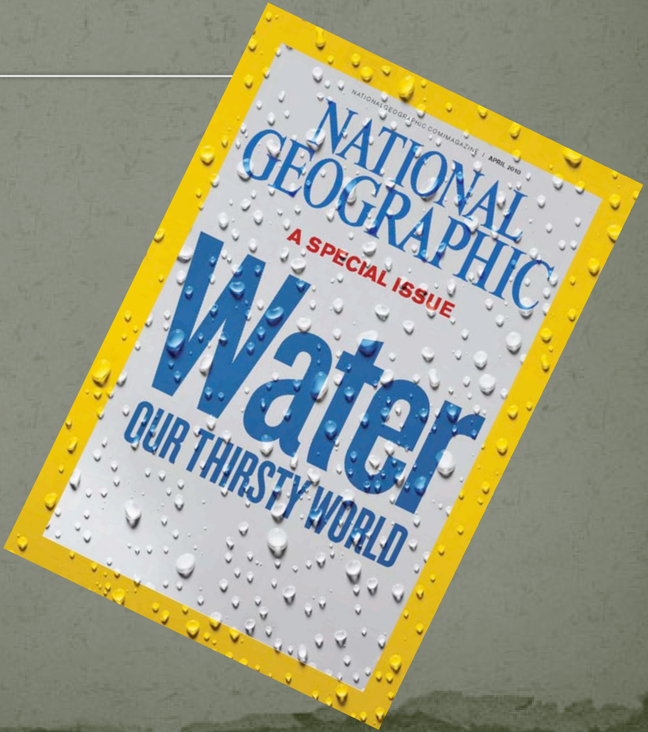
CRASR
Center for Reservoir & Aquatic Systems Research

Nutrients in the aquatic environment: Impact to aquatic plants

Robert Doyle, Ph.D.
Baylor University

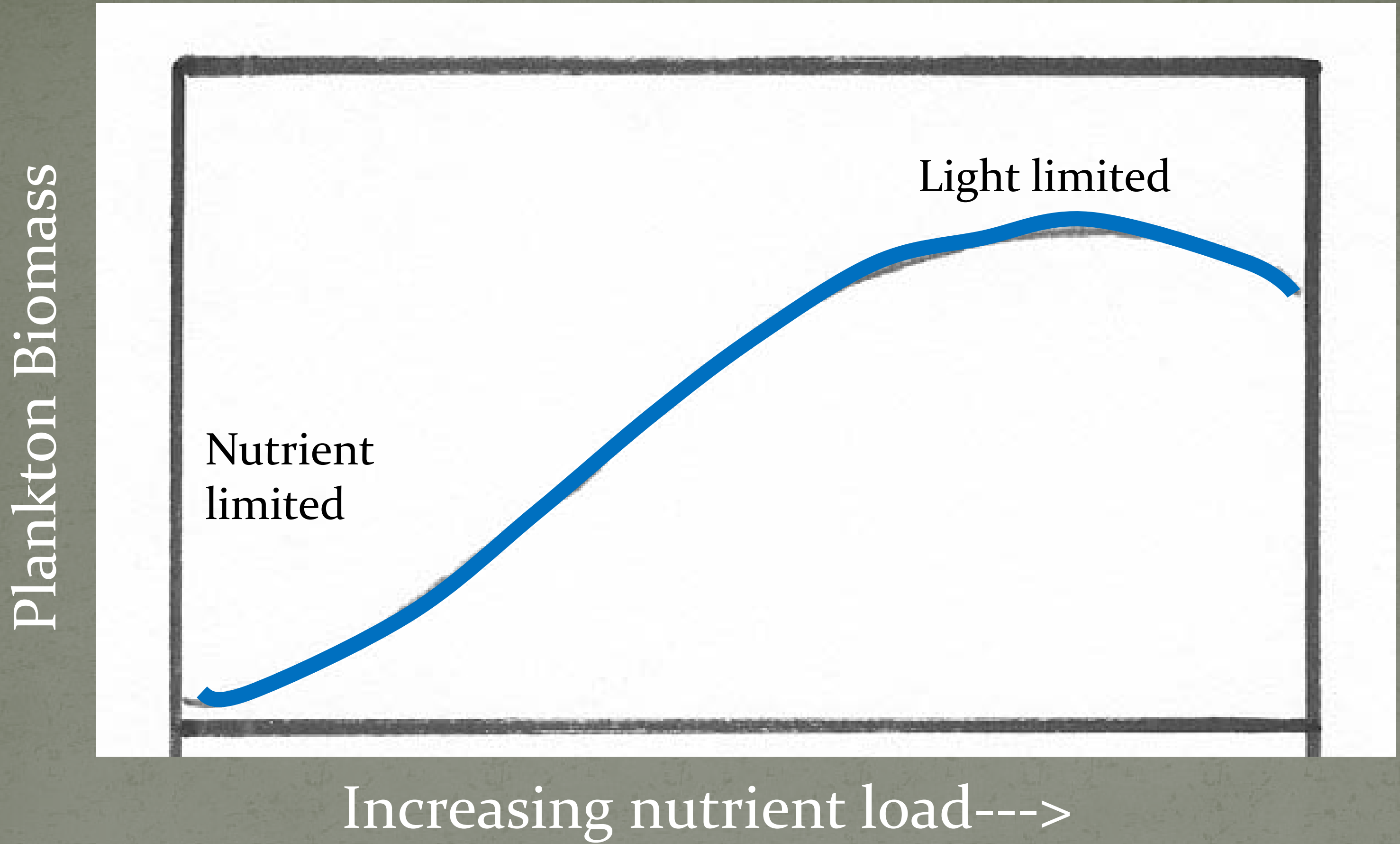


Major Problems w/ Aquatic Ecosystems

- 1) Distribution & Overuse- not enough to go around
- 2) Eutrophication- too much of a good thing
- 3) Emerging Pollutants & the “Tragedy of the Commons”
- 4) “Transformer” Exotic Species
- 5) Disturbances

Topics for Today

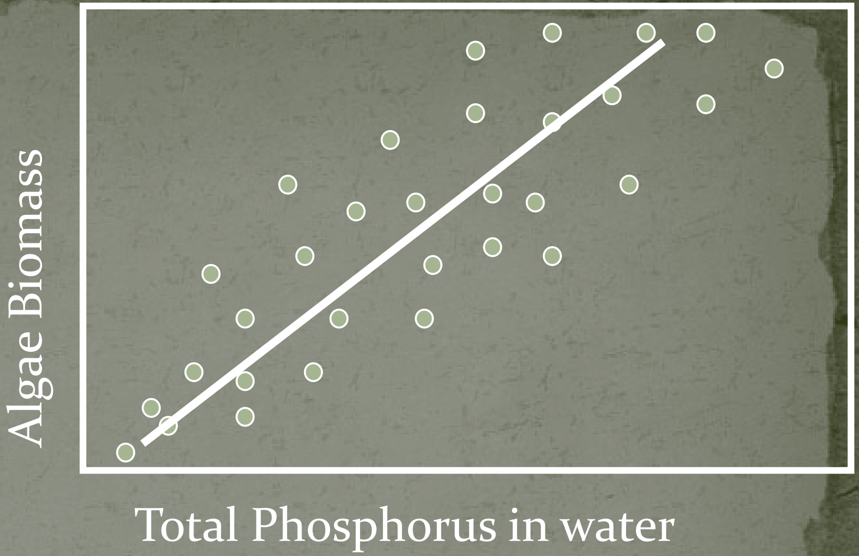
- Impacts of eutrophication on general trends of primary producers in lake
- Alternate stable states for smaller lakes of intermediate fertility
- Shifts in macrophyte species with eutrophication
- “Ecological Stoichiometry:” a constraint on herbivory?



General trends in primary productivity of phytoplankton, macrophytes, and epiphytes with increasing nutrient loading (from Sand-Jensen, 1980)

Nutrient Limitation of Plankton

- Algae need nutrients to grow
  - C, N, P, Ca, etc, etc, etc
- P (sometimes N?) limit plankton productivity
- LOTS of data

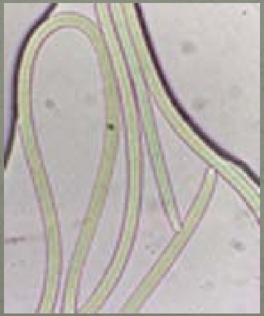


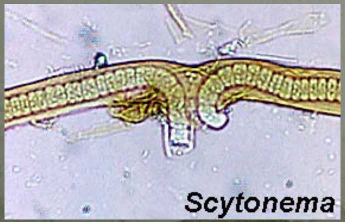
Aerial view of Lake 227 in 1994. Note the bright green colour caused by algae stimulated by the experimental addition of phosphorus for the 26th consecutive year. Lake 305 in the background is unfertilized. (photo by Karen Scott)

Eutrophication Impacts

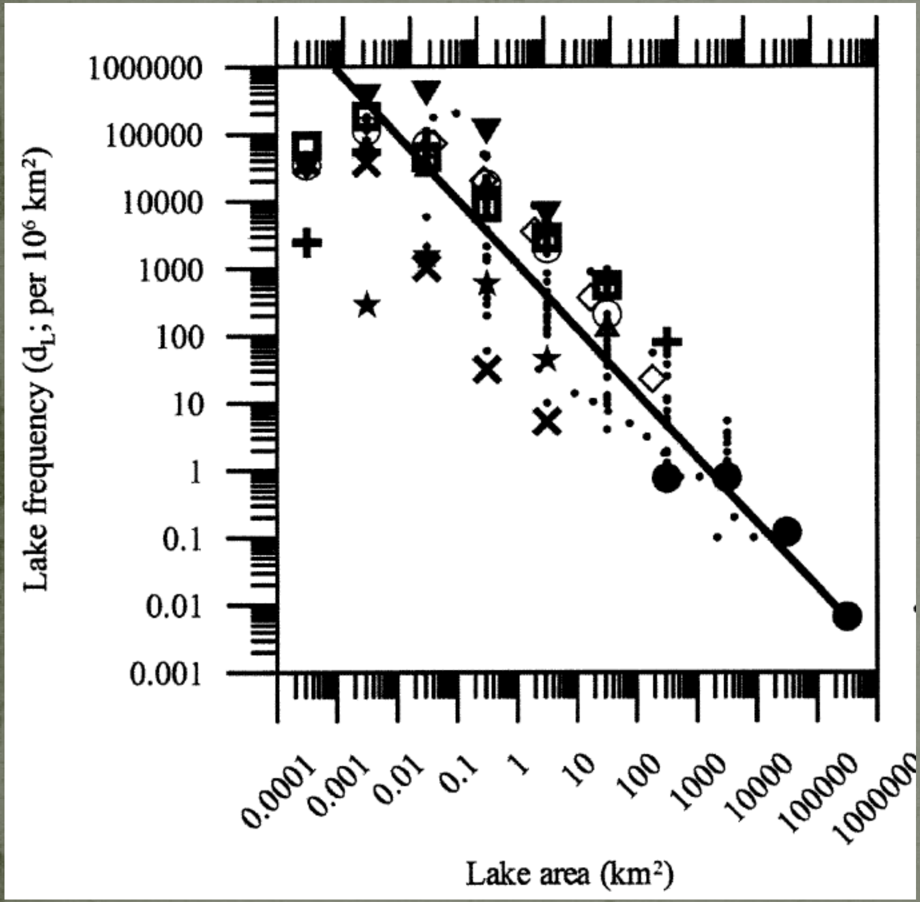
- AMOUT OF ALGAE: Algae blooms....
  more nutrients→ more algae!
  - cloud the water and block light penetration
  - algae die, sink to the bottom and use up all the oxygen-→ chemical changes to the water

- Shifts in algal species dominance:
  Nutrient enrichment favors less desirable algal species (stimulate blue-green algae)
  - Low palatability
  - Many cause taste and odor problems



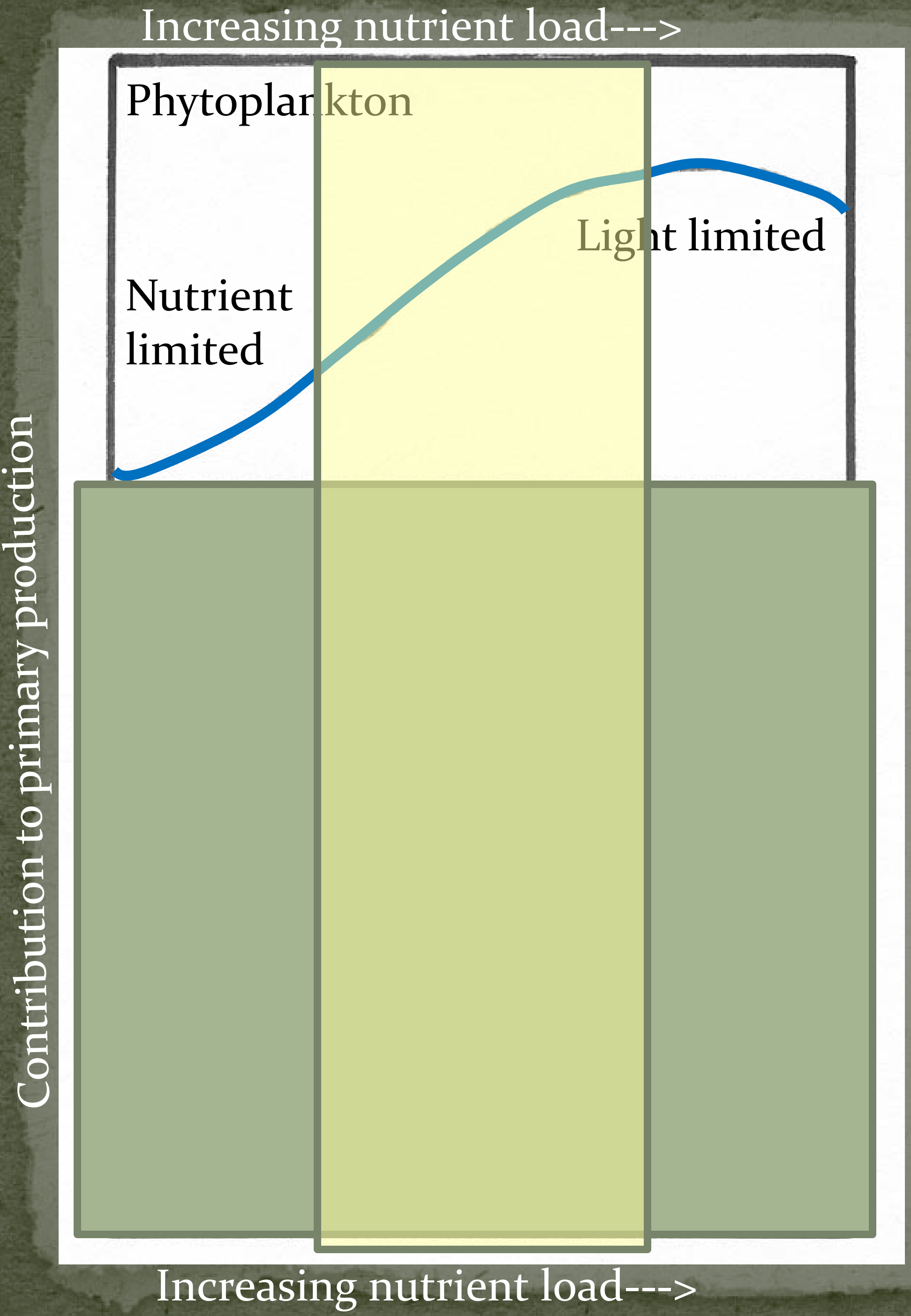


Why the focus on plankton & pelagic (open water)? Wetzel told us littoral zone was a "bathtub ring"



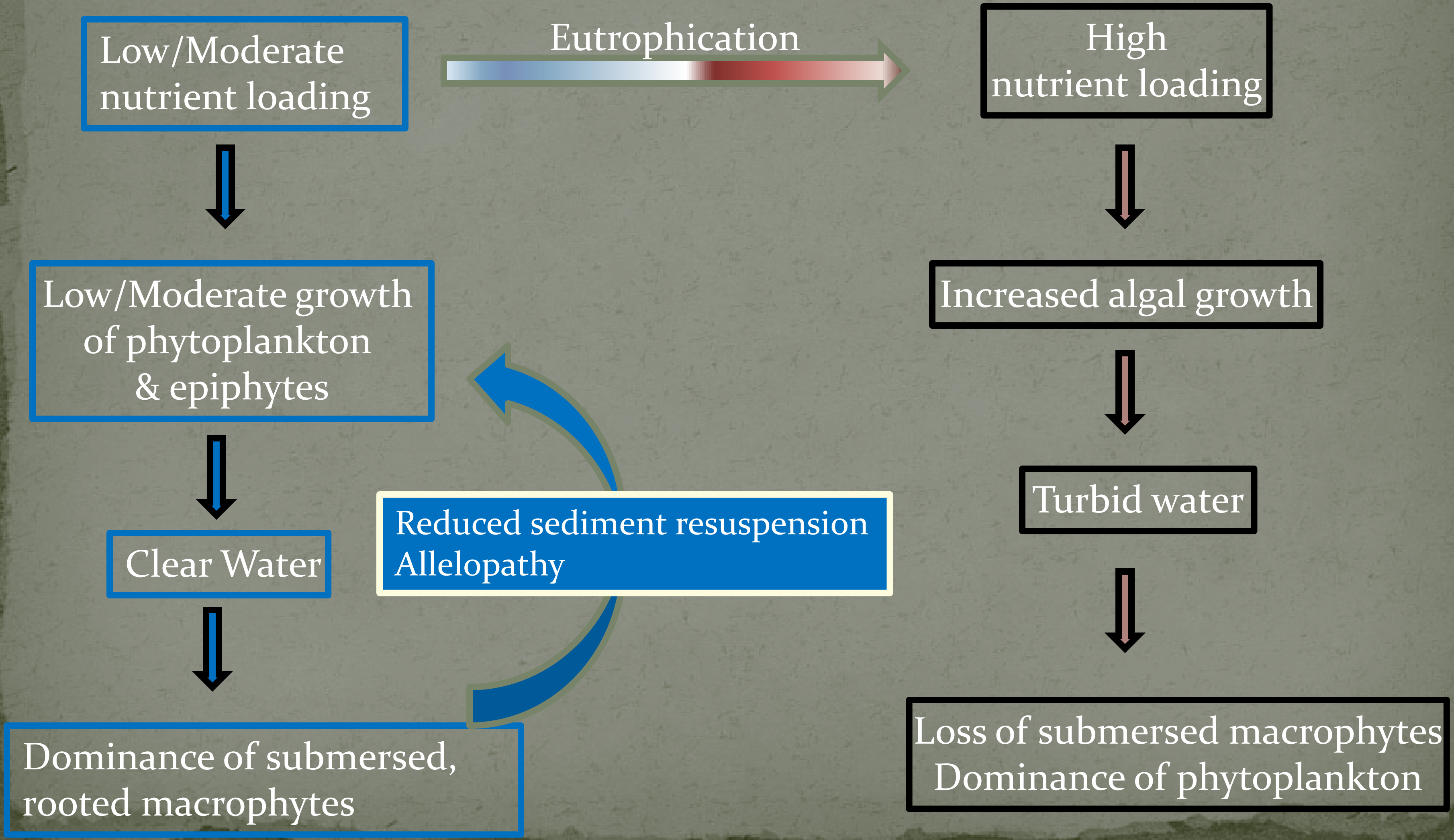
- 304 million lakes
- > 1000 km²
  - 122 lakes
  - 30 % total surface area
- > 100 km²
  - 1452 lakes
  - 37.5% of total surface area

Downing et. al. 2006, The global abundance and size distribution of lakes, ponds, and impoundments. *L&O (51) 2388-2397*



General trends in primary productivity of phytoplankton, macrophytes, and epiphytes with increasing nutrient loading (from Sand-Jensen, 1980)

Relationship of aquatic plants to eutrophication (modified from Phillips '78)



Low/Moderate nutrient loading

Eutrophication

High nutrient loading

Low/Moderate growth of phytoplankton & epiphytes

Increased algal growth

Clear Water

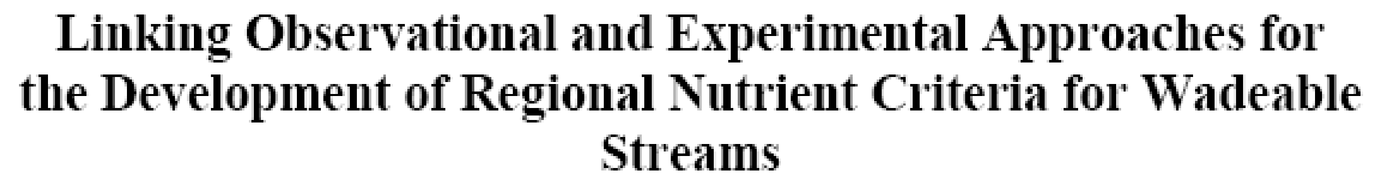
Reduced sediment resuspension
Allelopathy

Turbid water

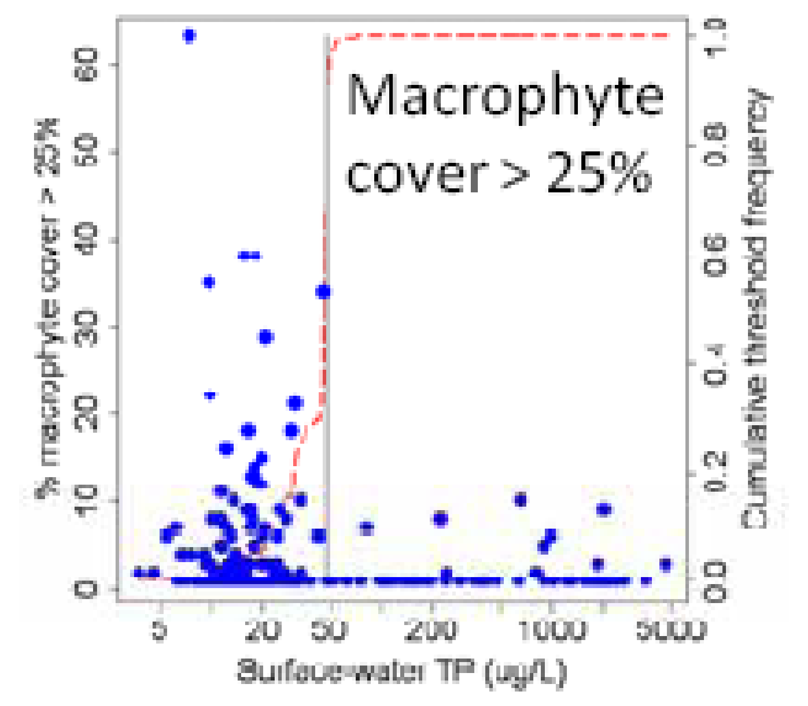
Dominance of submersed, rooted macrophytes

Loss of submersed macrophytes
Dominance of phytoplankton

Ecological Thresholds…



Linking Observational and Experimental Approaches for the Development of Regional Nutrient Criteria for Wadeable Streams



- Ryan King 2009, two-year monitoring study of 26 streams in Brazos River basin
- All responses showed strongly non-linear (threshold) responses

Alternate Stable State

- Observation: Shallow lakes of intermediate fertility tend to exist either as a turbid, algal dominated system or as a clear, macrophyte dominated system
- Lakes can, and do, alternate between these states

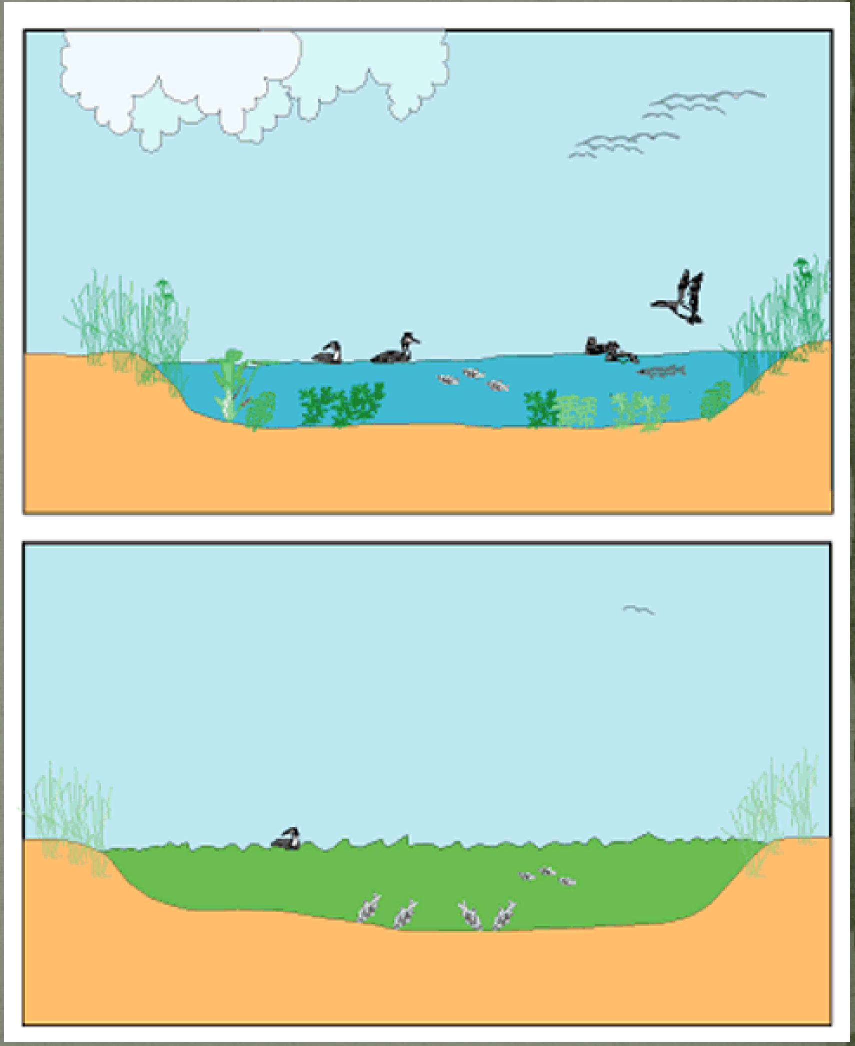
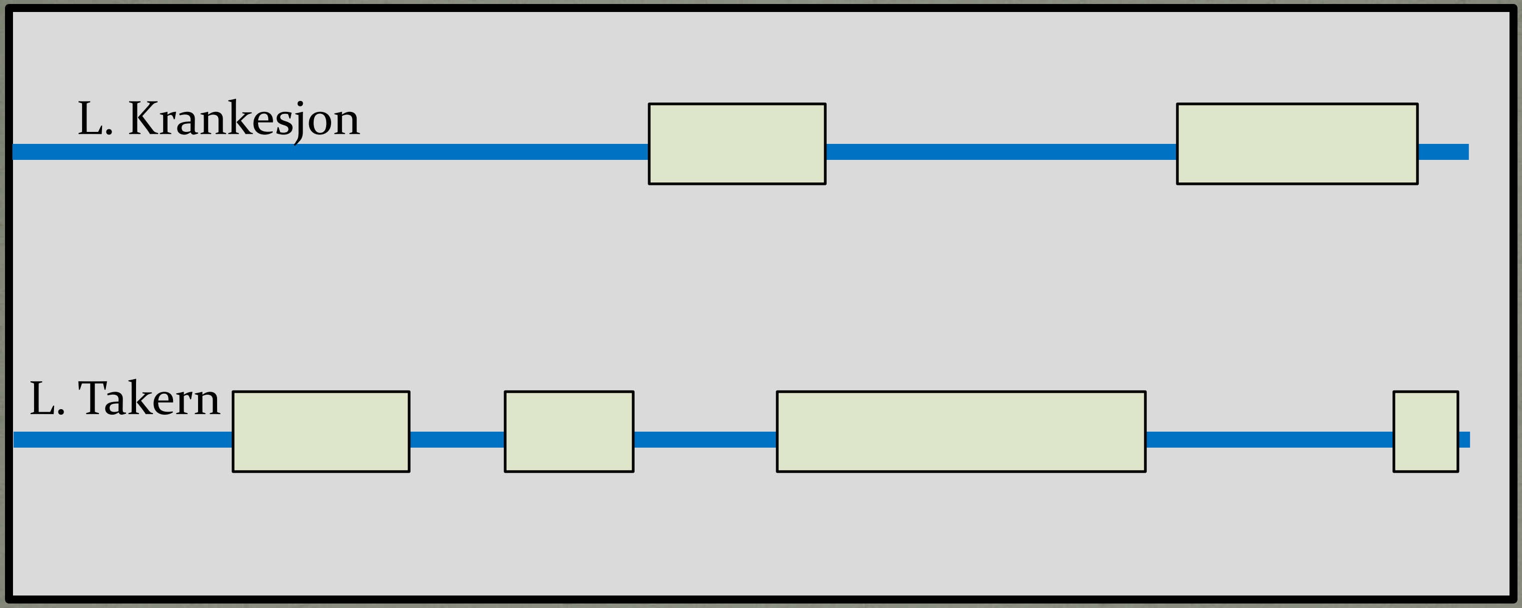


Fig. 1. Schematic representation of a shallow lake in a vegetation-dominated clear state (upper panel) and in a phytoplankton-dominated turbid state in which submerged vegetation is largely absent and fish and waves stir up the sediments (from Scheffer 1997).

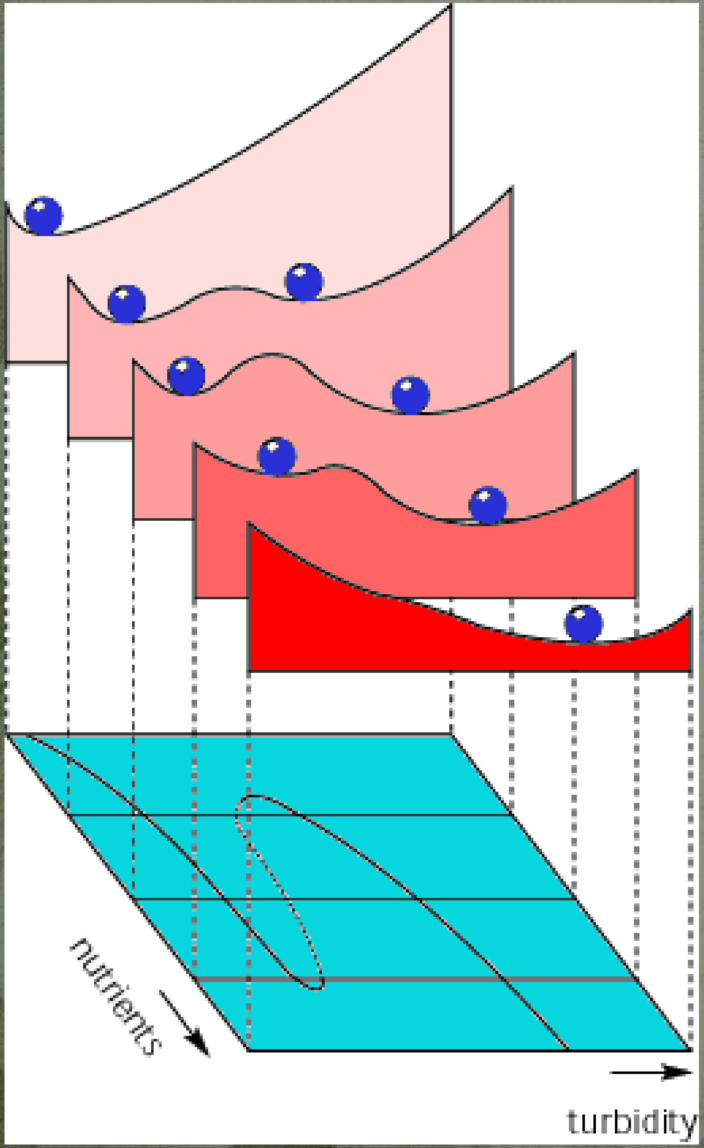
Alternate Stable States in Swedish Lakes

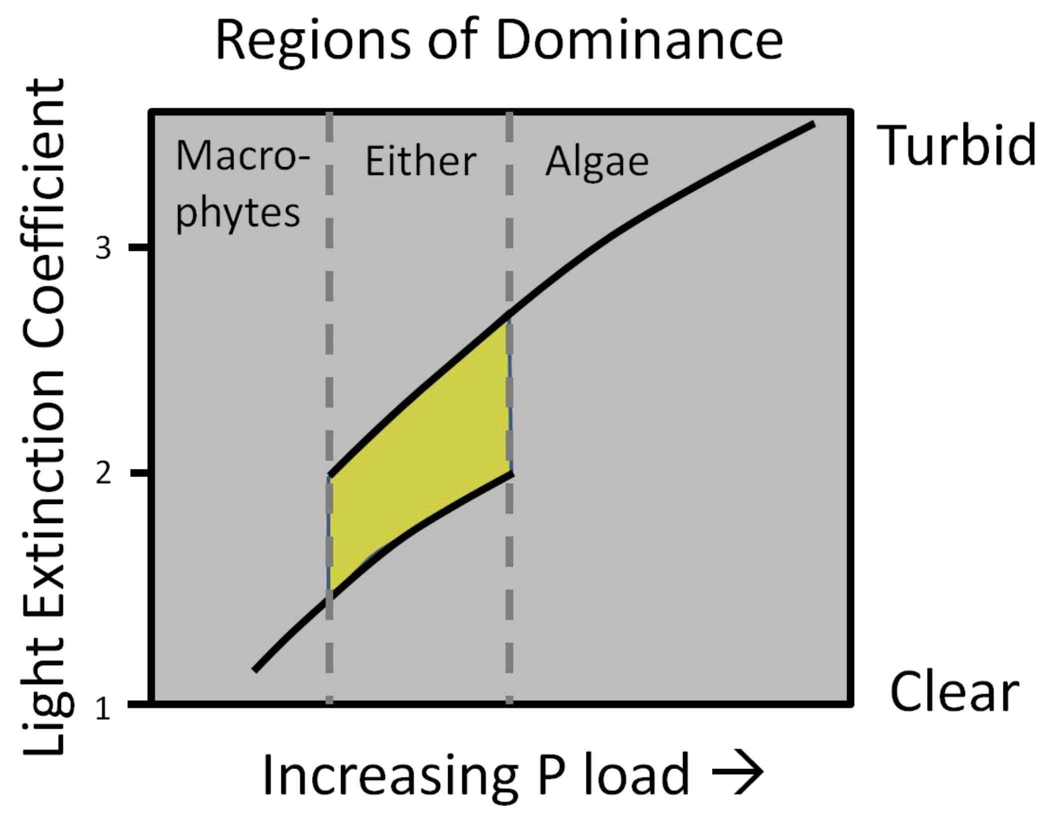


1900 2000

From Blindow et.al. 1993. Repeated shifts between a turbid state (green box) dominated by algae and a clear state dominated by macrohytes (blue line) between 1900 and 1990.

(FromScheffer et al. 1993).
LEFT: "Marble-in-a-cup" representation of the stability properties of lakes at five different levels of nutrient loading.
RIGHT: Increasing nutrient load results in hysteresis where either algae or macrophytes may dominate





Alternate Stable State: examples we've heard of:

Figure 12. In 1997, Big Muskego showed all the classic signs of a clear-water, aquatic plant-dominated system, with beneficial native aquatic plants and a balanced fisheries.

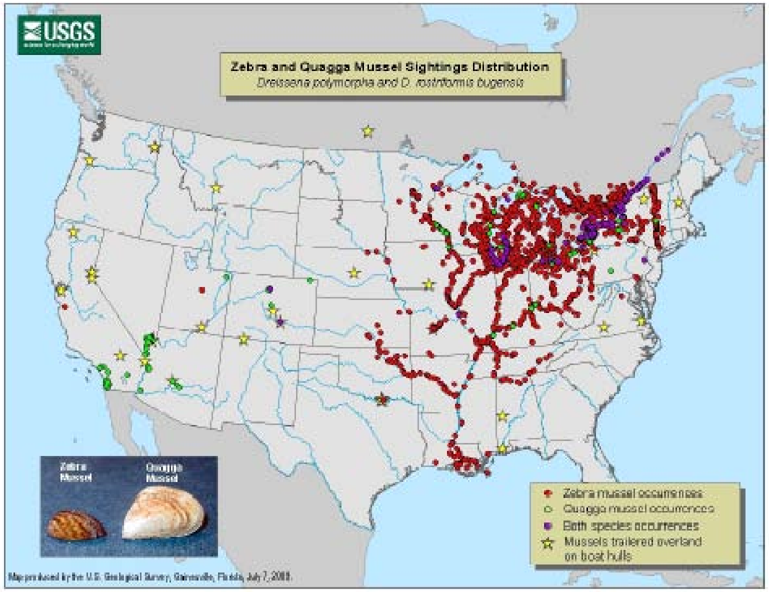


Figure 1. *Dreissenid mussel distribution in the United States as of July 2009 (from USGS website).*

Shifts in nutrients→ shifts in macrohyte species

3 Phosphorus and Aquatic Plants 39

Table 3.2 Species distribution and water nutrient status

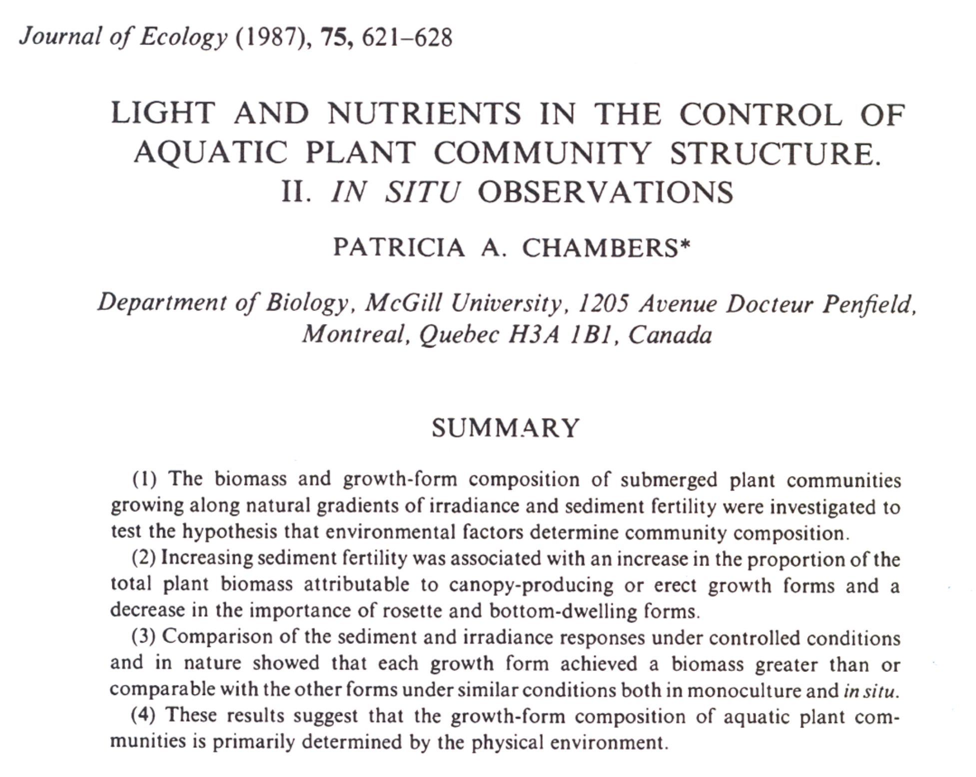
Species	Nutrient status
Acorus calamus L.	Eutrophic
Alisma lanceolatum With	Eutrophic
Alisma plantago-aquatica L.	Eutrophic
Apium inundatum L.	Oligotrophic
Apium nodiflorum (L.) Lag.	Mesotrophic to eutrophic
Berula erecta (Huds.) Coville	Oligotrophic
Butomus umbellatus L.	Eutrophic
Callitriche hamulata Kütz. ex Koch	Oligotrophic to eutrophic
Callitriche obtusangula Le Gall	Eutrophic
Callitriche platycarpa Kütz.	Oligotrophic to eutrophic
Callitriche stagnalis Scop.	Oligotrophic to mesotrophic
Callitriche truncata Guss. ssp. *occidentalis*	Mesotrophic
Carex rostrata Stokes	Oligotrophic
Catabrosa aquatica (L.) Beauv.	Oligotrophic to mesotrophic
Ceratophyllum demersum L.	Eutrophic
Ceratophyllum submersum L.	Eutrophic
Eleocharis palustris (L.) Roemer & Schultes	Oligotrophic to mesotrophic
Elodea canadensis Michx	Mesotrophic
Elodea nuttallii (Planchon) St John	Mesotrophic to eutrophic
Glyceria fluitans R. Br.	Oligotrophic to eutrophic
Groenlandia densa (L.) Fourr.	Oligotrophic to mesotrophic
Helodes palustris Spach	Oligotrophic
Hippuris vulgaris L.	Oligotrophic to mesotrophic
Hottonia palustris L.	Oligotrophic to mesotrophic
Hydrocharis morsus-ranae L.	Mesotrophic
Hydrocotyle vulgaris L. fo aq.	Oligotrophic
Iris pseudacorus L.	Oligotrophic to eutrophic
Juncus bulbosus L.	Oligotrophic
Juncus subnodulosus Schrank aq. fo.	Oligotrophic
Lemna gibba L.	Eutrophic
Lemna minor L.	Mesotrophic to eutrophic
Lemna trisulca L.	Mesotrophic
Littorella uniflora (L.) Ascherson	Oligotrophic
Luronium natans (L.) Rafin.	Oligotrophic
Lycopus europaeus L.	Oligotrophic to eutrophic
Mentha aquatica L.	Oligotrophic to eutrophic
Menyanthes trifoliata L.	Oligotrophic
Montia fontana L. agg.	Oligotrophic
Myosotis gr. *palustris* (*M. scorpioides* L.)	Mesotrophic
Myriophyllum alterniflorum DC.	Mesotrophic
Myriophyllum spicatum L.	Eutrophic
Myriophyllum verticillatum L.	Mesotrophic
Najas marina L.	Eutrophic
Najas minor L.	Eutrophic
Nasturtium officinale R. Br. agg.	Mesotrophic to eutrophic
Nuphar lutea (L.) Sibth. & Sm.	Eutrophic
Nymphaea alba L.	Oligotrophic to mesotrophic
Nymphoides peltata (S. G. Gmelin) O. Kuntze	Mesotrophic
Oenanthe aquatica (L.) Poiret	Oligotrophic to mesotrophic
Oenanthe crocata L.	Oligotrophic to mesotrophic
Oenanthe fluviatilis (Bab.) Coleman	Mesotrophic to eutrophic

(continued)

- We understand that different species appear under different trophic conditions
- Table from Gabriel Thiebaut's 2008 chapter *Phosphorus and Aquatic Plants*

Book= *The Ecophysiology of Plant-Phosphorus Interactions*

80's-90's Patricia Chambers' work
Impacts of fertility on growth-form



Journal of Ecology (1987), **75,** 621–628

LIGHT AND NUTRIENTS IN THE CONTROL OF
AQUATIC PLANT COMMUNITY STRUCTURE.
II. *IN SITU* OBSERVATIONS

PATRICIA A. CHAMBERS*

*Department of Biology, McGill University, 1205 Avenue Docteur Penfield,
Montreal, Quebec H3A 1B1, Canada*

SUMMARY

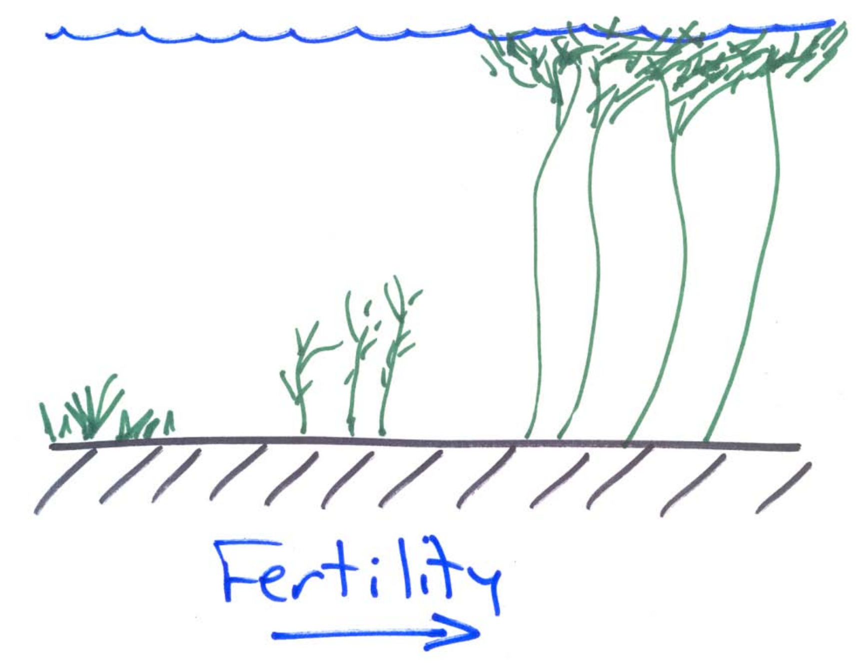
(1) The biomass and growth-form composition of submerged plant communities growing along natural gradients of irradiance and sediment fertility were investigated to test the hypothesis that environmental factors determine community composition.

(2) Increasing sediment fertility was associated with an increase in the proportion of the total plant biomass attributable to canopy-producing or erect growth forms and a decrease in the importance of rosette and bottom-dwelling forms.

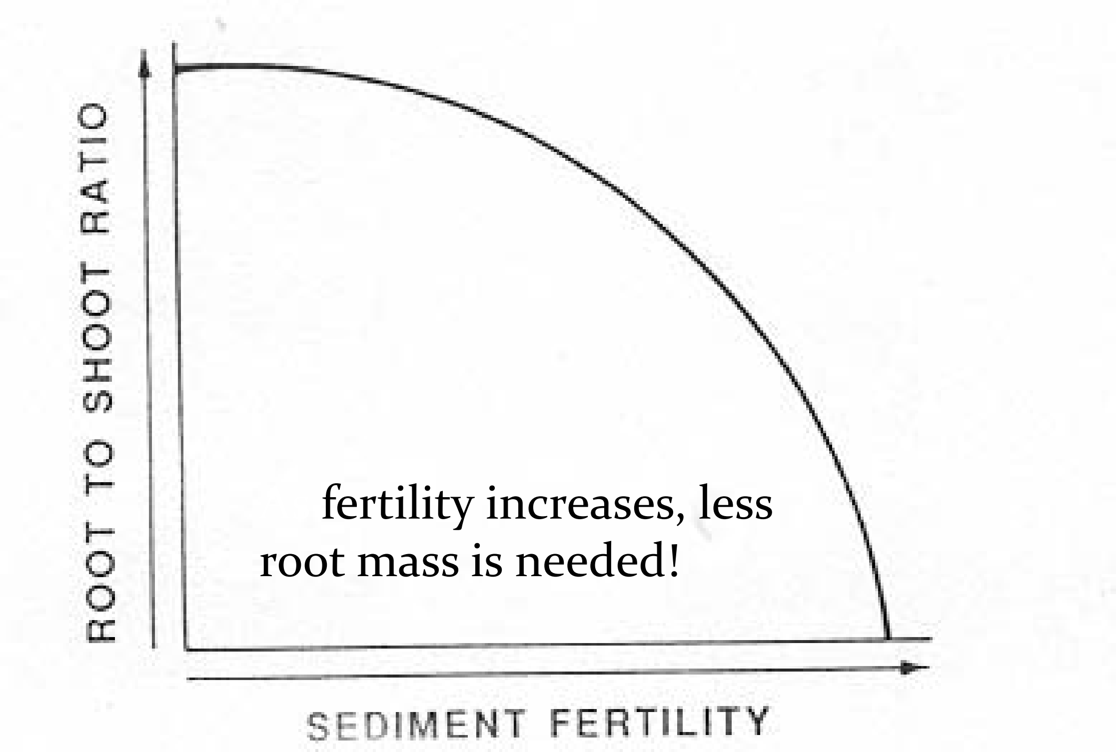
(3) Comparison of the sediment and irradiance responses under controlled conditions and in nature showed that each growth form achieved a biomass greater than or comparable with the other forms under similar conditions both in monoculture and *in situ*.

(4) These results suggest that the growth-form composition of aquatic plant communities is primarily determined by the physical environment.

- Increased fertility → canopy-producers



Fertility impacts aquatic plants



fertility increases, less root mass is needed!

- Increasing fertility →less root biomass

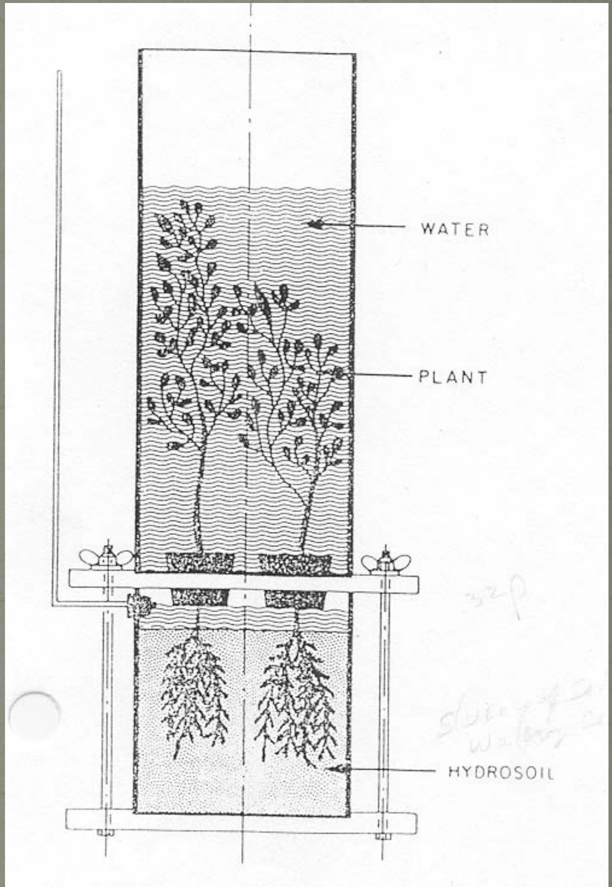


Fig. 1. Chambers for growing aquatic plants so that the ^{32}P-labelled hydrosoil is isolated from the unlabelled water

Fig. 3. Idealized relationship between macrophyte root:shoot ratio and sediment fertility. This relationship applies to all life forms of rooted aquatic macrophytes, and is based on information obtained from a variety of sources (see text).

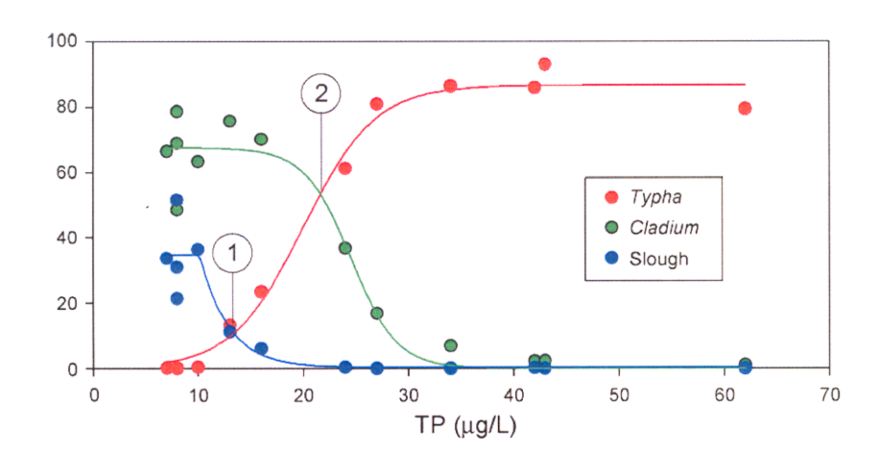
Increased fertility favors canopy forming and floating species

Hydrilla at Wakulla Springs, Florida
Hydrilla verticillata
Photo by Vic Ramey
Copyright 1998 Univ. Florida

Water hyacinth
Eichhornia crassipes
Photo by A. Murray
Copyright 2001 Univ. Florida

P enrichment → shift in Everglades species

- Scot Hagerthey et. al. 2008
- High P loading has shifted everglades species dominance from sawgrass to cattail



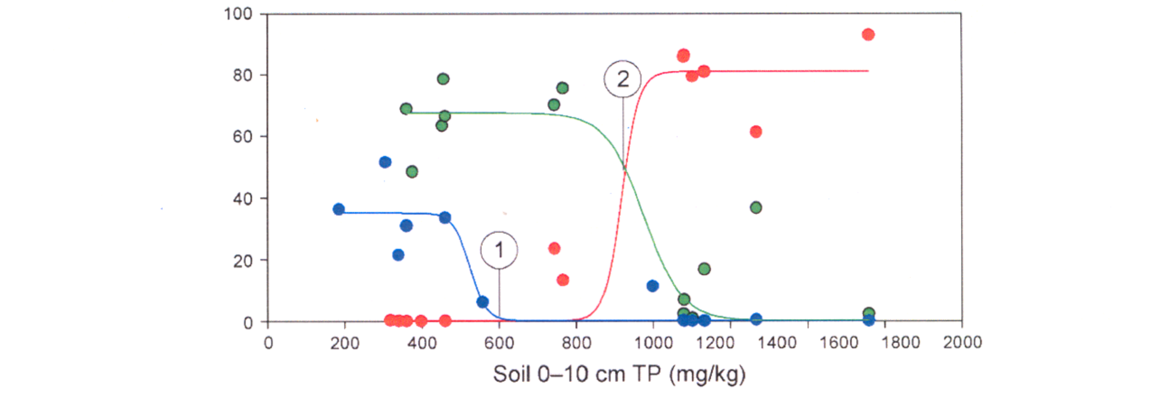
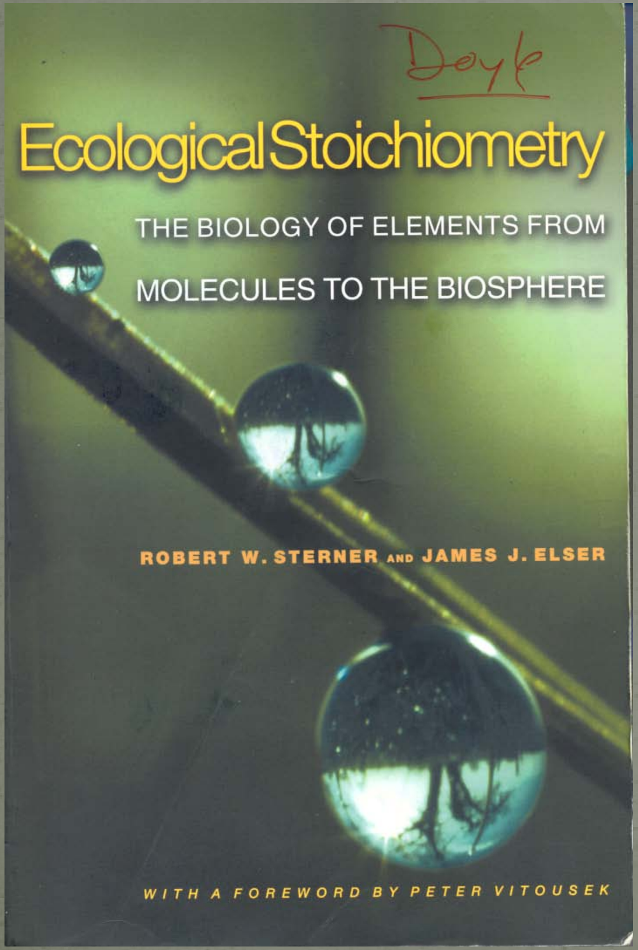


FIG. 4. Nonlinear relationship between the controlling variable (TP) and the ecosystem state variables (vegetation cover of different types). Points 1 and 2 (in large open circles) denote where critical P thresholds were surpassed and resulted in shifts from the slough and *Cladium* low-nutrient stability regimes to the high-nutrient *Typha* stability regime. Note that the percent cover of *Typha* increases as slough cover decreases without a subsequent shift in *Cladium* cover (point 1). This suggests that there are two low-nutrient stability regimes (slough and *Cladium*) and that they respond to eutrophication differently.

Ecological Stoichiometry



Doyle

Ecological Stoichiometry

THE BIOLOGY OF ELEMENTS FROM MOLECULES TO THE BIOSPHERE

ROBERT W. STERNER AND JAMES J. ELSER

WITH A FOREWORD BY PETER VITOUSEK

- We all remember Redfield ratios
  - C:N:P   105:15:1
- Composition of trophic level "N" places significant constraints on level "N+1"
- It's <u>not</u> just about energy (carbon)!

Shade et. al. *Ecology Letters*.

Stoichiometric tracking of soil nutrients by a desert insect herbivore

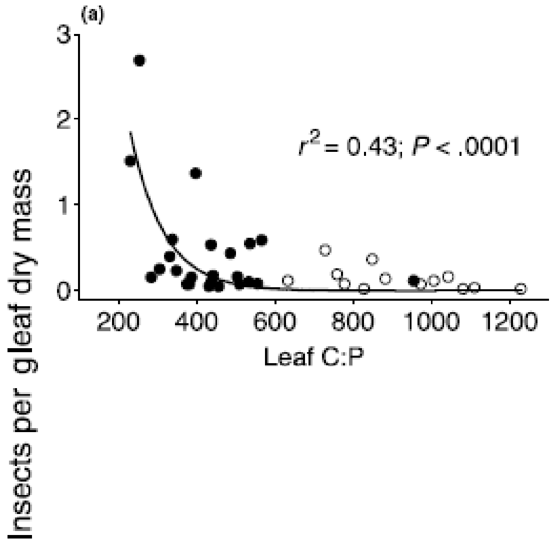
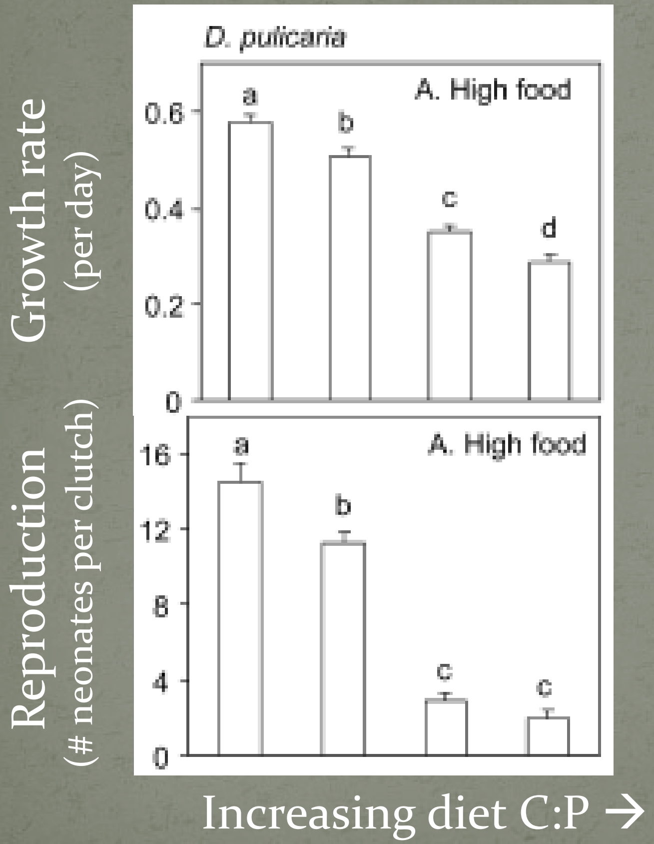


Figure 3 Relationship between abundance of *Sabinia* and leaf chemical characteristics. (a) Mesquite leaf C/P and (b) %lignin of mesquite leaves. For both C/P and %lignin, regression lines were determined using an exponential decay model, which showed the best fit to the data for both variables. Open circles are September 2000, closed circles are April 2001.

- "Biogeochemistry and population biology have developed independently, with few attempts at linkage, almost none of which were mechanistically based.
- We hypothesize that biogeochemical cycling is linked to herbivore population dynamics through the influence of soil nutrient availability on foliar nutrient content, which constrains herbivore investment in phosphorus (P)-rich molecules necessary for growth."
- Low P-availability → reduced herbivores
- PLANT NUTRIENT CONTENT MATTERS

Acharya et. al. *Oecologia.* Effects of stoichiometric dietary mixing on *Daphnia* growth and reproduction



- “Herbivores often encounter nutritional deficiencies in their diets because of low nutrient content of plant biomass.”
- Low P-availability → reduced growth rate & reproduction
- PLANT NUTRIENT CONTENT MATTERS

Summary:

- Increasing eutrophication results in a shift from macrophyte dominance to algae dominance

- At levels if intermediate fertility, most lakes can exist in either of two stable states

- Eutrophication favors canopy-forming and floating sp.
  - Water column light limitation
  - Nutrient uptake

- Nutrient content of plant biomass places constraints on herbivore populations