Consequences of eutrophication for freshwater macrophytes

Elisabeth M. Gross, Alexandrine Pannard & Gudrun Bornette




Consequences of eutrophication for macrophytes

I. Consequences for primary production

II. Consequences for the physical-chemical environment

III. Consequences for plant community composition & biodiversity

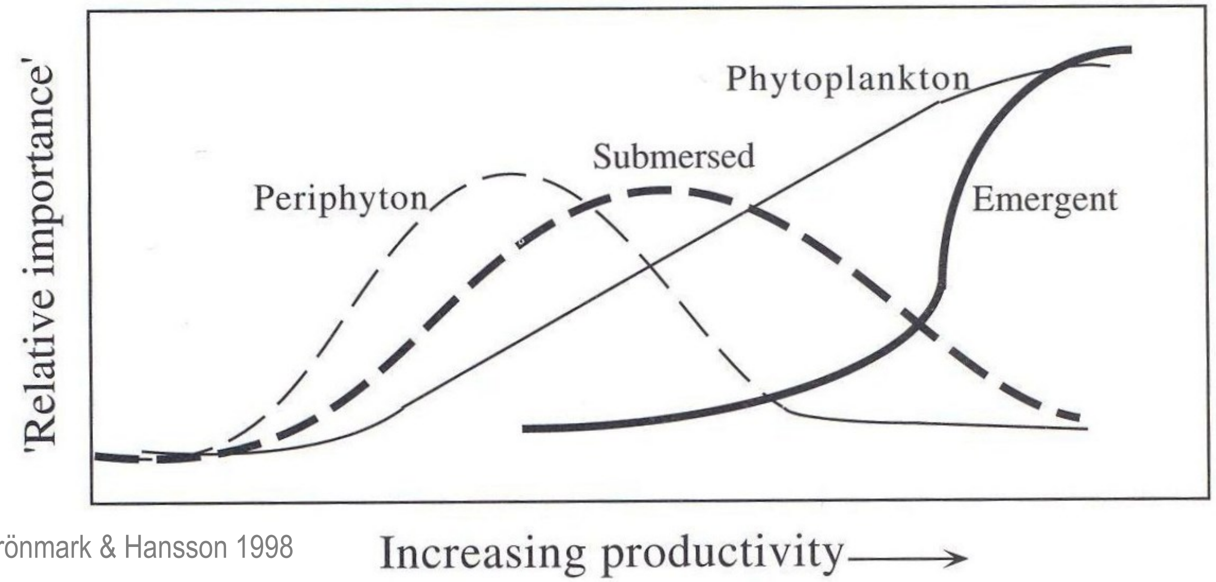
IV. Consequences for food webs & habitats




I. Consequences for primary production

Impact of nutrient loading on primary producers in lentic systems

- Nutrient sources: water & sediment
- Succession of different functional groups of primary producers; succession of macrophyte species
- Shift from nutrient to light limitation



Brönmark & Hansson 1998

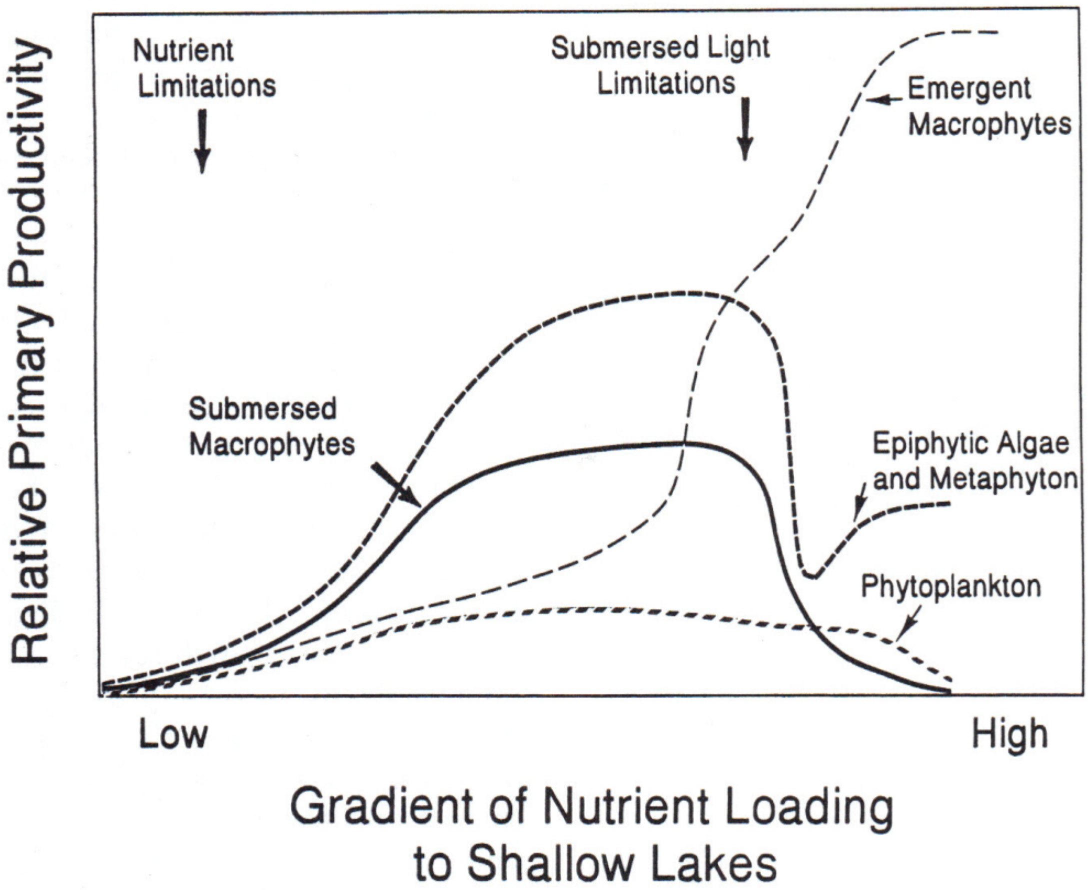
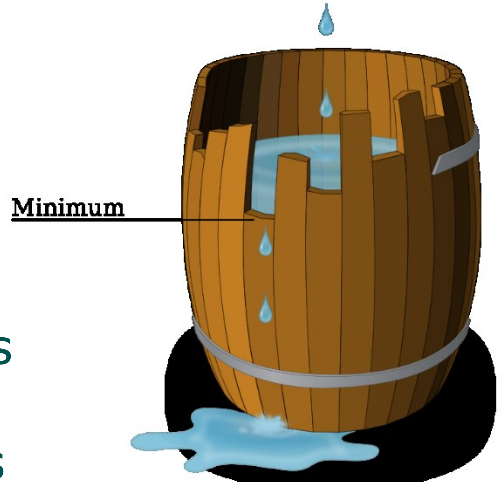


FIGURE 19-21 Relative changes in primary productivity of phytoplankton, macrophytes, and attached microflora along a gradient of nutrient loading to a spectrum of lake ecosystems. (From Wetzel, 1999a, expanded and modified from Wetzel and Hough, 1973.)

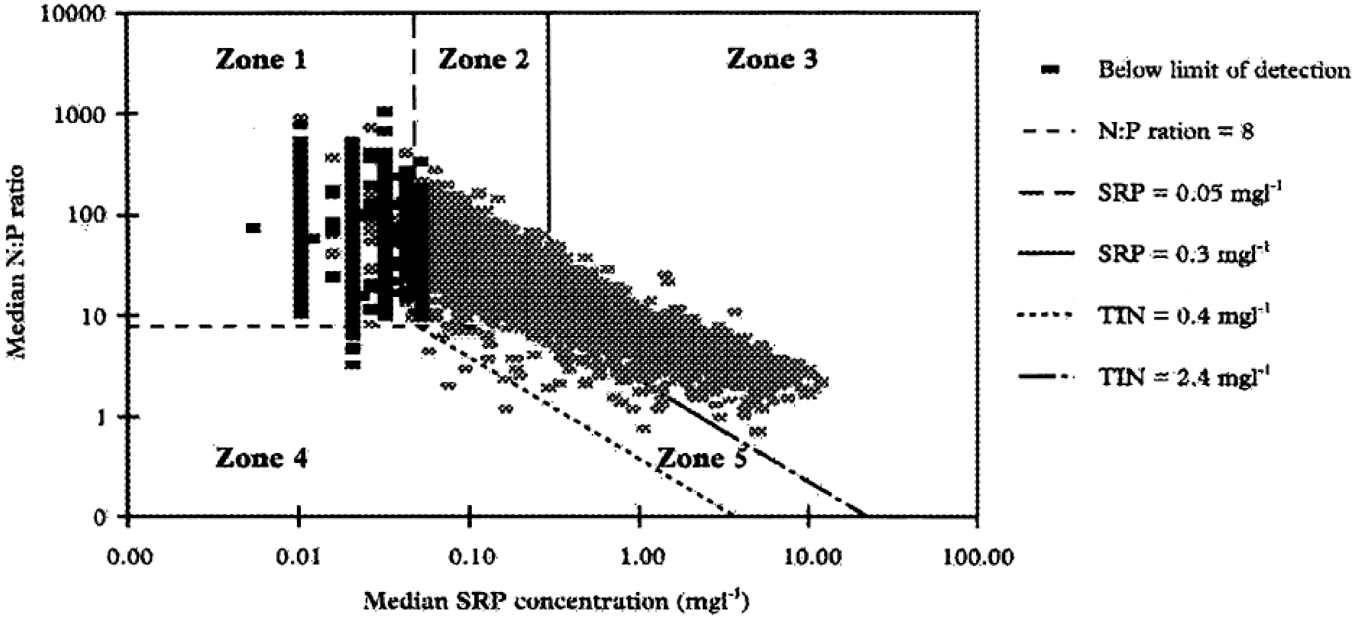
Wetzel – Limnology, 3rd ed. 2001

Nutrient availability



- Liebig's law of the minimum
- Freshwater systems rather P-limited
- Terrestrial/marine systems rather N-limited
- Possible co-limitation
- Synergistic effects by adding both N and P
- Absolute and relative concentration – stoichiometric relation (N:P)

Fig. 1 The potential for phosphorus and nitrogen limitation of riverine plant growth in England and Wales



Zone 1 - P likely to be limiting
Zone 2 - P may be limiting for part of the growing season
Zone 3 - Neither N or P likely to be limiting
Zone 4 - N likely to be limiting
Zone 5 - N may be limiting for part of the growing season

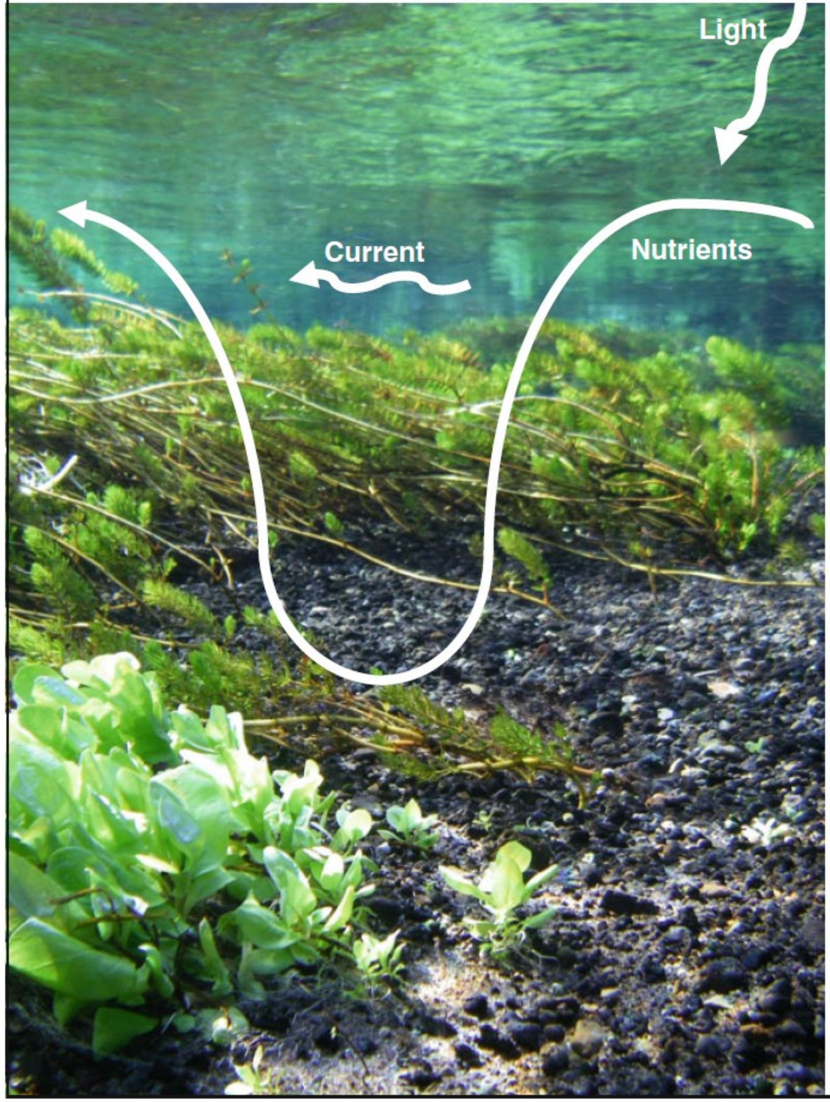
Mainstone & Parr 2002

Environmental factors affecting macrophyte growth in lotic systems

- Retention time
- Hydraulic drag x light interaction
- Nutrients in water and sediment
- Temperature
- Substrate

Current - Macrophyte stands will be stimulated at low velocities up to ~0.1m/s, decline with increasing velocities, and be eliminated by velocities >~1 $m \cdot s^{-1}$. Stable flows will promote maximum abundances (1-3)

Light - Will be limiting unless stands are first limited by nutrients or other factors (4-6)



Algae - Epiphytic algae always coat aquatic macrophytes and may shade their leaves and lead to light, inorganic carbon, or nutrient limitation (7-10)

Inorganic carbon - Production may be limited by the availability of dissolved inorganic carbon (5,10-13).

Temperature - Will generally increase production, although temperature optima vary among species (5,14).

Nutrients in water - Macrophytes may increase in nutrient rich waters and will be a source of nutrients to sediment (15-19), or macrophytes may decrease because of epiphyte stimulation (9,20,21). Nutrients taken up from the water will spiral downstream through the plant tissues, sediments, and water (22).

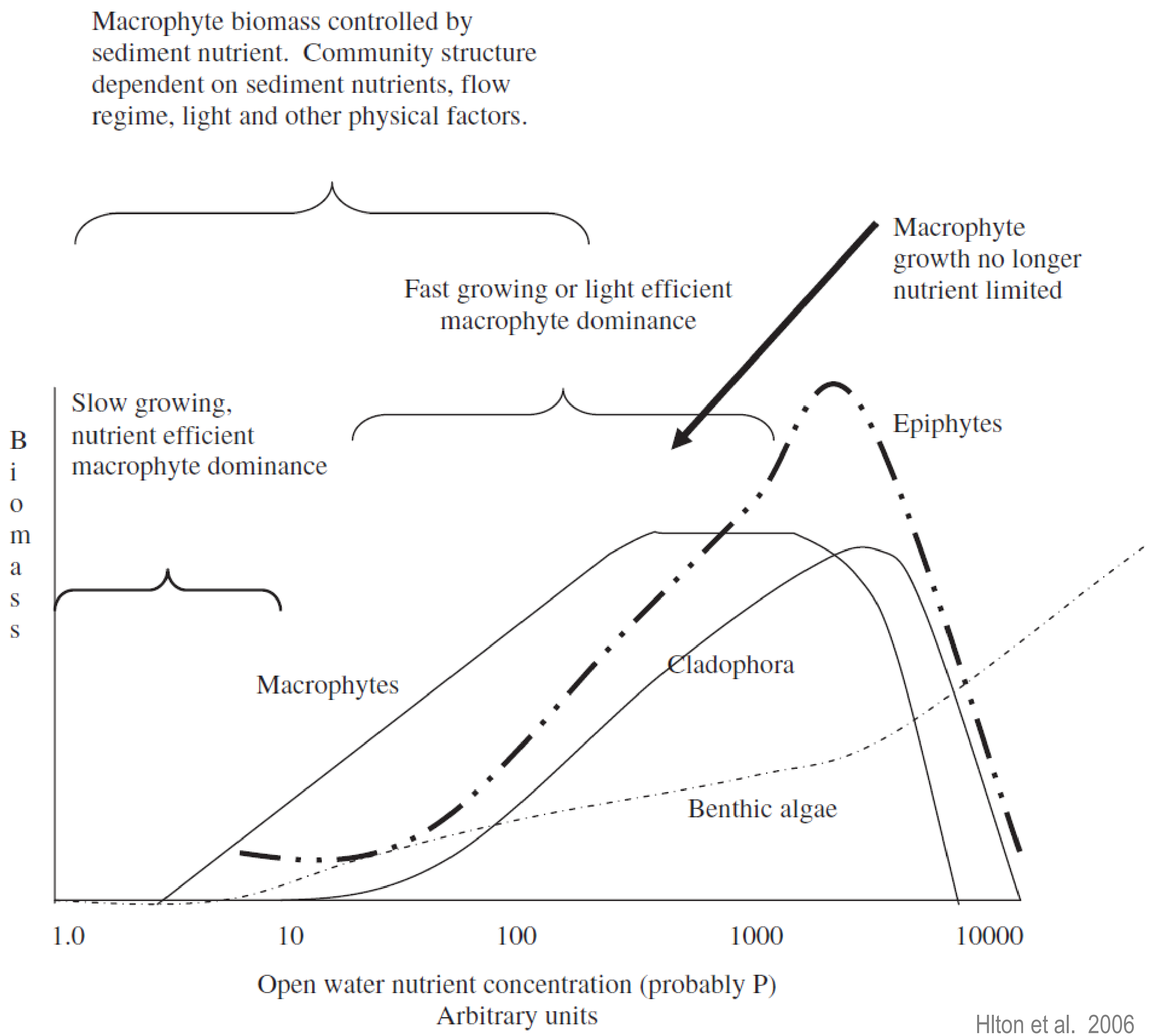
Nutrients in sediment- Sediments will often be the primary source of at least P for rooted aquatic plants (23,24), especially if P in the water column is low. Fe is a micronutrient but Fe and Al oxides in sediment will reduce the bioavailability of P (25-27).

Substrate - Fine sediments may be nutrient rich but enriched organic matter can also lead to anoxia in sediments, leading to shorter plant roots, plant stress, and uprooting (6, 13, 28-29).

Mebane et al. 2014

Nutrient loading effects on riverine macrophytes

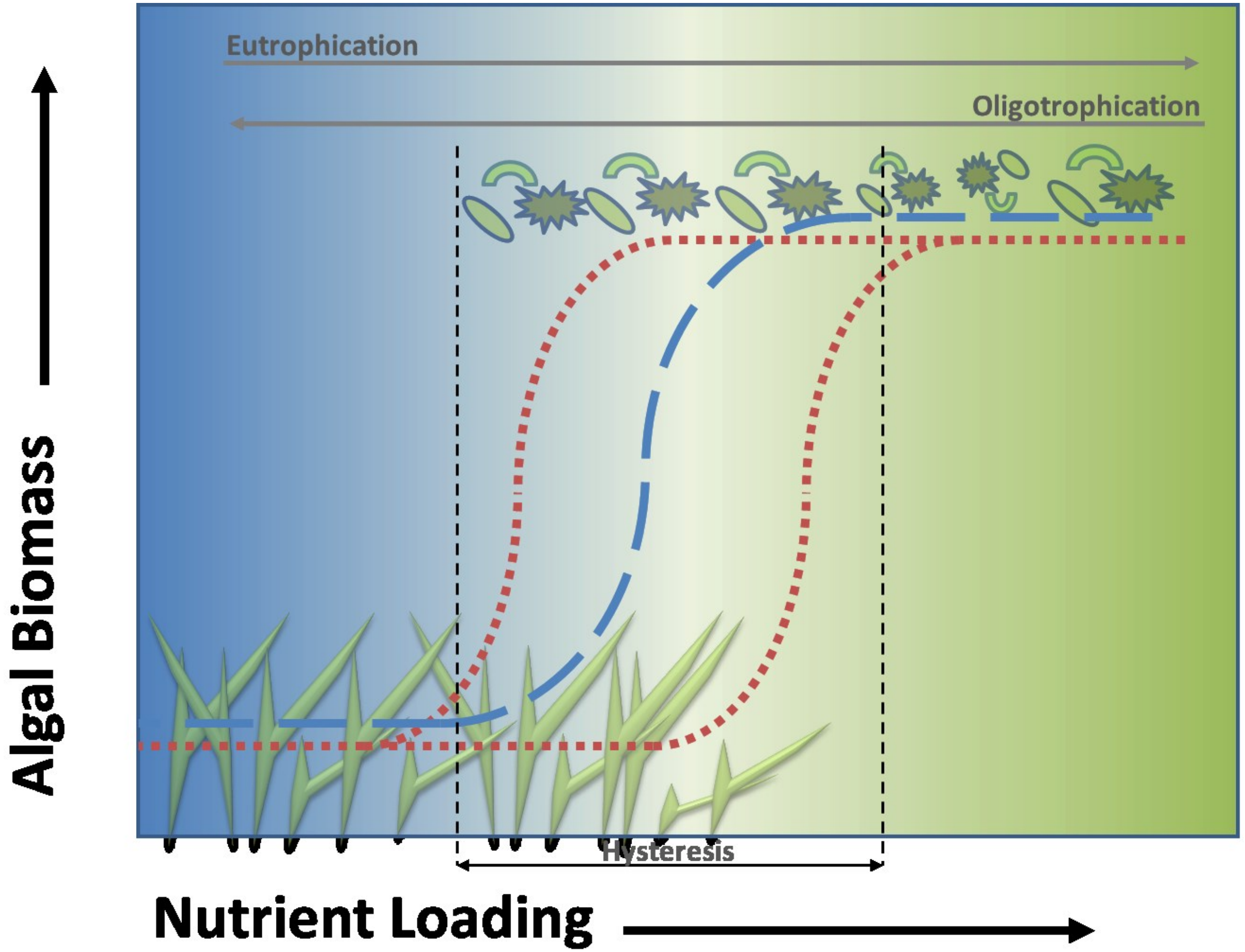
- Succession of macrophytes, competition with epiphytes
- Filamentous algae (*Cladophora*,…)
- Flooding risk with high macrophyte growth



HIton et al. 2006

Shallow eutrophic lakes: Gradual or sudden shift in the dominant functional group…

- Dominance of submerged aquatic vegetation OR
- Phytoplankton dominance
- Hysteresis : 2 possible “stable” states at same nutrient loading

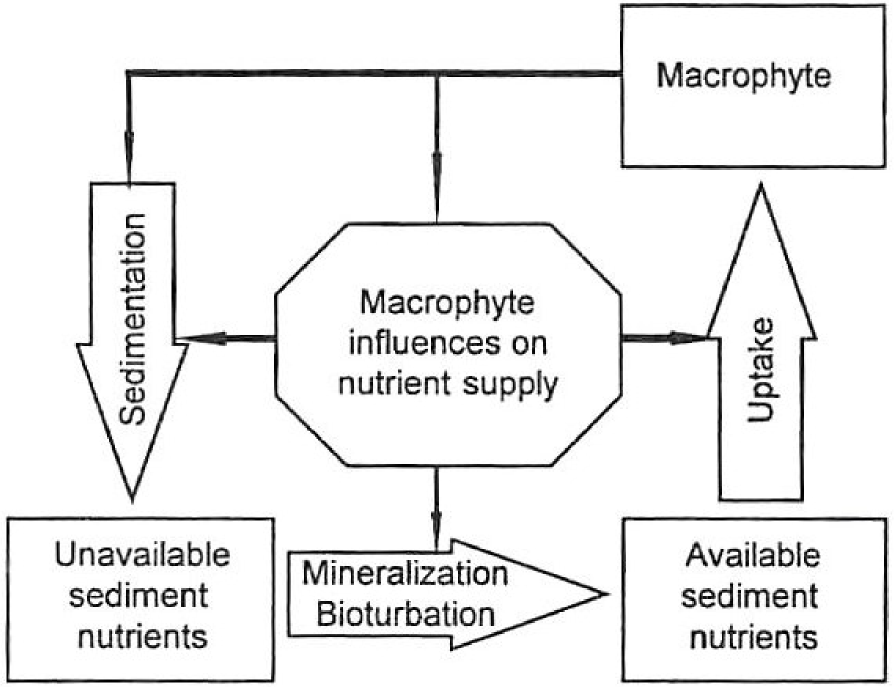


Credit: Annette Janssen

II. Consequences for the physical-chemical habitat

Macrophytes affect sedimentation rates

- Direct and indirect effects on nutrient supply via sedimentation and uptake
- Optimum growth depends on light availability and sedimentation



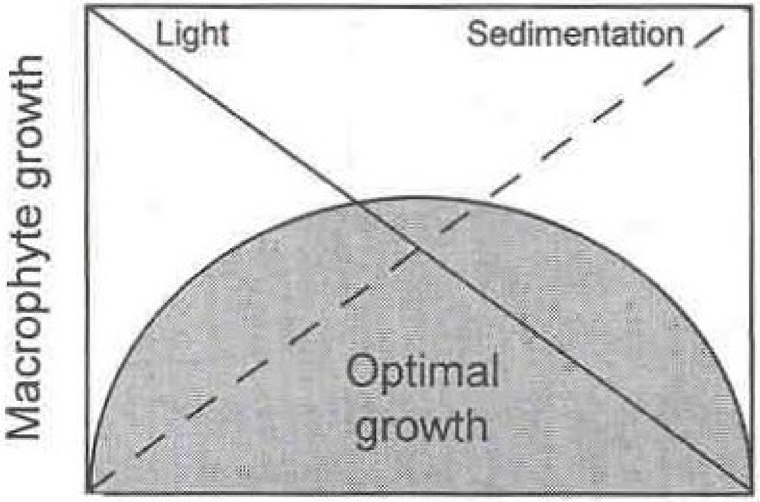
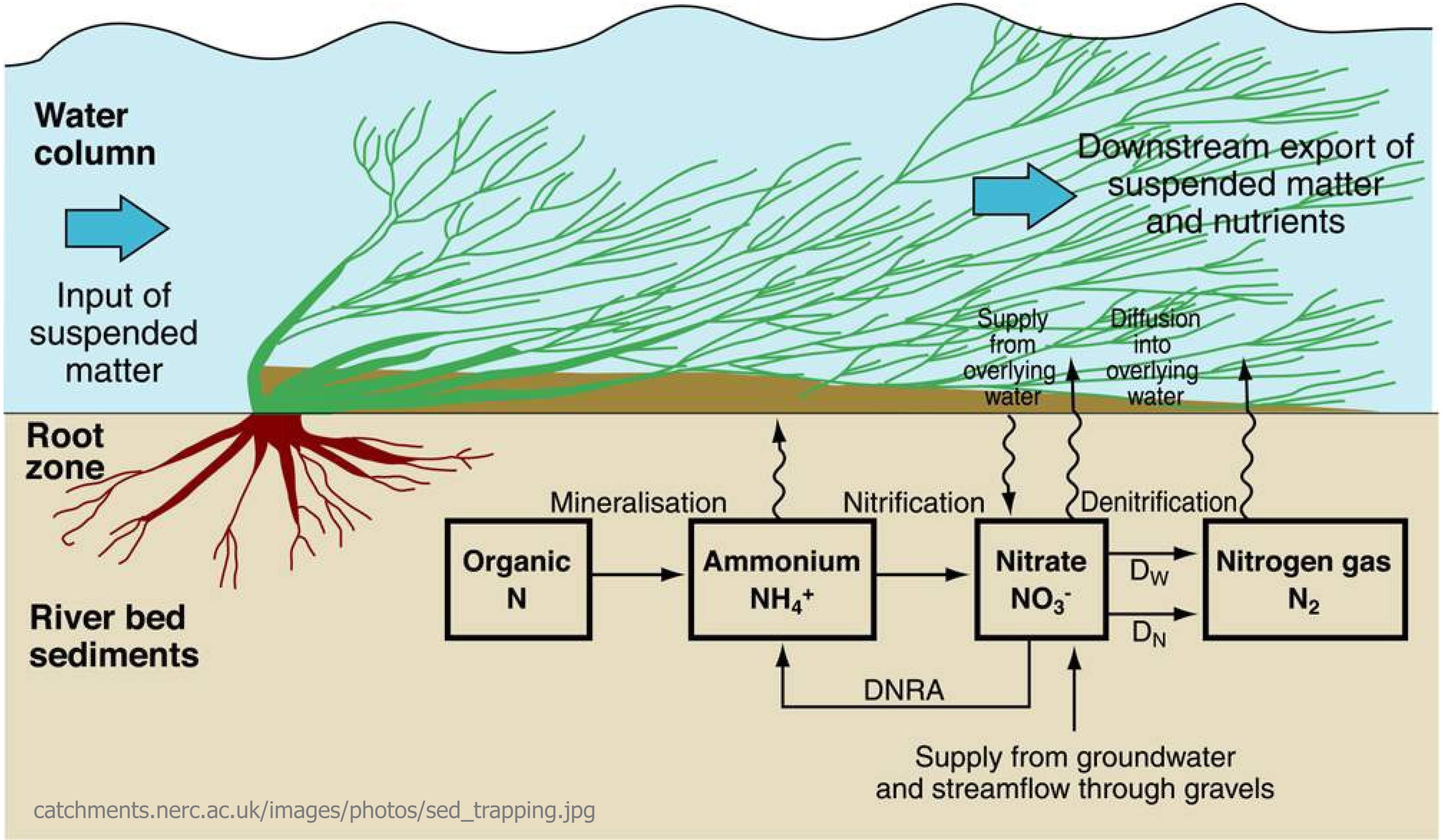


Figure 10.2. Conceptual diagram of interacting roles of underwater light and sedimentation in affecting macrophyte growth.

Figure 10.1. Conceptual diagram of macrophyte influences on nutrient supply as an interactive function of sedimentation and sediment processing.

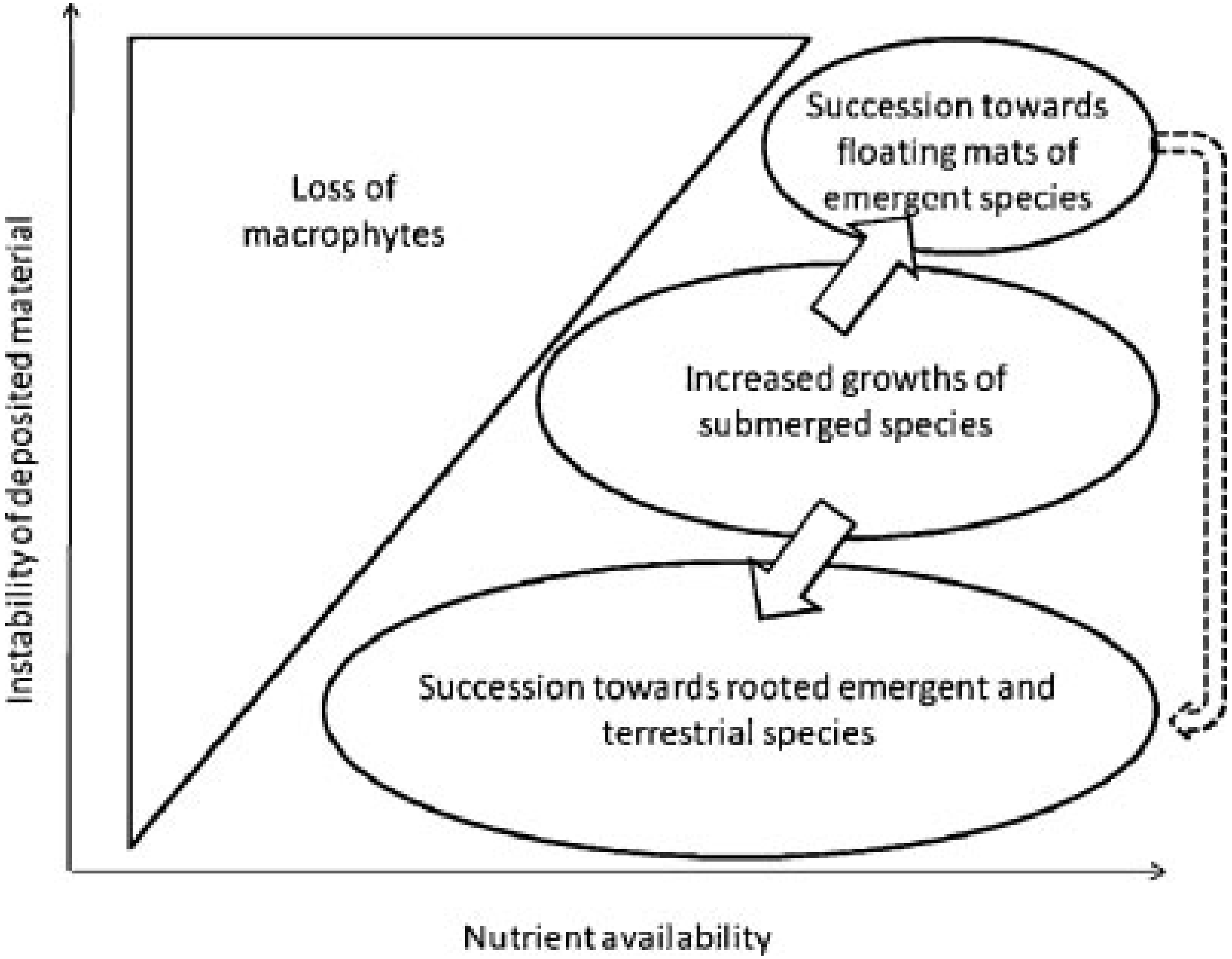
Barko & James, in Jeppesen et al. 1998

Impact of water crowfoot on sediment dynamics



Macrophytes as ecosystem engineers in rivers..

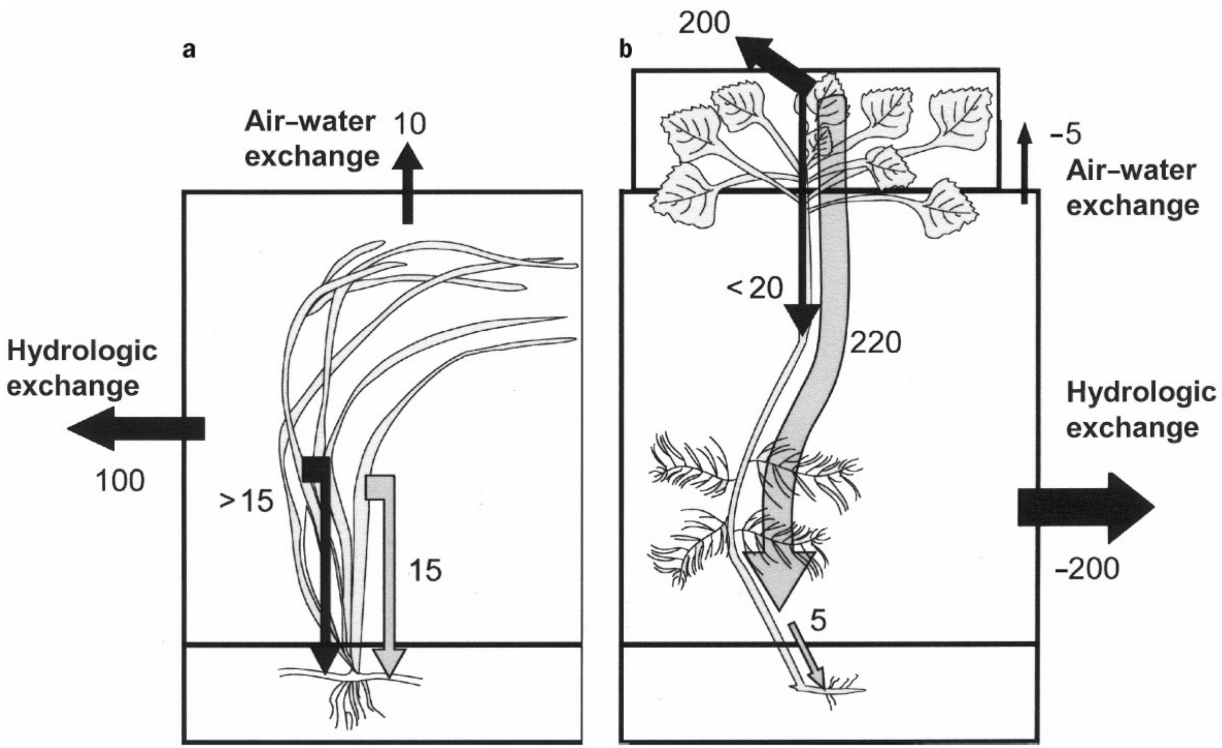
- Transitory deposition of fine sediments
- Stability and nutrient content of sediment determines dominant vegetation



Jones et al. 2012

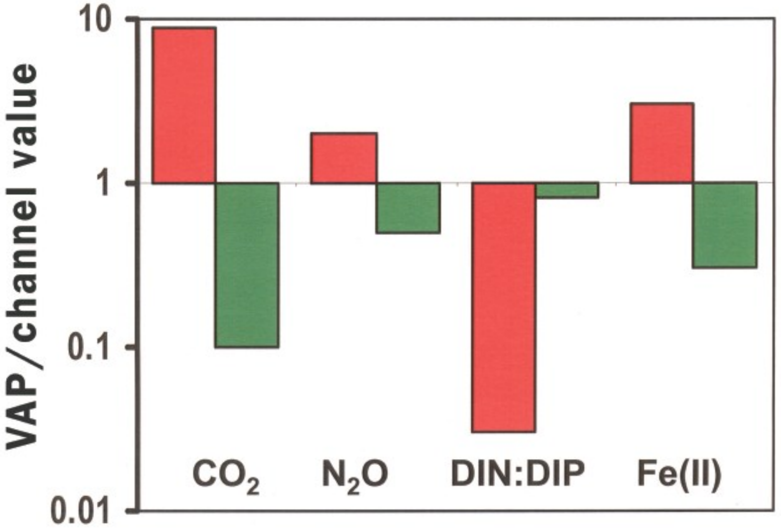
Floating macrophytes hamper gas exchange…

- High water nutrient levels & high temperatures favour free-floating macrophytes
- "Invasive" species, e.g. *Trapa natans*




Trapa, showing floating leaves (top), submerged leaves (bottom left) and nut (right) (after: CTRIVCOORD)

Trapa natans
Vallisneria americana



Caraco et al. 2006

III. Consequences for community structure and biodiversity

Foto: M. Mörtl

Systems at risk: Softwater lakes dominated by isoetid vegetation

- Oxygenated sediment
- Increase in organic matter:
  - De-rooting of isoetids
  - Internal eutrophication
- Replacement by tall-growing macrophytes

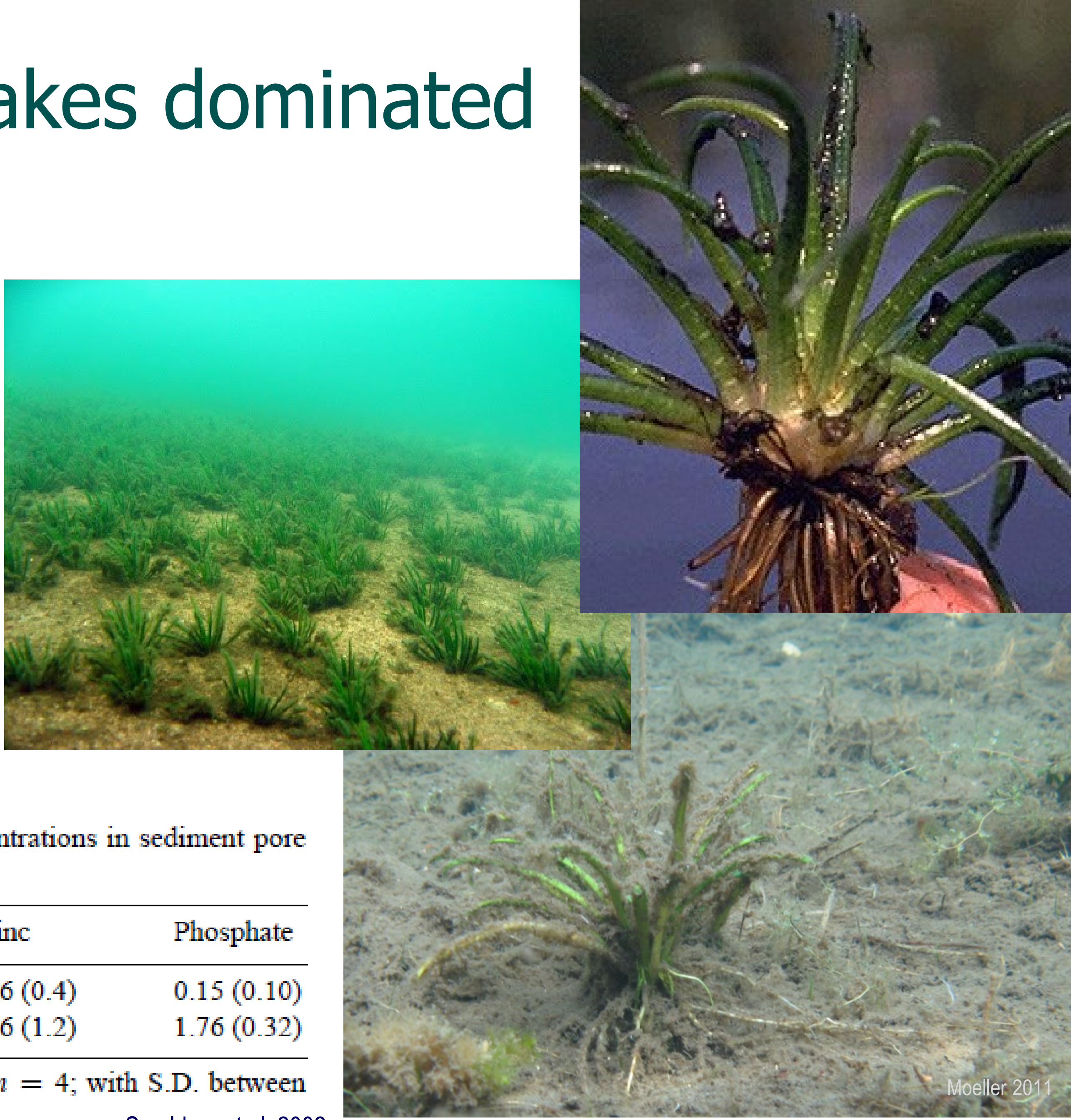


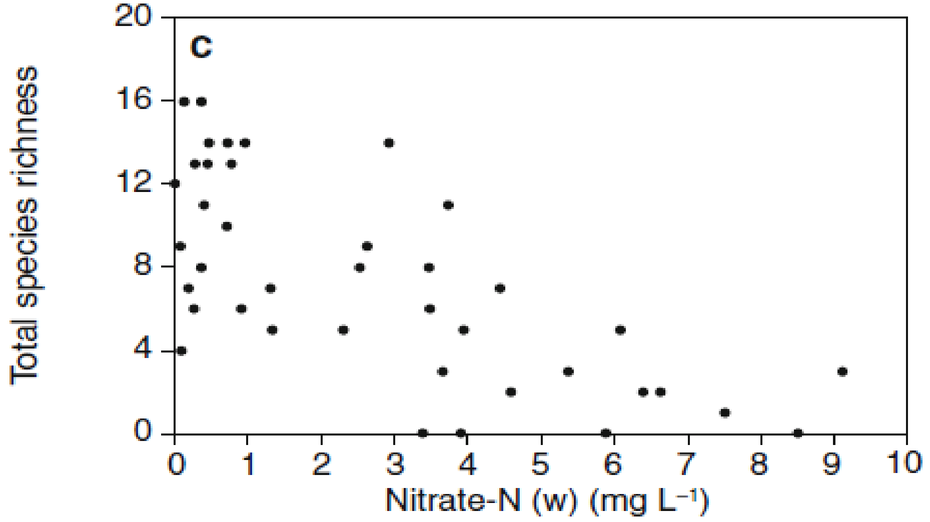
Table 1
Effects of isoetid vegetation removal on iron, manganese, zinc and phosphate concentrations in sediment pore water of lake Dybingen (SW Norway)

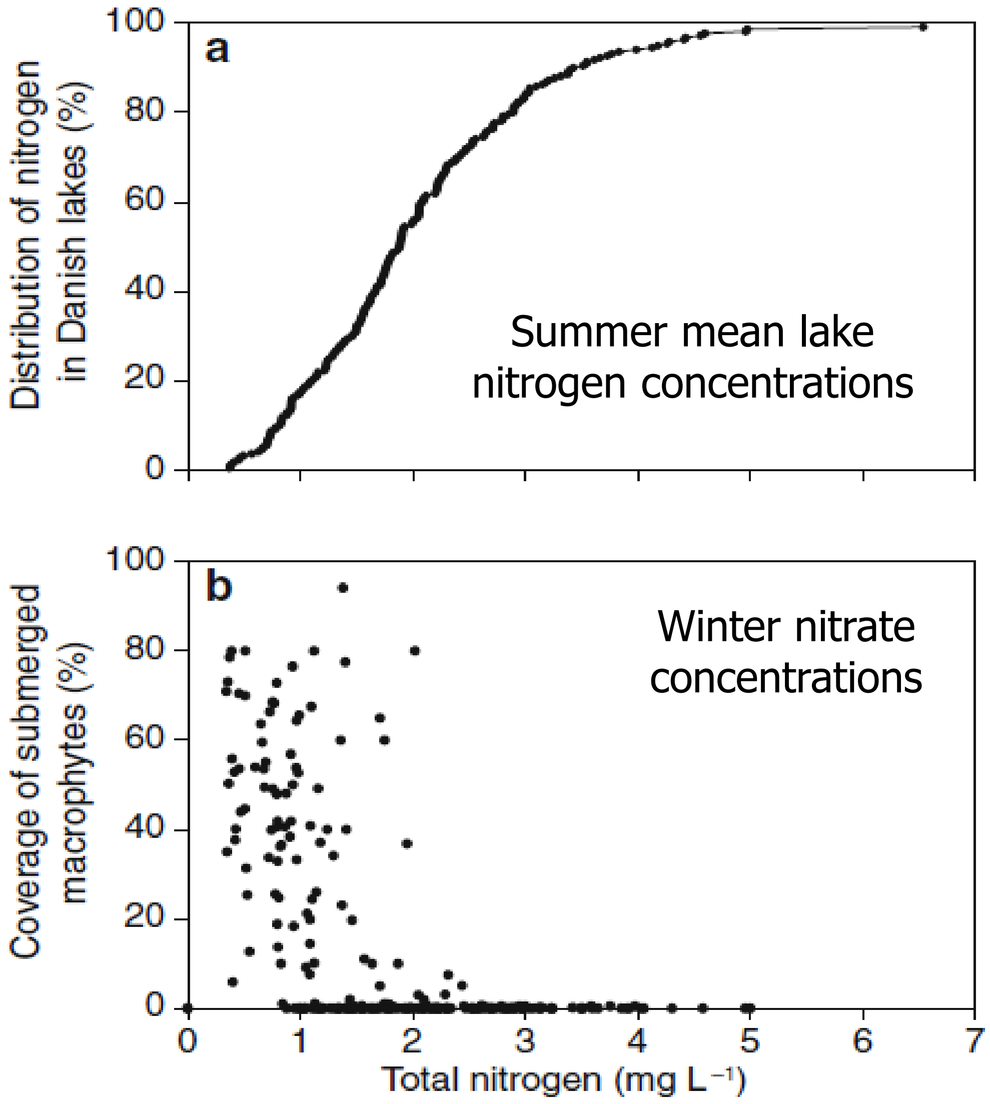
	pH	Iron	Manganese	Zinc	Phosphate
Isoetid vegetation	5.80 (0.16)	0.6 (0.3)	1.7 (0.5)	0.6 (0.4)	0.15 (0.10)
Isoetids removed	5.77 (0.06)	77.4 (34.6)	18.6 (4.3)	3.6 (1.2)	1.76 (0.32)

Samples were taken 1 year after vegetation was removed from representative plots ($n = 4$; with S.D. between parenthesis).

Smolders et al. 2002

Nitrate affects macrophyte abundance & species richness



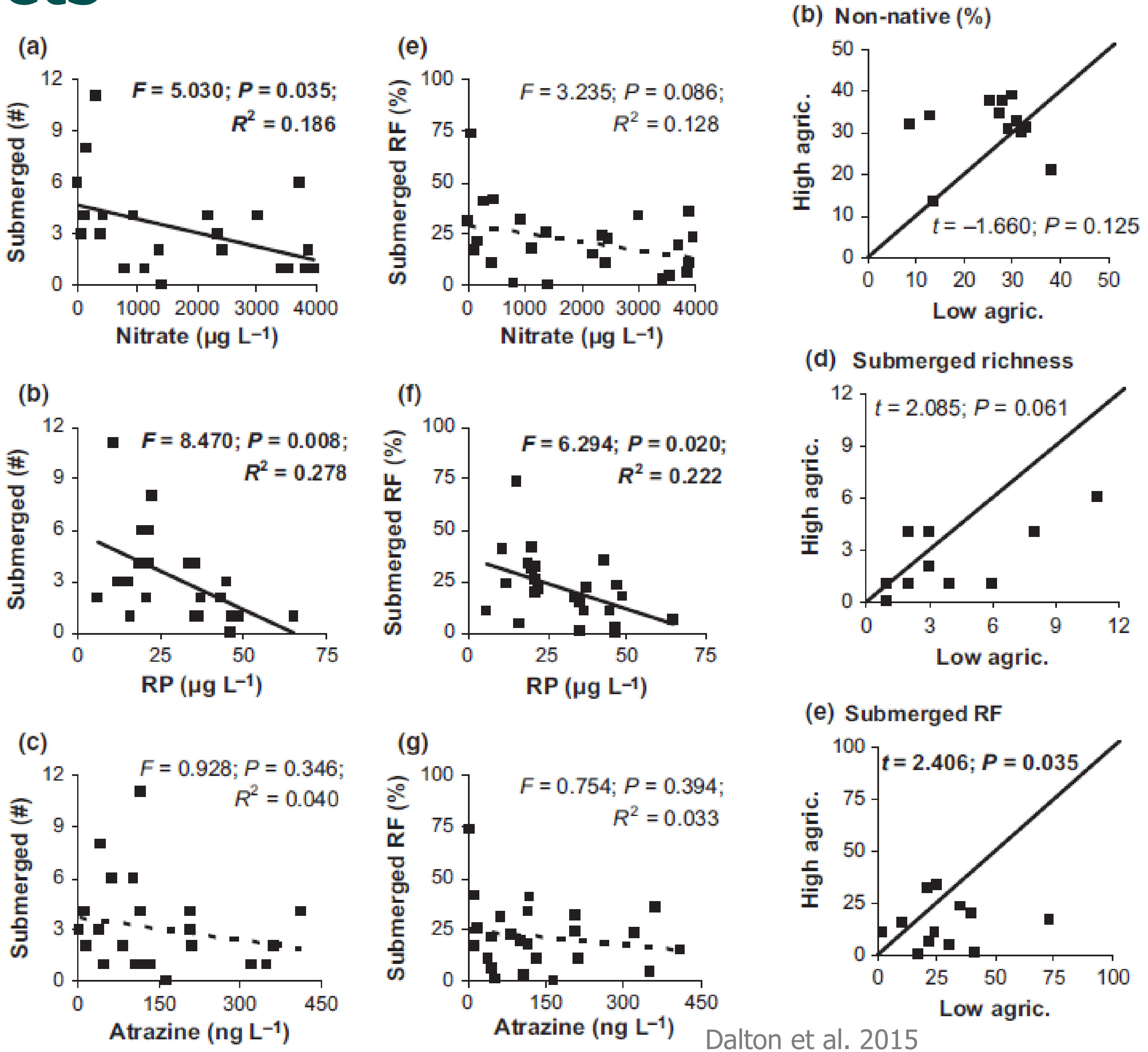


- Climate change: changed patterns in precipitation and heat waves
- Negative effects on macrophyte coverage and species richness

Jeppesen et al. 2011

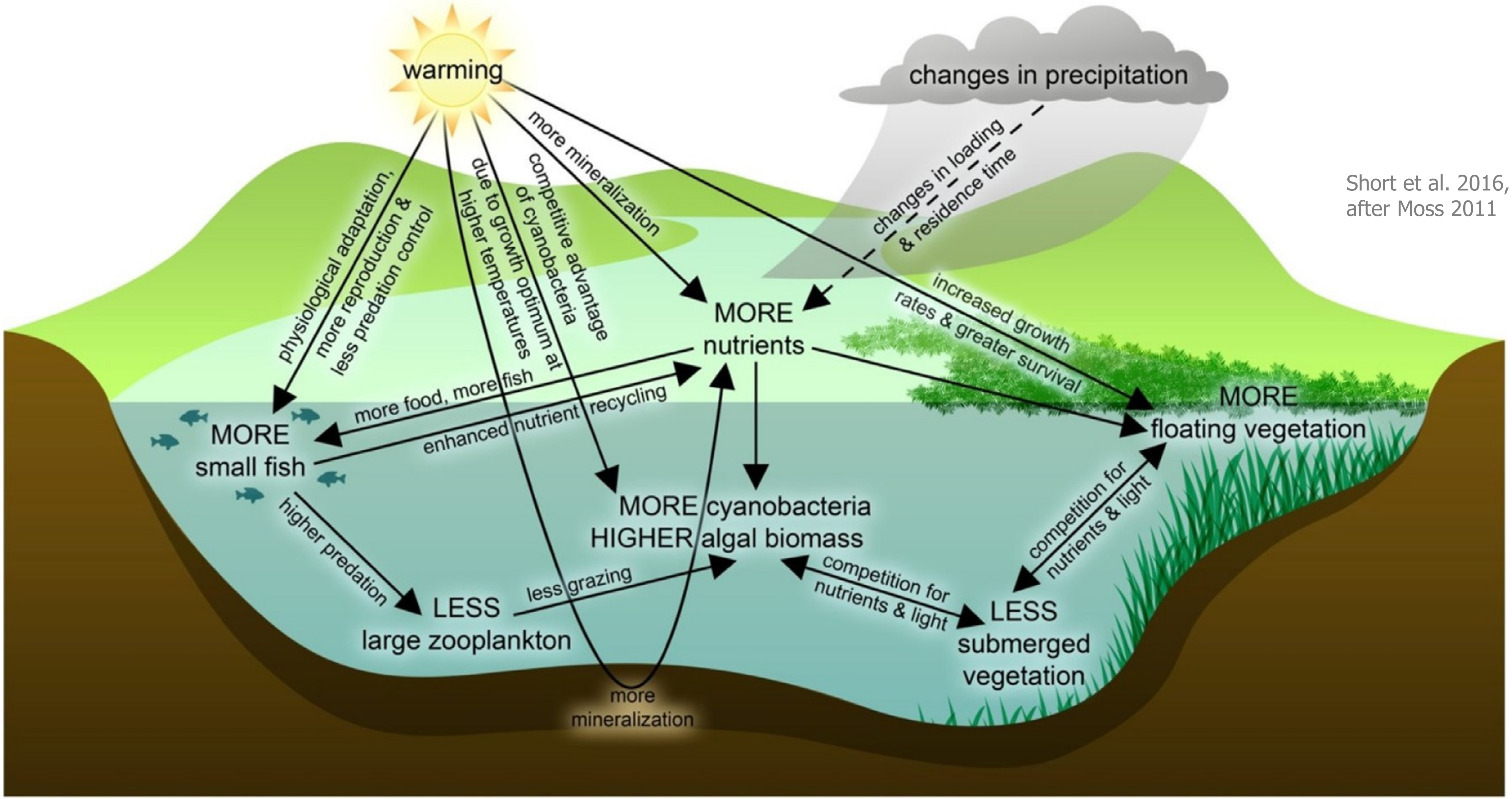
Herbicide x nutrient effects

- Few studies targeting combined impact of pesticides & eutrophication
- Case study South Nation River catchment, Ontario, Canada
- Nutrient effects overriding effect of atrazine



Dalton et al. 2015

Nutrient x temperature interactions



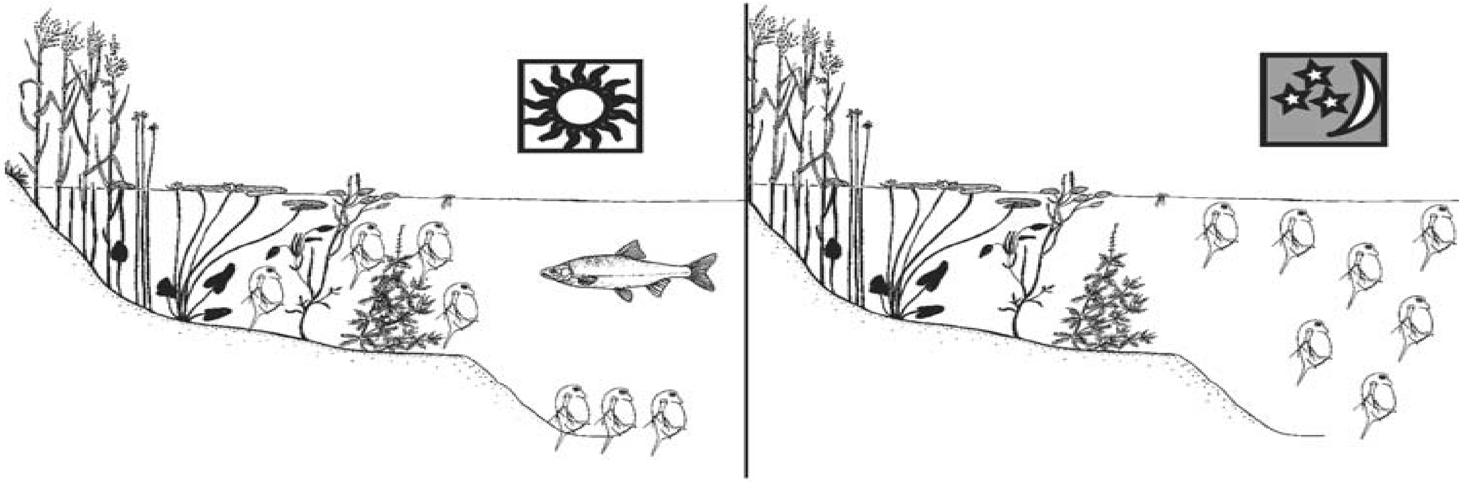
Short et al. 2016, after Moss 2011

IV. Consequences for food webs and habitat

Foto: P. Wagner

Macrophytes influence pelagic & benthic food webs

- "Structuring" role of submerged macrophytes
- "Benthic-pelagic" coupling



Gyllström & Hansson 2003

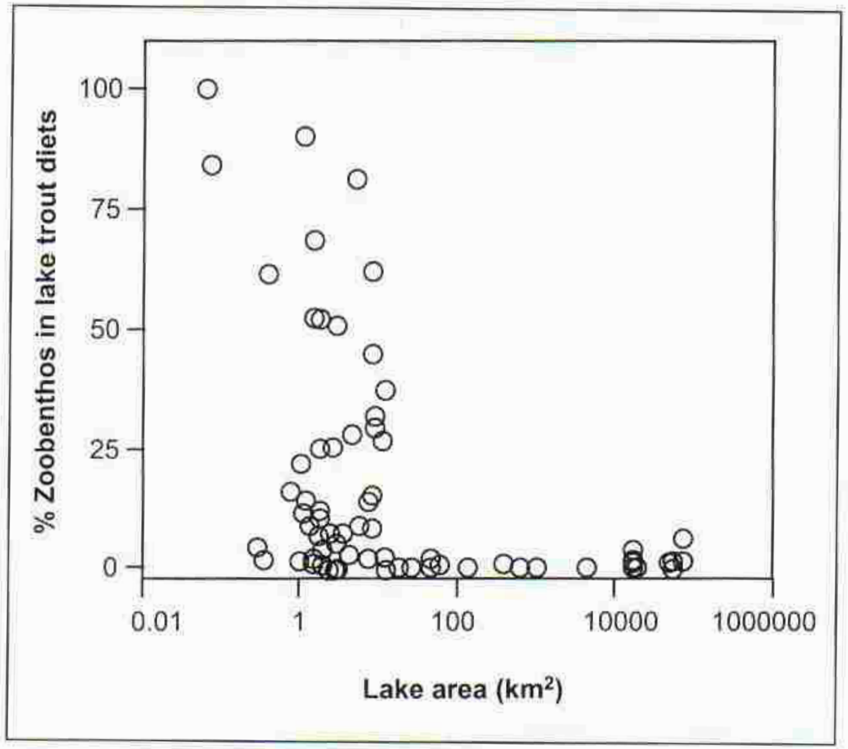


Figure 8. The direct contribution of zoobenthos to lake trout diets across a gradient of lake areas. Data are compiled from Vander Zanden and Rasmussen 1996.

Vadeboncoeur et al. 2002

Change in biological structure with eutrophication

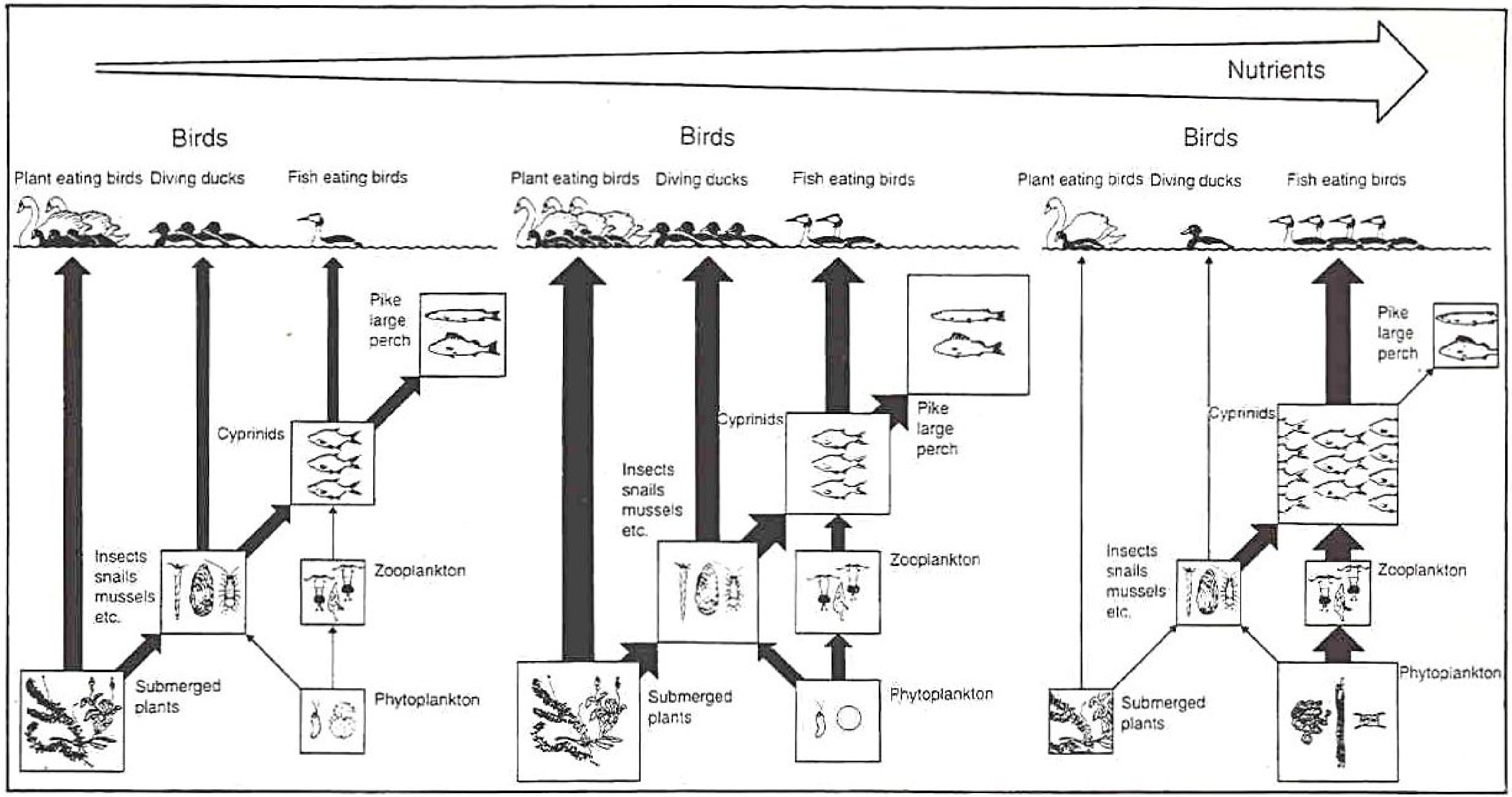
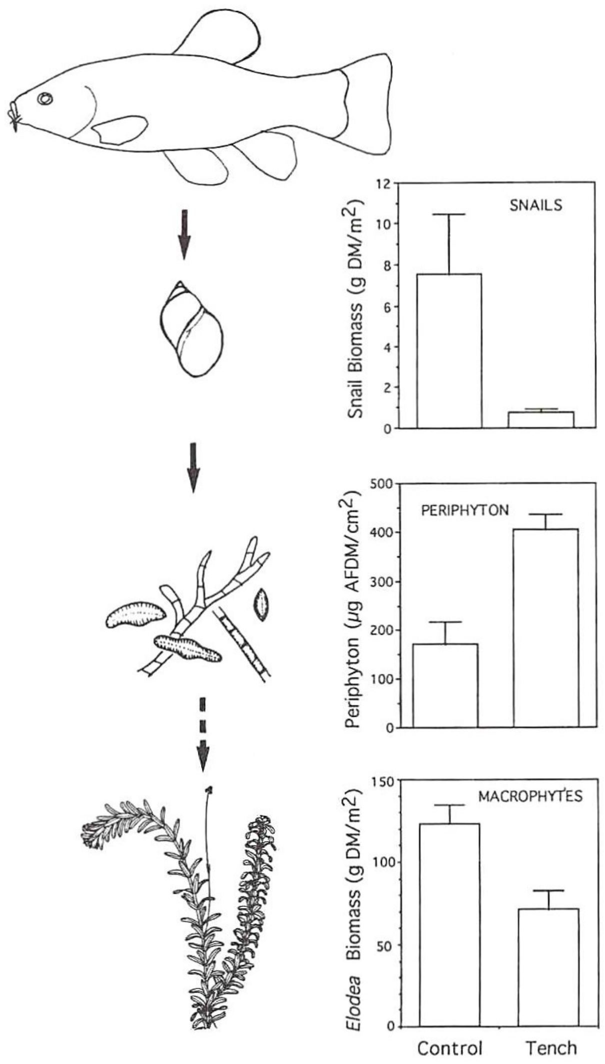


Fig. 1. Scheme illustrating how biological structure and the impact of various processes change with increasing nutrient supply (from left to right). Today, the majority of Danish lakes are found to the right of the scale, whereas they last century typically were found to the left. Partly from Andersson et al. (1990).

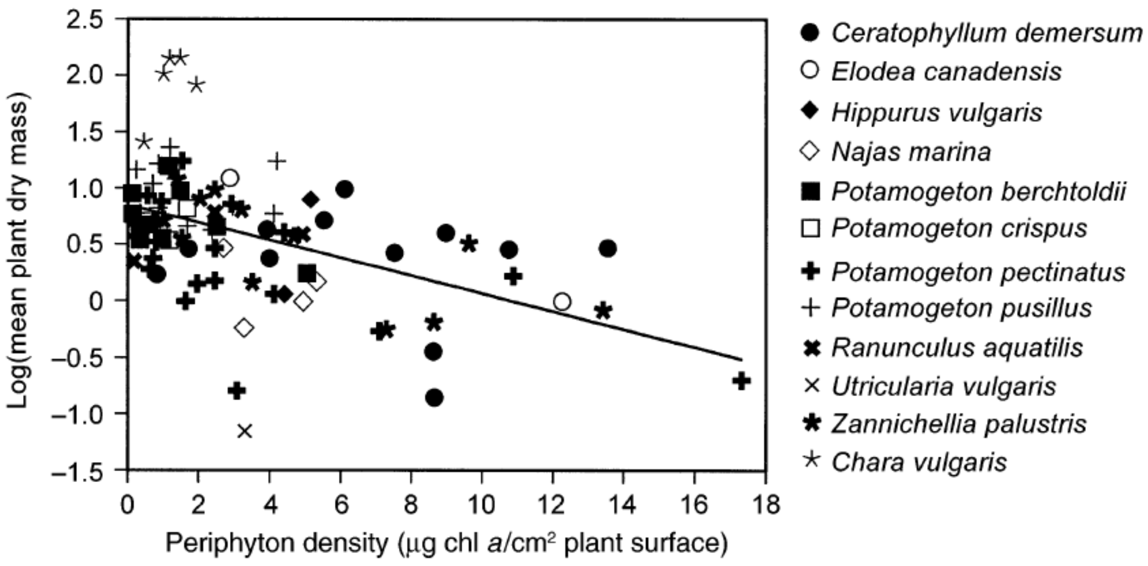
Jeppesen 1998

What controls epiphyte density on macrophytes?

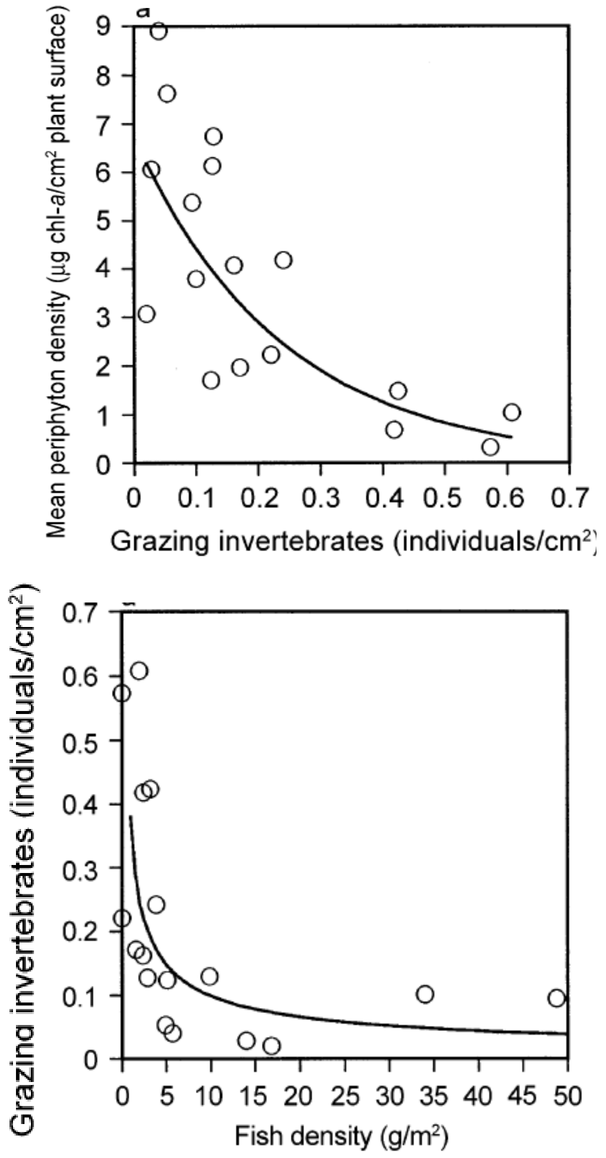


Brönmark & Vermaat., in Jeppesen et al. 1998

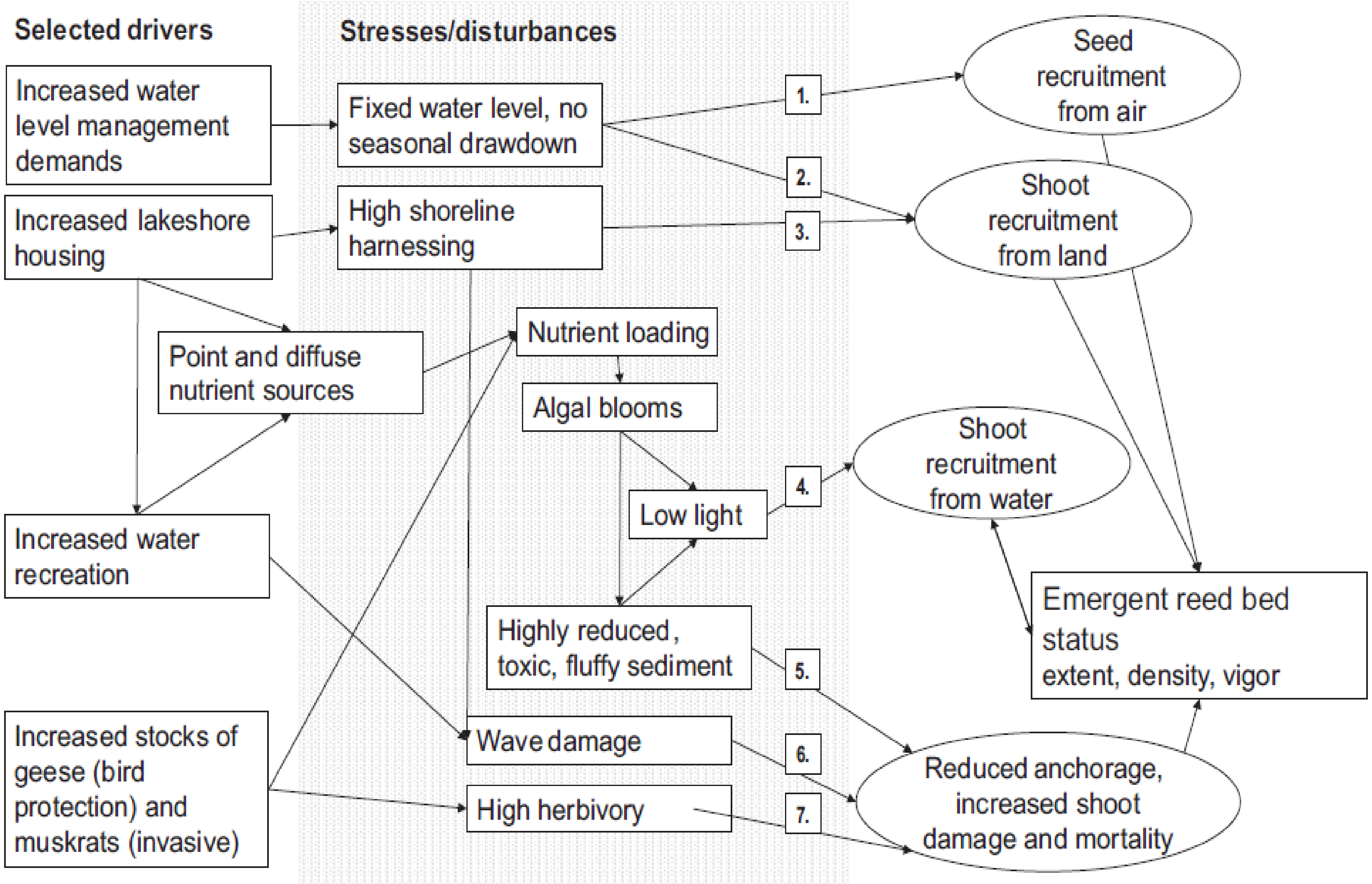
- No correlation with nutrient content



Jones & Sayer 2003



Herbivory can enhance macrophyte loss



Vermaat et al. 2016

- Major factors accounting for reed bed declines
  - Housing development
  - Eutrophication
- Muskrat affects recolonization/ restoration programs

A first hypothesis for eutrophication effects on submerged macrophytes

- Eutrophication enhances epiphytic algae
- Lowers allelopathic capacity of submerged macrophytes
- This will enhance phytoplankton growth
- Subsequent loss of submerged macrophytes

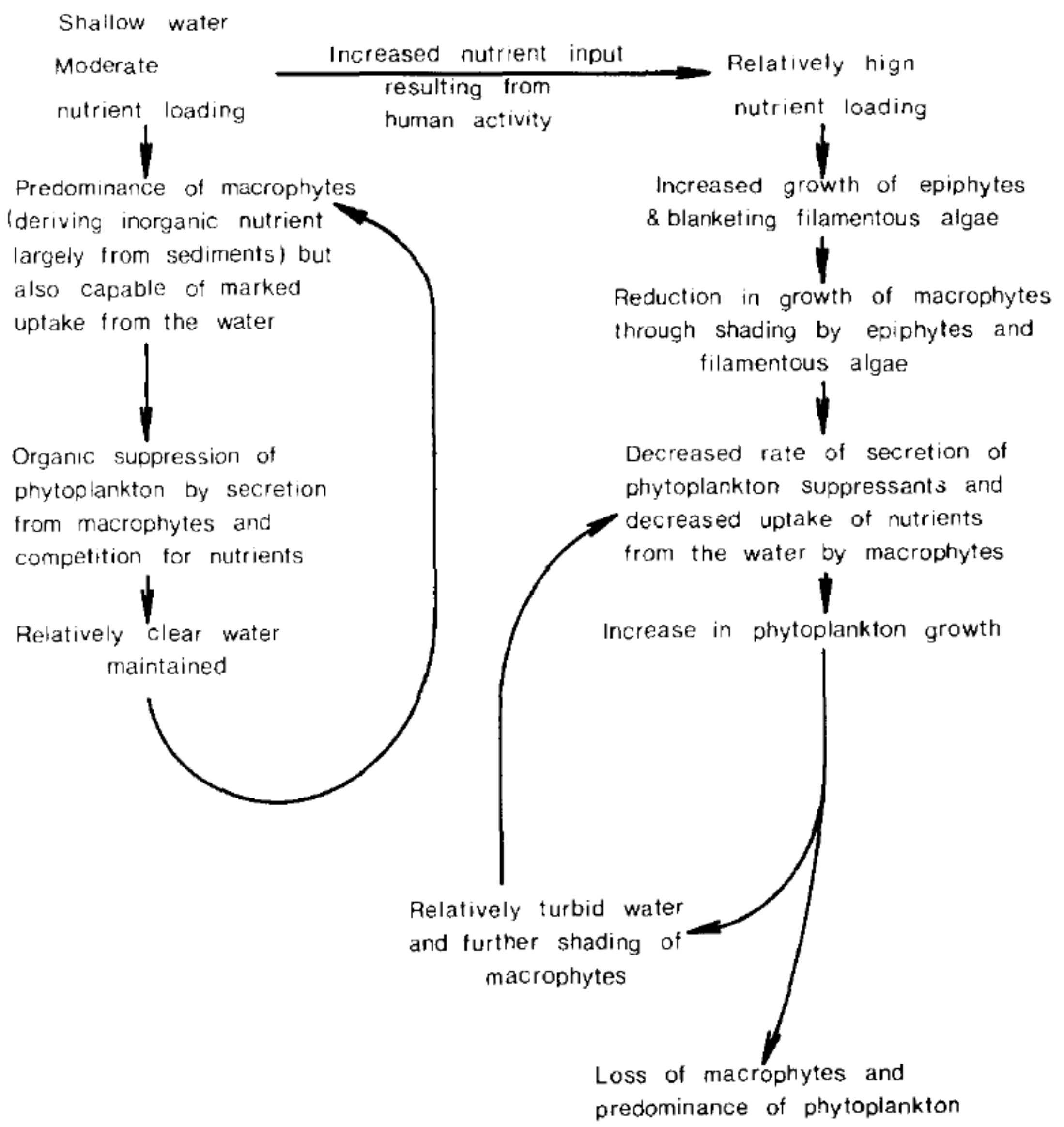
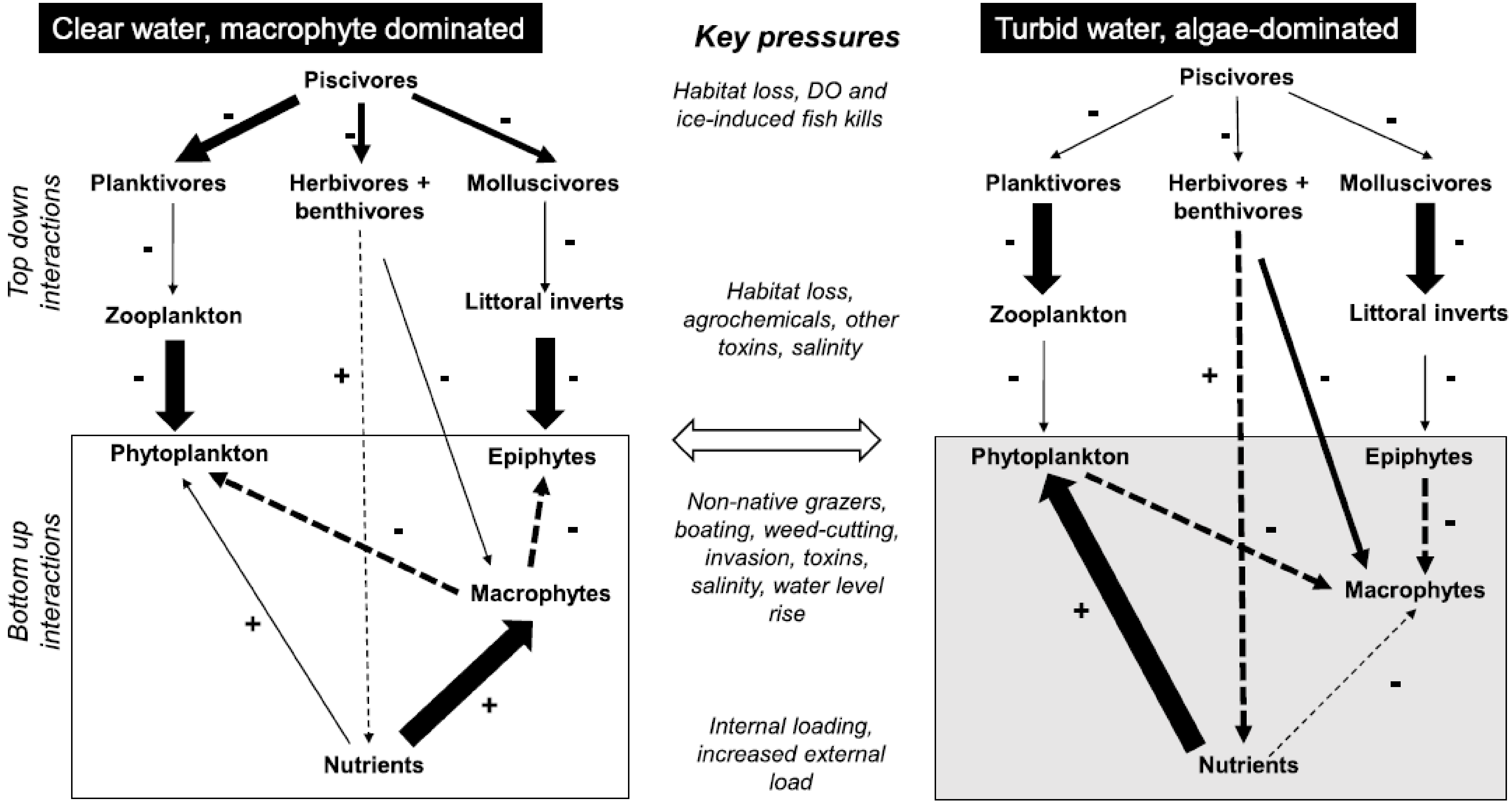


Fig. 1. Hypothesis to account for decline in macrophyte populations when lakes are fertilized.

Phillips-Eminso-Moss 1978

An updated view on major interactions in shallow lakes



Phillips-Willby-Moss 2016

V. Conclusions

- Eutrophication enhances primary production and leads to shifts in the dominance of functional groups
- Negative effects on the physical-chemical habitat & reciprocal interactions with dominant plants
- Loss of species richness/diversity
- Loss of habitat function and negative effects on food webs
- Additional factors: Climate change, pollutants, invasive species,…..