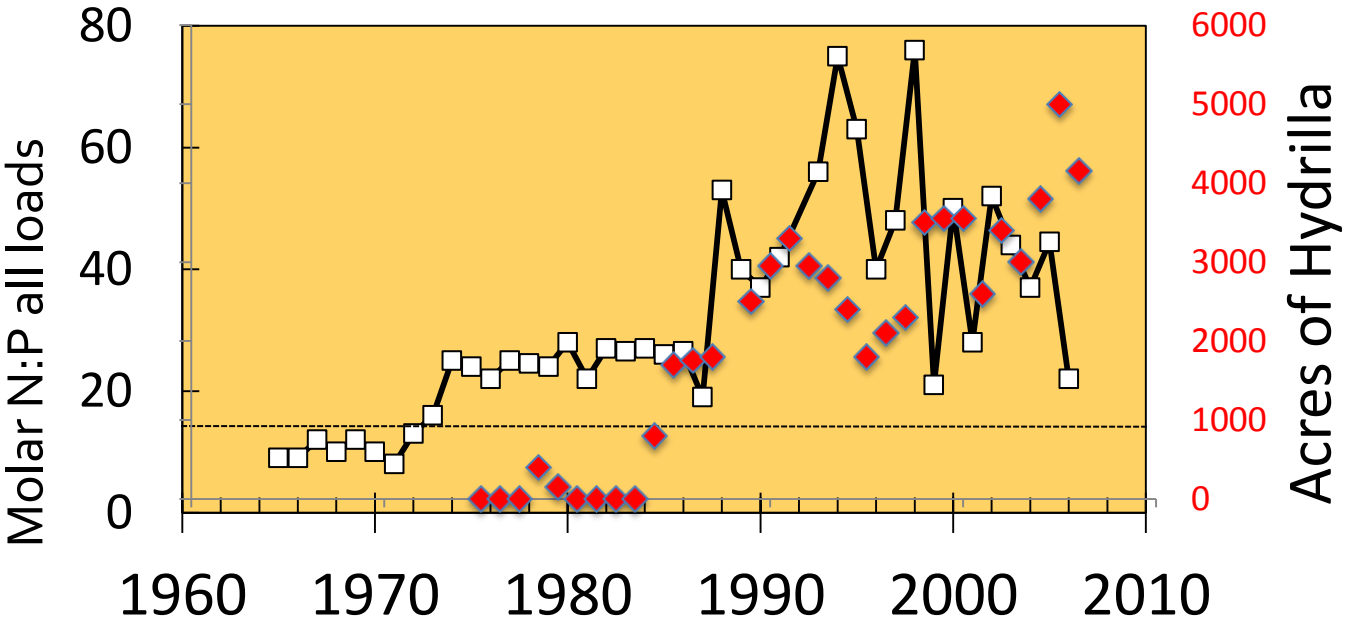
Rhine River



Source data: Van Niewenhuyse 2007; Leuvin et al. 2009

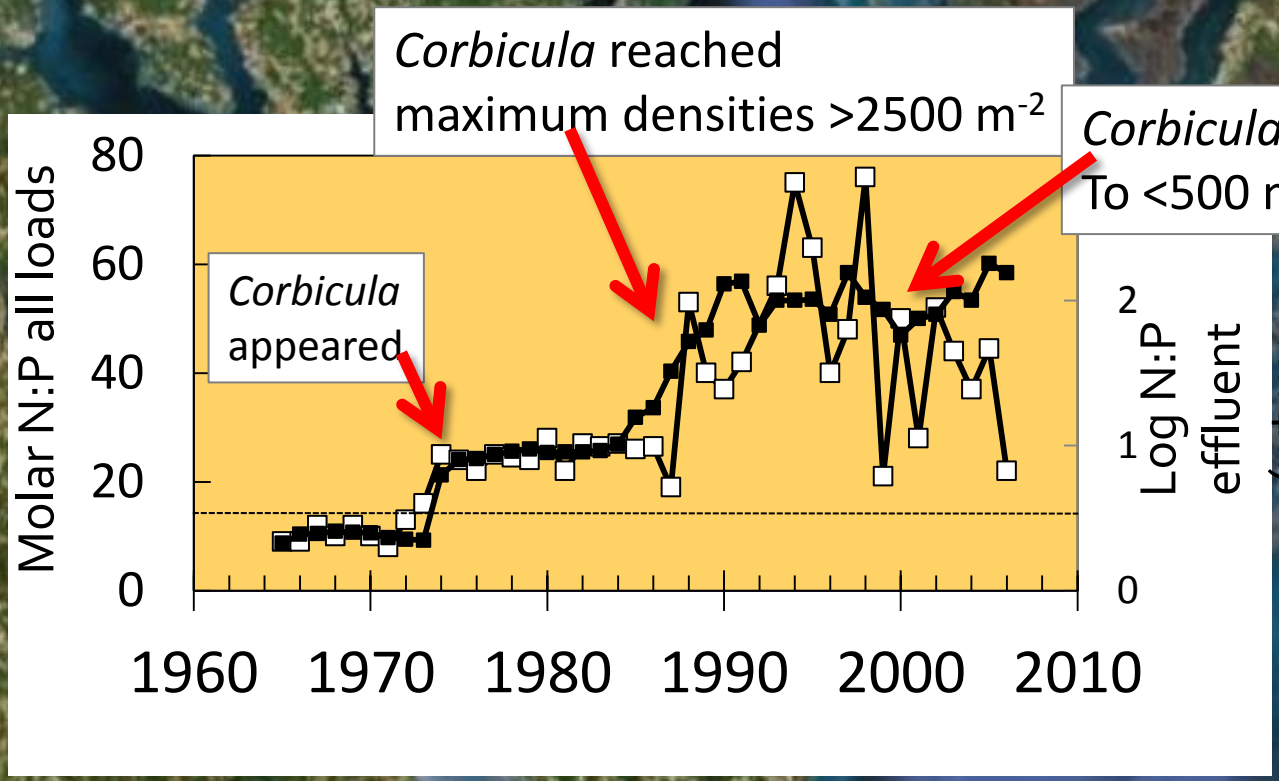
Rhine

Potomac River, Chesapeake Bay

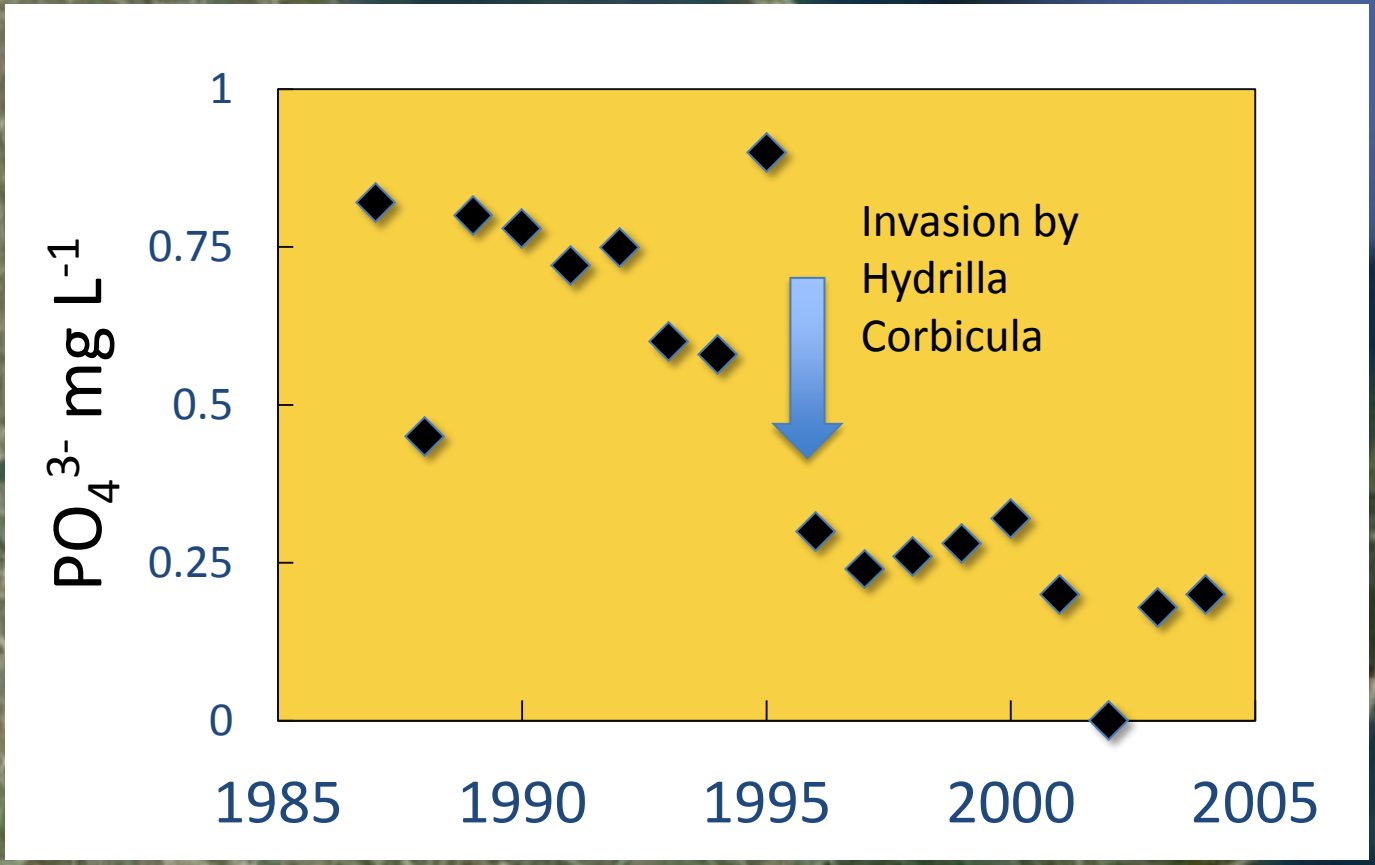


Data SIO, NOAA, U.S. Navy, NGA, GEBCO

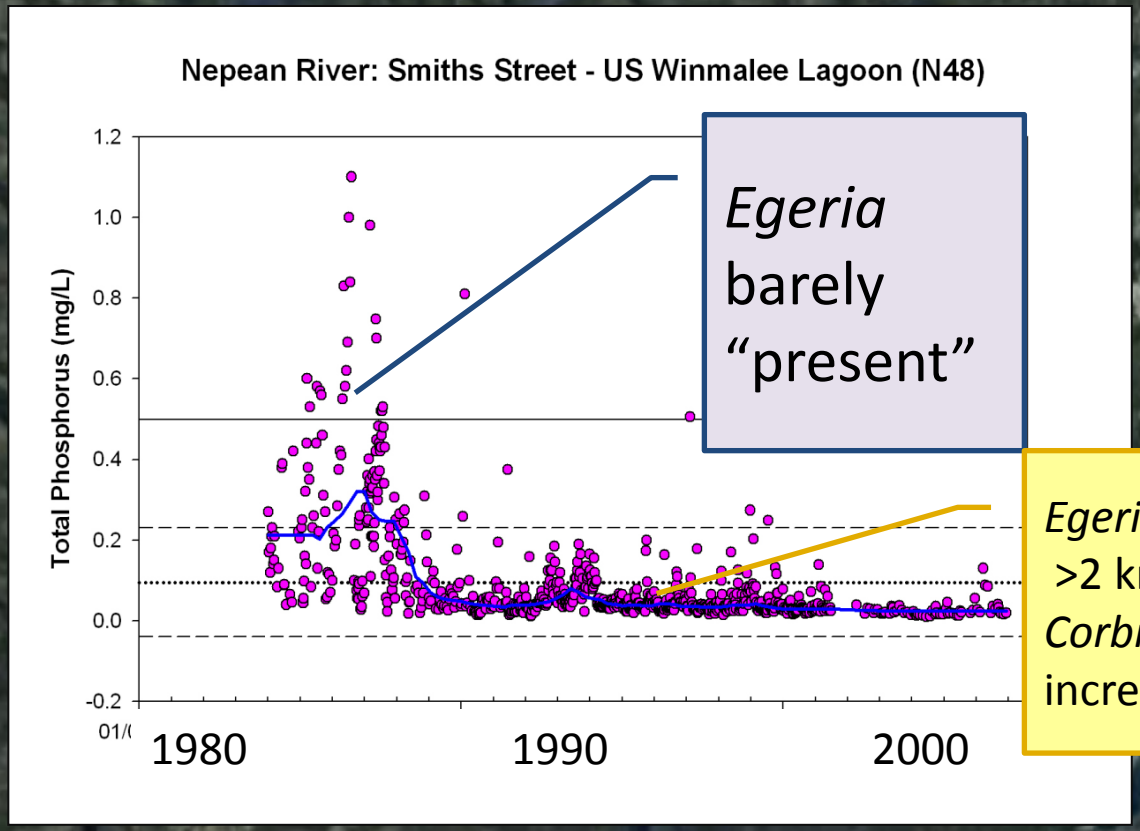
Potomac River, Chesapeake Bay



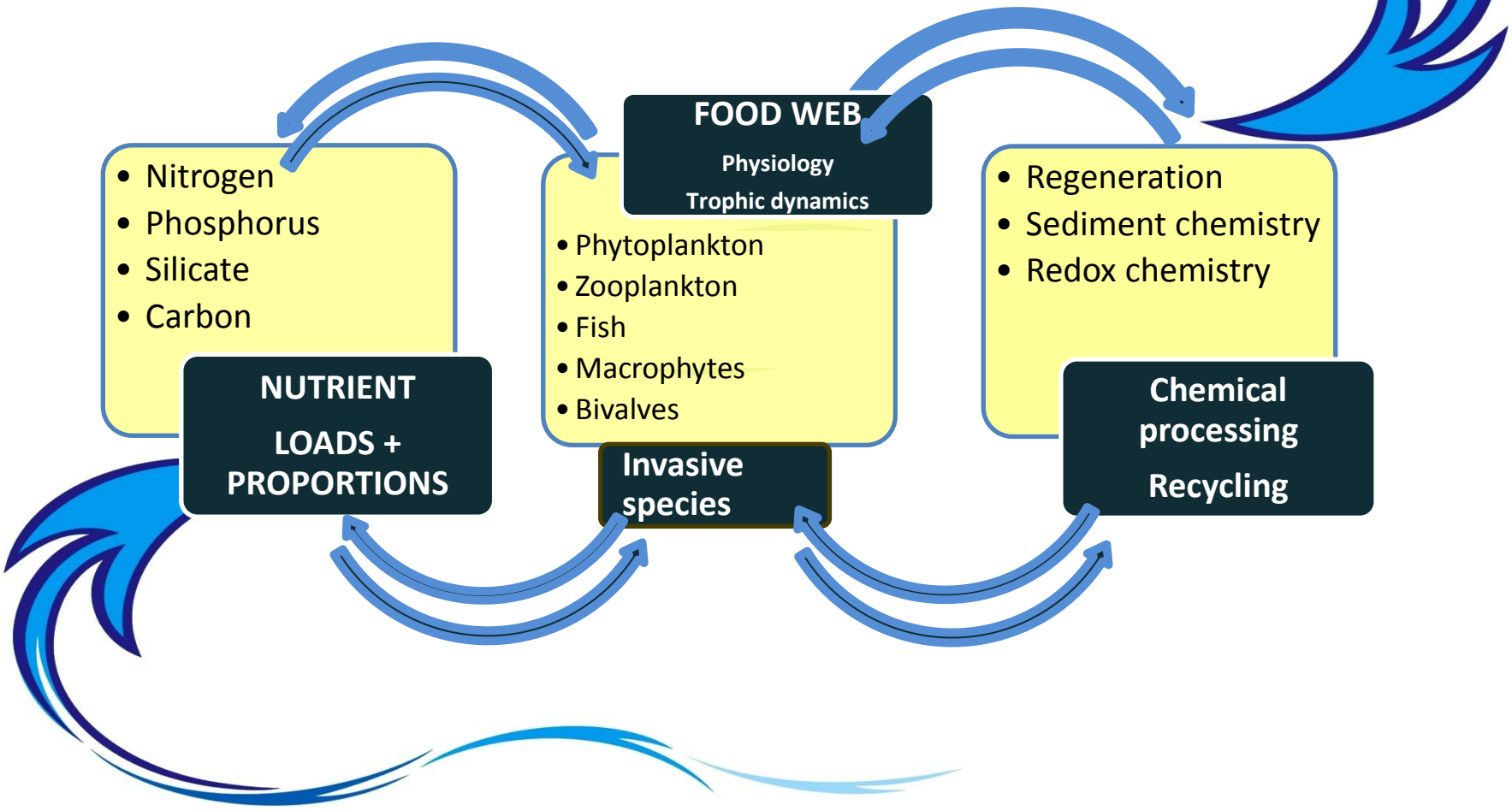
Lower Ebro River, Spain



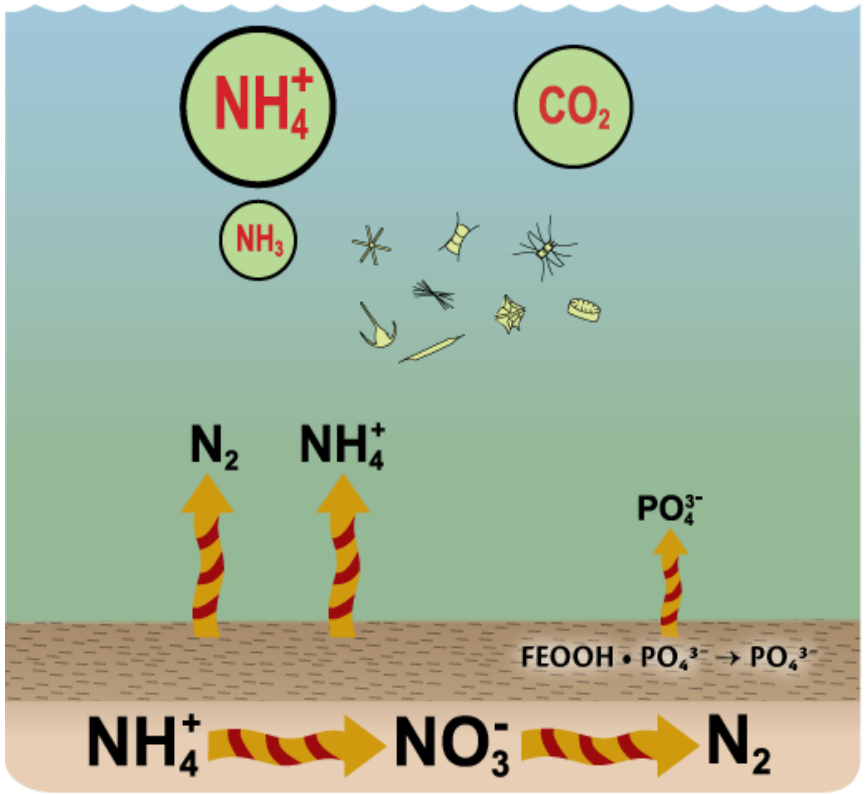
Lower Hawkesbury-Nepean River, Australia

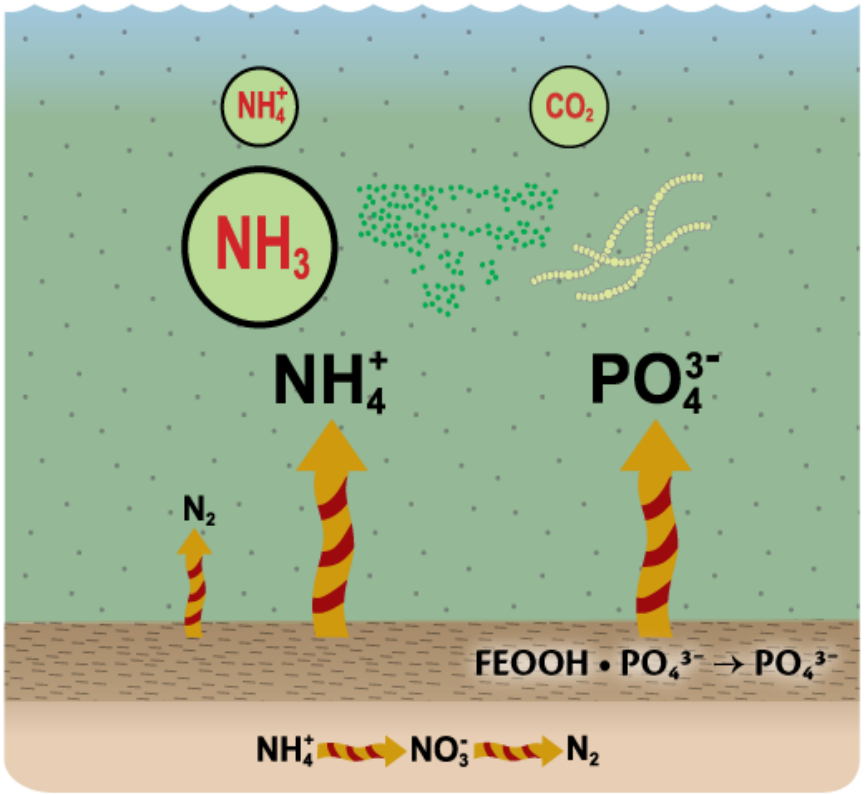


Ultimately it's all connected …and a grand mass balance



Nutrients and flow





Sediments are reservoirs of nutrients
Fluxes change with salinity, pH, temperature

Glibert et al. 2011

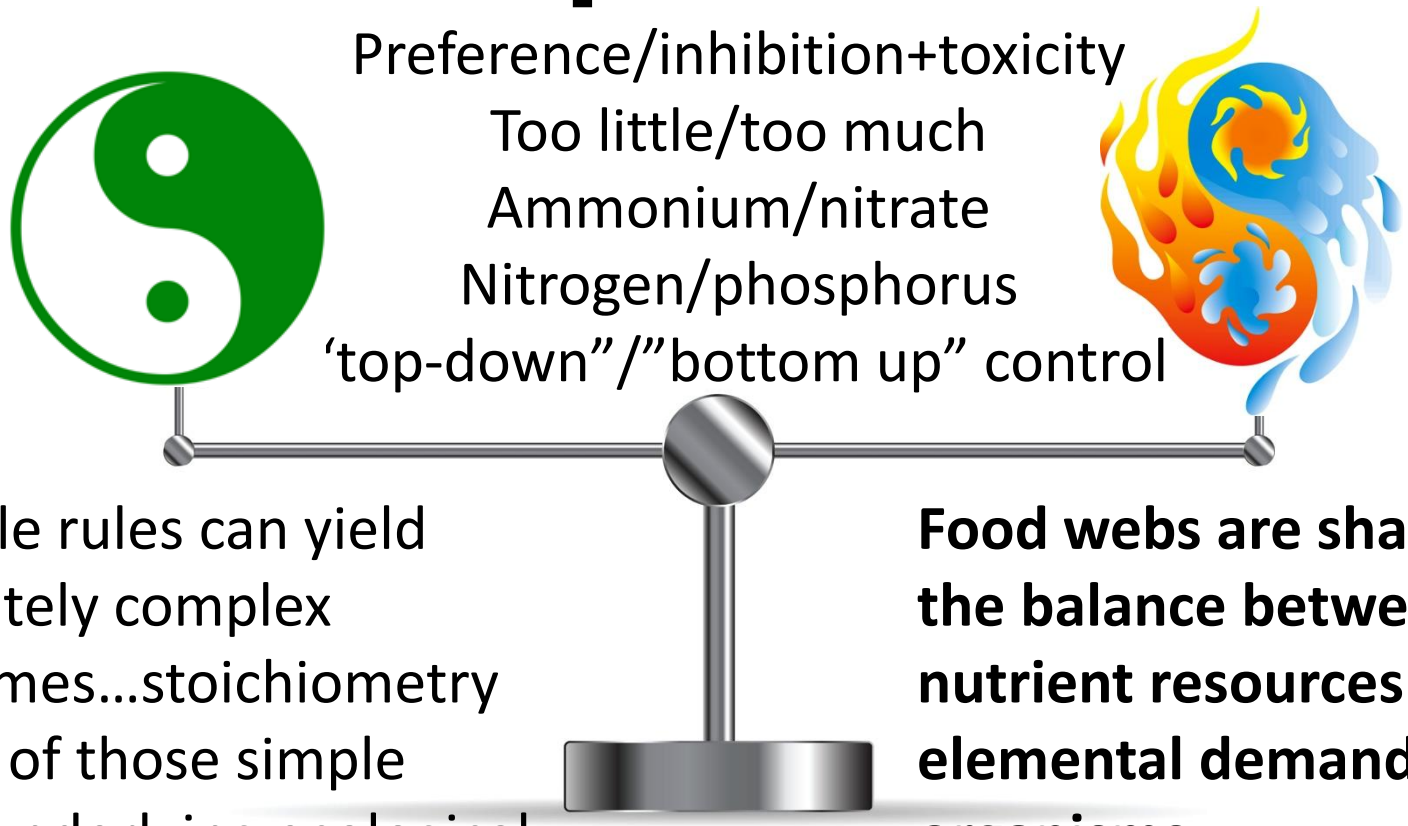
Nutrients and flow

Residence time (exposure time) to beneficial nutrients or inhibitory/toxic compounds

Flow

- Imports new nutrients
- Dilutes point source inputs
- Alters reactions at the sediment surface
- Exports nutrients downstream where they can form blooms displaced in time and space from the source.

Ecosystem is in Dynamic Balance
Nutrients are part of that balance



"Simple rules can yield intricately complex outcomes…stoichiometry is one of those simple rules underlying ecological and biological complexity"

Sterner and Elser 2002

Food webs are shaped by the balance between nutrient resources and the elemental demands of the organisms

RECAP

- Ammonium is a ***paradoxical*** nutrient
- Nutrient ratios DO matter, altering the QUALITY of food at all levels
- Too much nutrient can be a stress, as is too little
- The Bay Delta is not unique in the trajectory of many food web changes with changes in nutrient loads and ratios
- Nutrient changes can alter the ecosystem providing opportunities for invasive species to thrive
- Ecological stoichiometry may help to provide a mechanism for relationships between fish and flow

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"Consumers can be 'destined for extinction' when faced with poor food quality"

Elser and Kuang