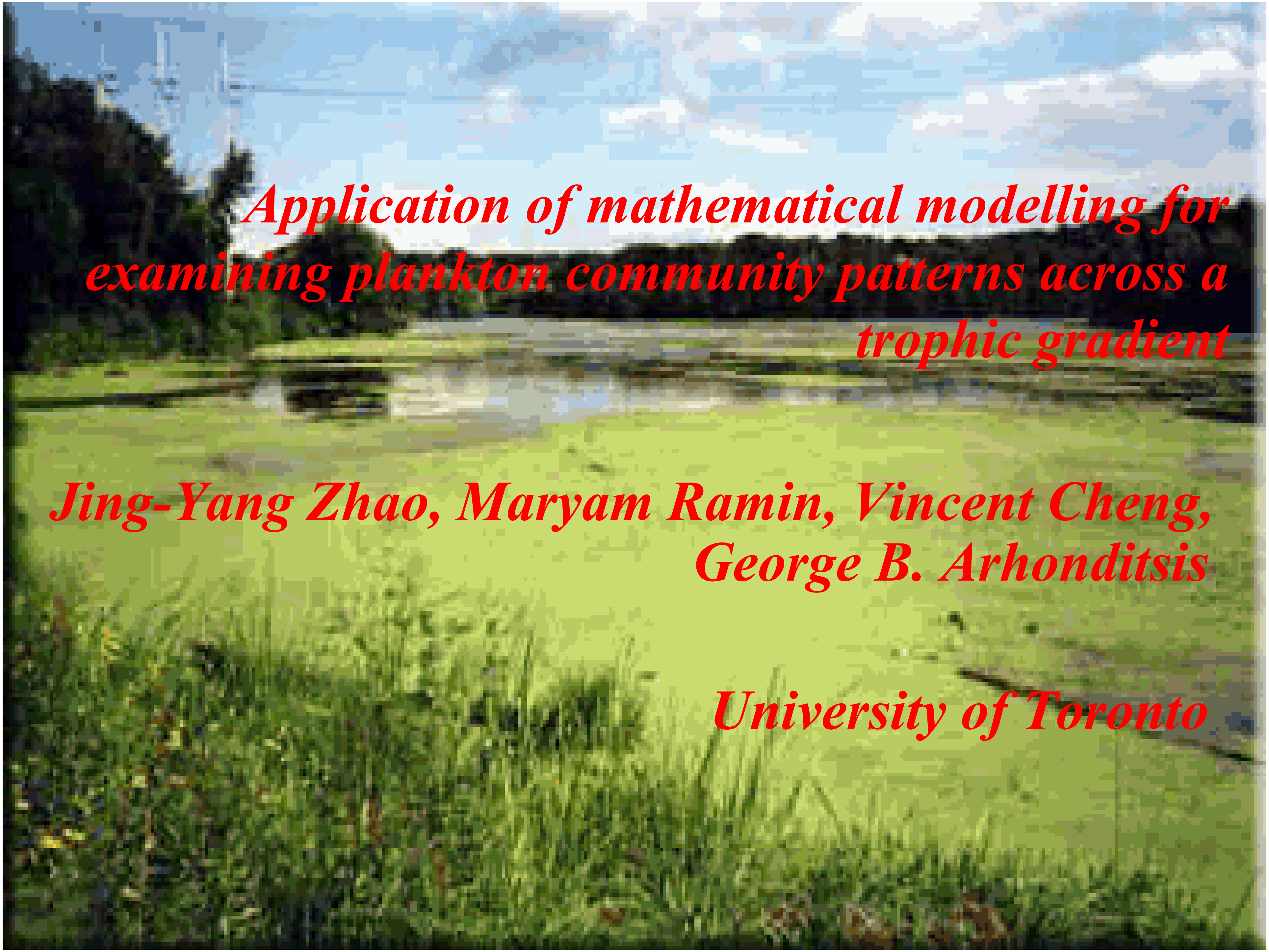

Application of mathematical modelling for examining plankton community patterns across a trophic gradient

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Objectives

- **Examination of the functional properties and the abiotic conditions under which the different plankton groups can dominate or can be competitively excluded in oligo-, meso- and eutrophic environments.**
- **Elucidation of the aspects (i.e., important causal links) of the complex interplay among physical, chemical and biological factors that drive epilimnetic plankton dynamics.**

Simple Models versus Complex Models

- *Simple Models*

– Mathematically more sound

– Results can be easily understood

– Focus on one specific explanation of a phenomenon and neglect important aspects of system dynamics (spatial heterogeneity, individual variability)

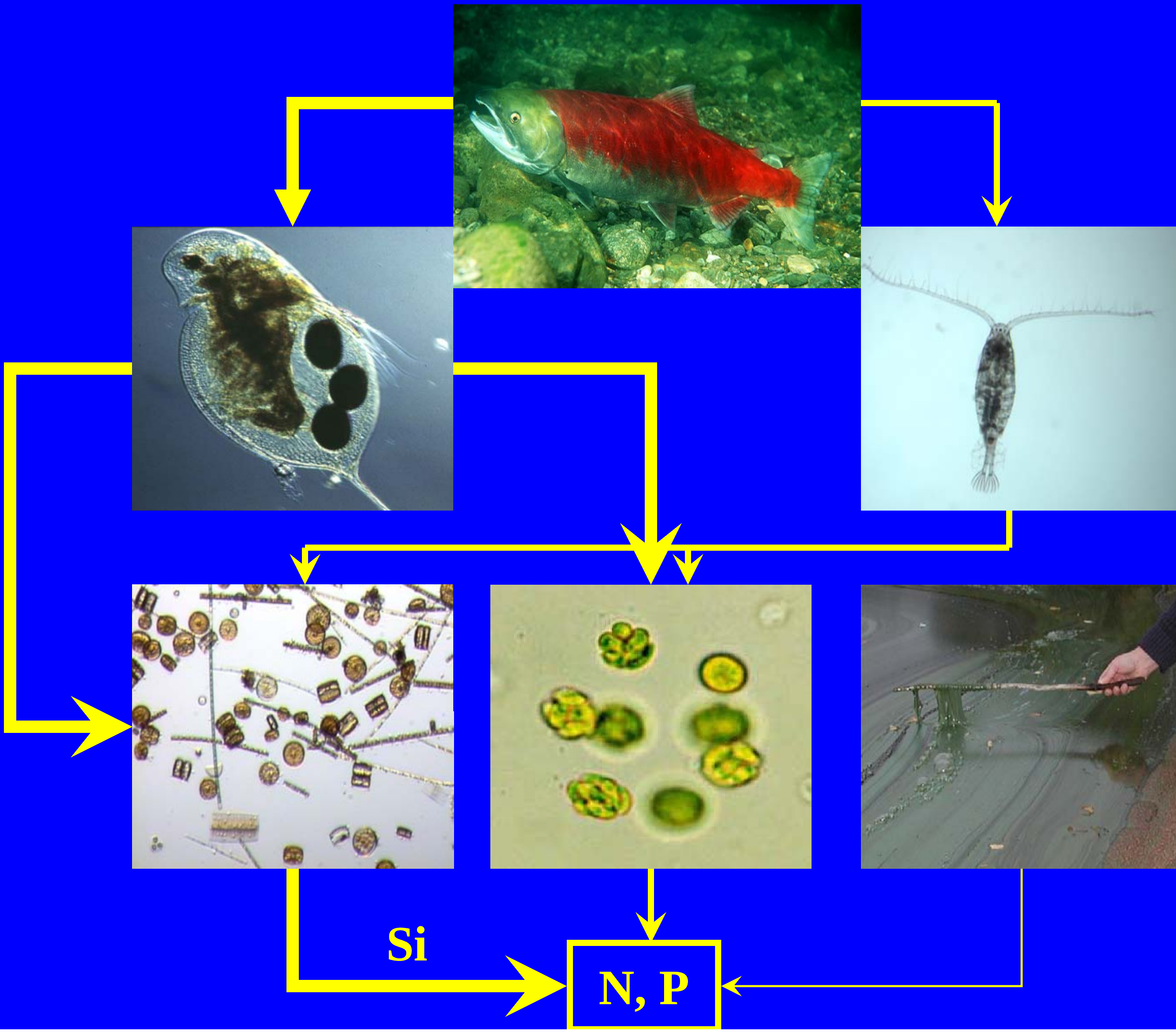
- *Complex Models*

– Mathematical features that can introduce artefacts

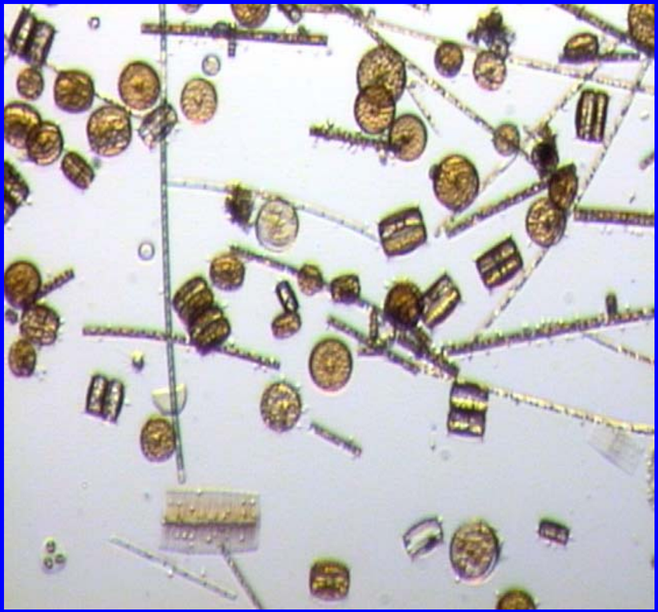
– Results can not be easily understood

– Parameterization that more closely represents real world dynamics

Food web structure



Diatoms



- High growth rates
- Strong P competitors
- Weak N competitors
- Si requirements
- High sinking velocity
- Lower temperature optima
- High metabolic rate
- High preference from zooplankton

Cyanobacteria

- Low growth rates
- Weak P competitors
- Strong N competitors
- Very low sinking velocity
- High temperature optima
- Low metabolic rate

- Low preference from zooplankton

Green Algae

Intermediate competitors

To more realistically depict the continuum between diatom- and cyanobacteria-dominated communities in our numerical experiments

Cladocerans

- High grazing rates
- P-rich animals
- Lower C:N ratio
- High temperature optima
- Higher metabolic rate
- Filter feeders

Copepods

- Lower grazing rates
- N-rich animals
- Lower C:P ratio
- Low temperature optima
- Lower metabolic rate
- Feeding selectivity

Effects of ingested food quality and quantity on zooplankton phosphorus production efficiency

Food Quality: HUFA, amino acids, protein content, digestibility

$$FQ_{(j)} = \left(\sum_{i=diat,green,cyan} FQ_{(i,j)} \sqrt{PHYT_{(i)}} + FQ_{det(j)} \sqrt{POC} \right) ZOOP_{C/PLIM(j)}$$

$$ZOOP_{C/PLIM(j)} = \begin{cases} Graz_{C/P(j)} \leq C:P_0 & 1 \\ Graz_{C/P(j)} > C:P_0 & \dfrac{C:P_0}{Graz_{C/P(j)}} \end{cases}$$

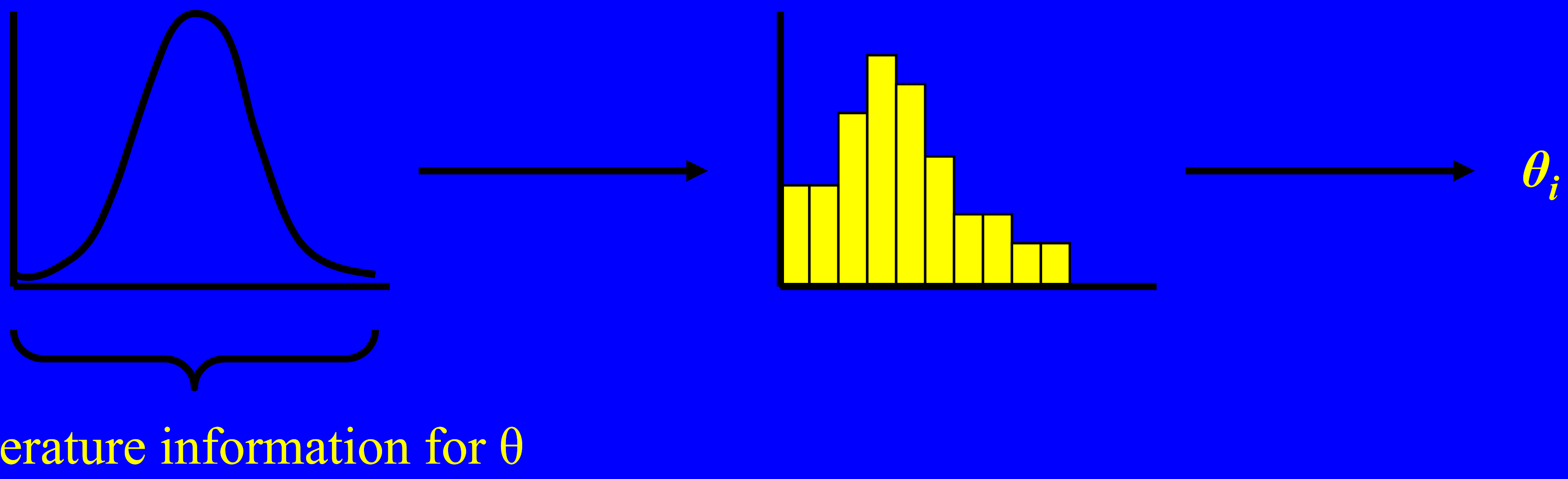
$$gref_{P(j)} = \frac{ef_{1(j)} FQ_{(j)}}{ef_{2(j)} + FQ_{(j)}}$$

Critical seston C:P threshold

Phosphorus production efficiency

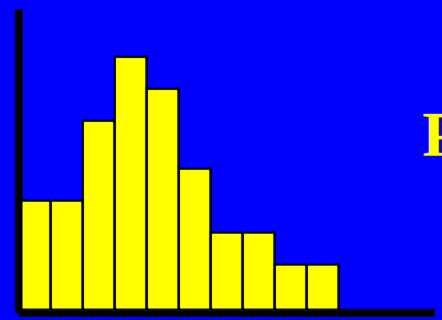
Methodology

- Identification of the plausible parameter range (min, max)
- Assignment of a probability distribution:
  (i) form (e.g., normal, uniform)
  (ii) calculation of the moments (central tendency, dispersion)
- Monte Carlo sampling



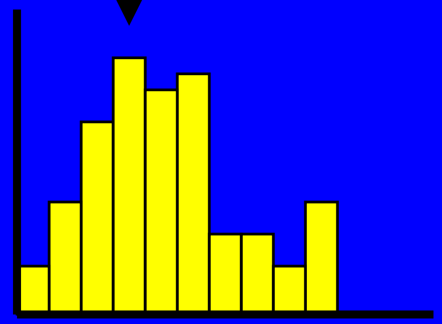
7,000 Monte Carlo sets θ^{k} for each trophic state

Parameter distributions



θ

$f(x_i, \theta^{k})$



$\tilde{y}_i$

Model outputs

Oligotrophic　　Mesotrophic　　Eutrophic

Nutrient Loading

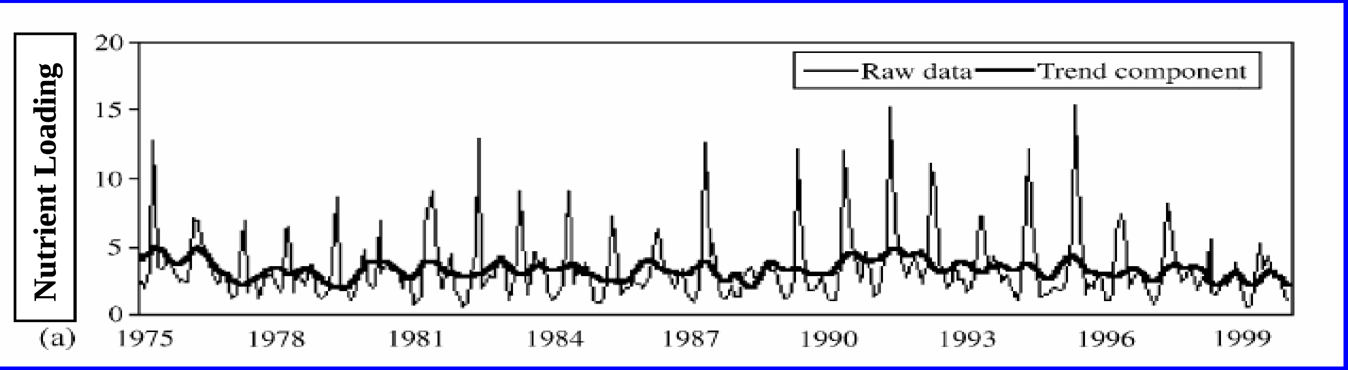
Solar Radiation

Epilimnion Temperature

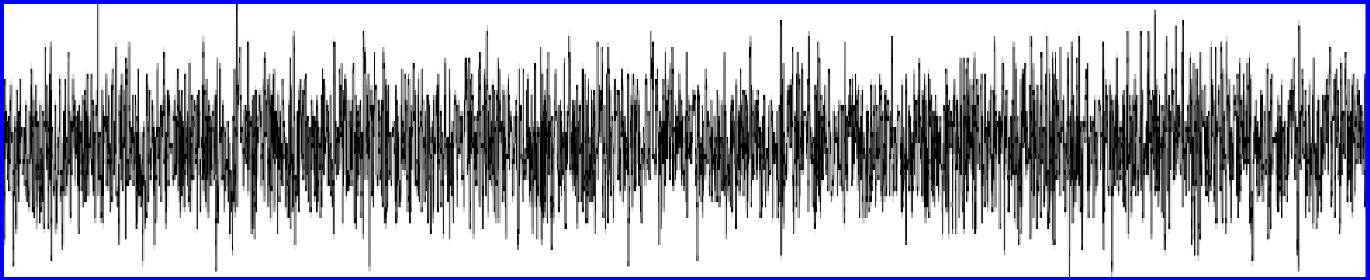
Hypolimnion Temperature

Vertical Mixing

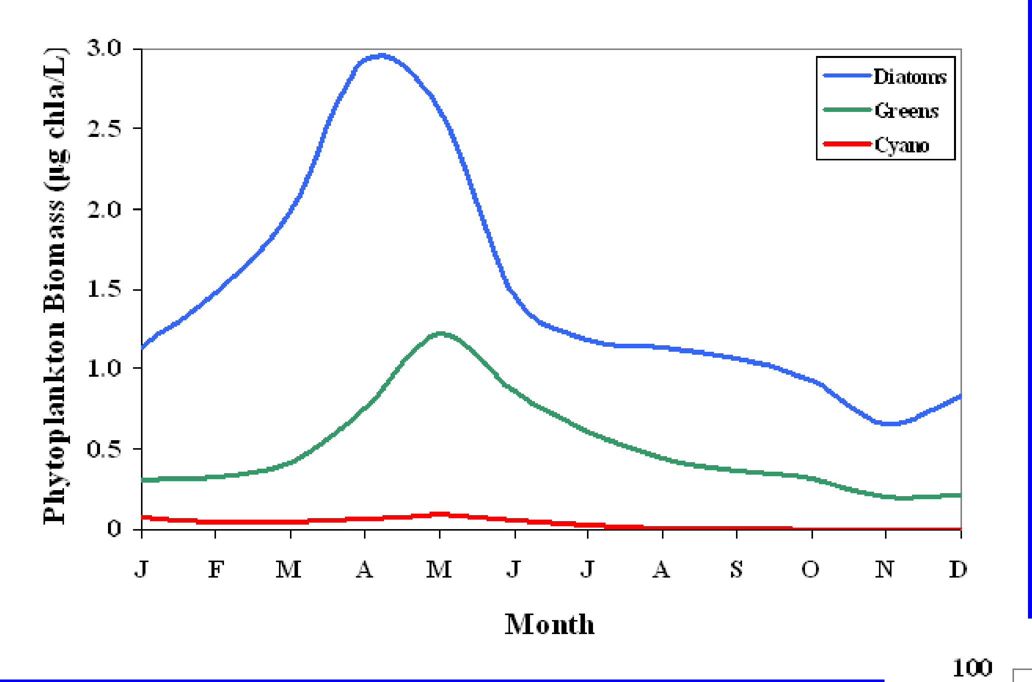
Interannual variability

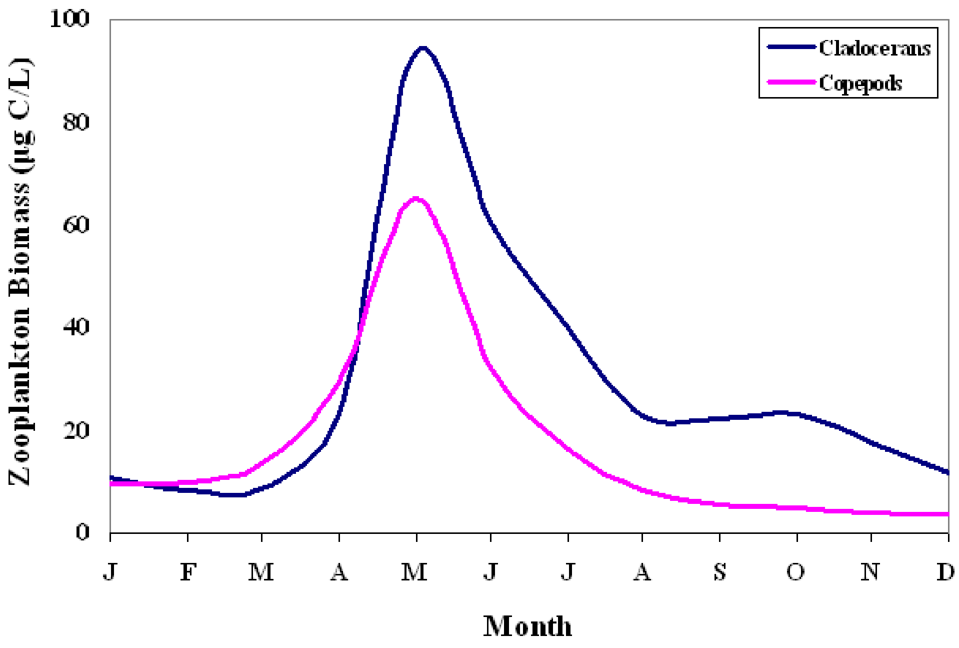


Intraannual variability

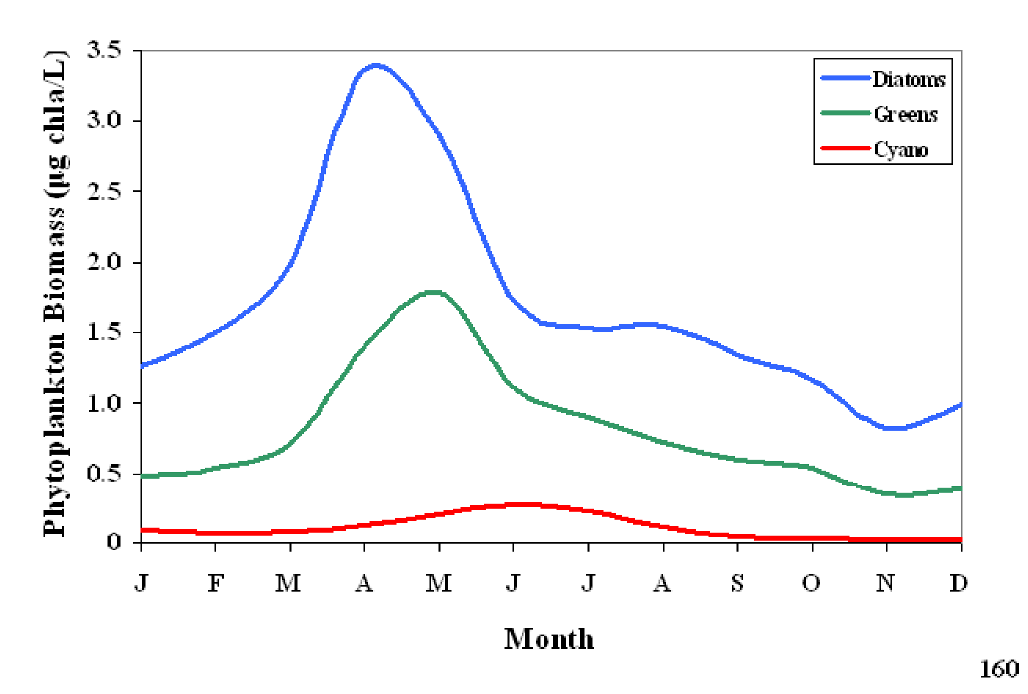


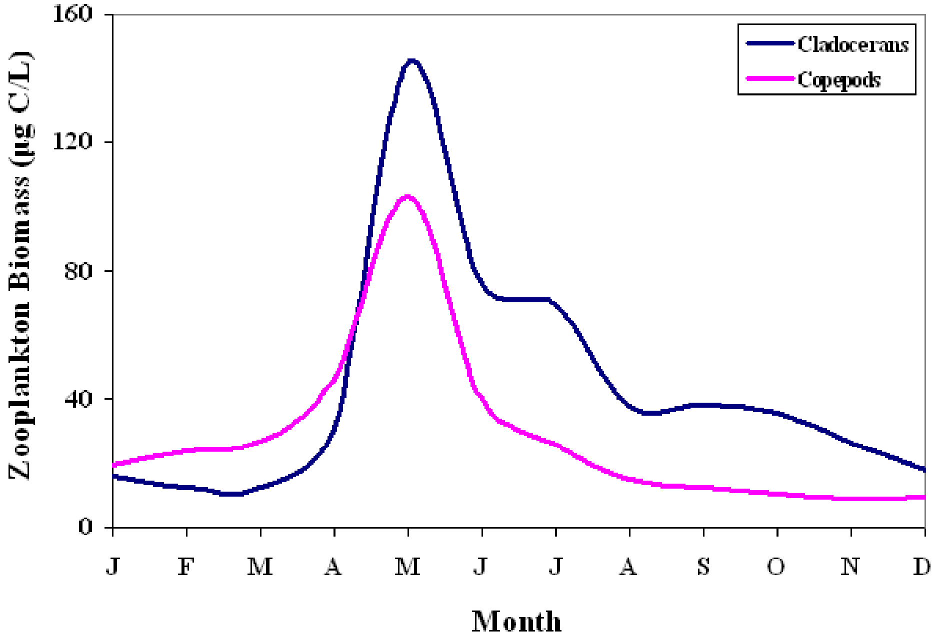
Oligotrophic environment



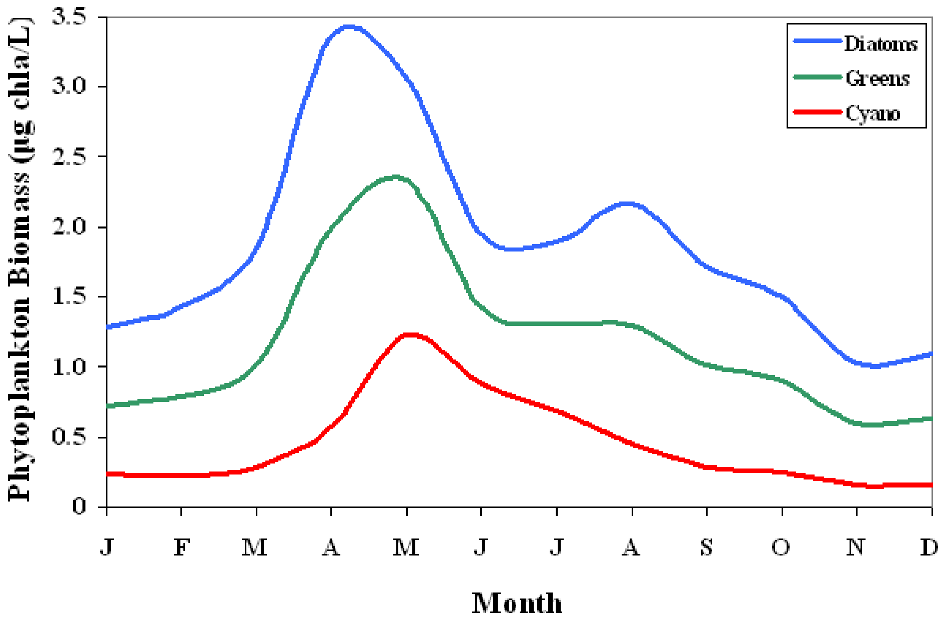


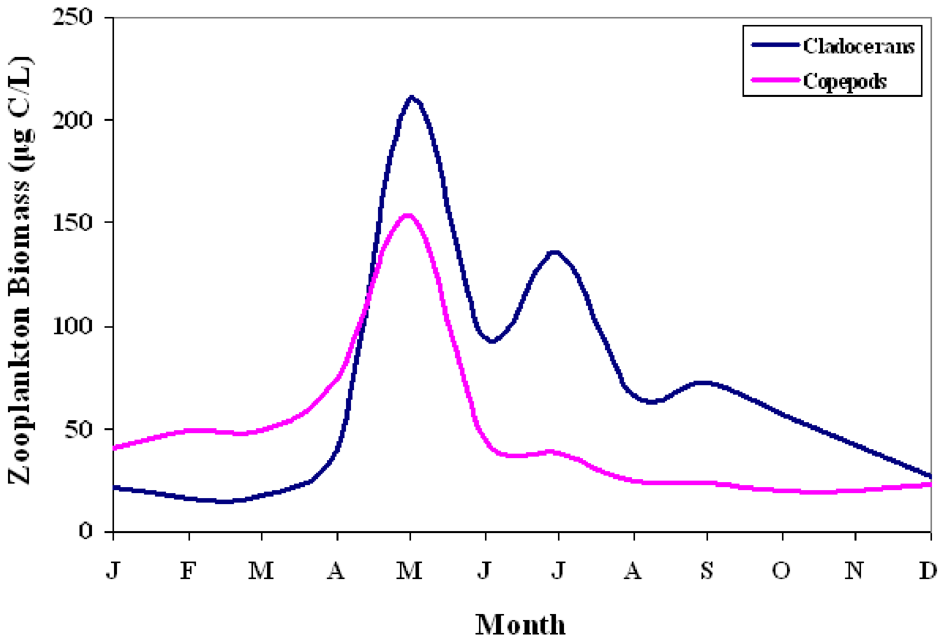
Mesotrophic environment



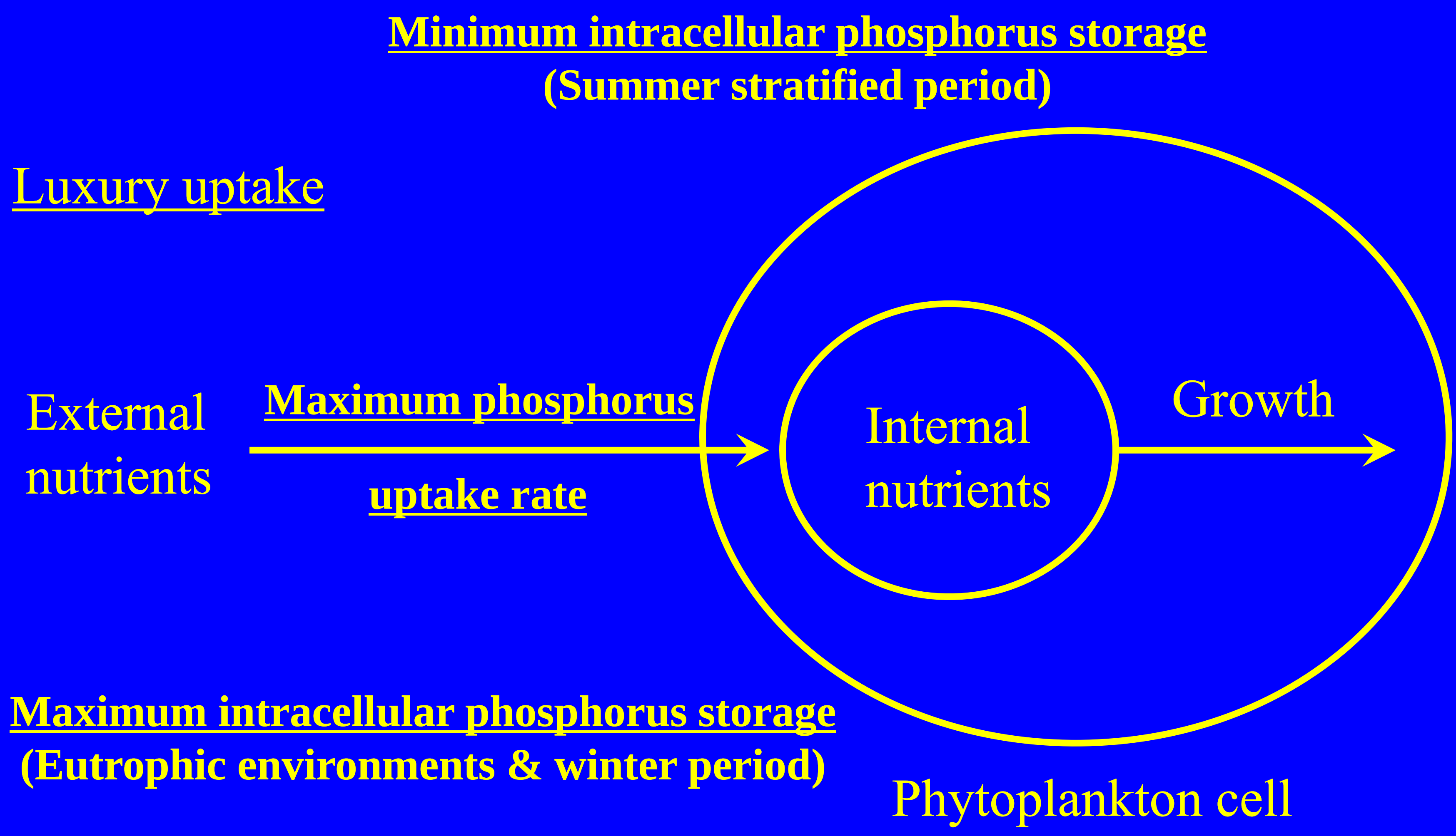


Eutrophic environment



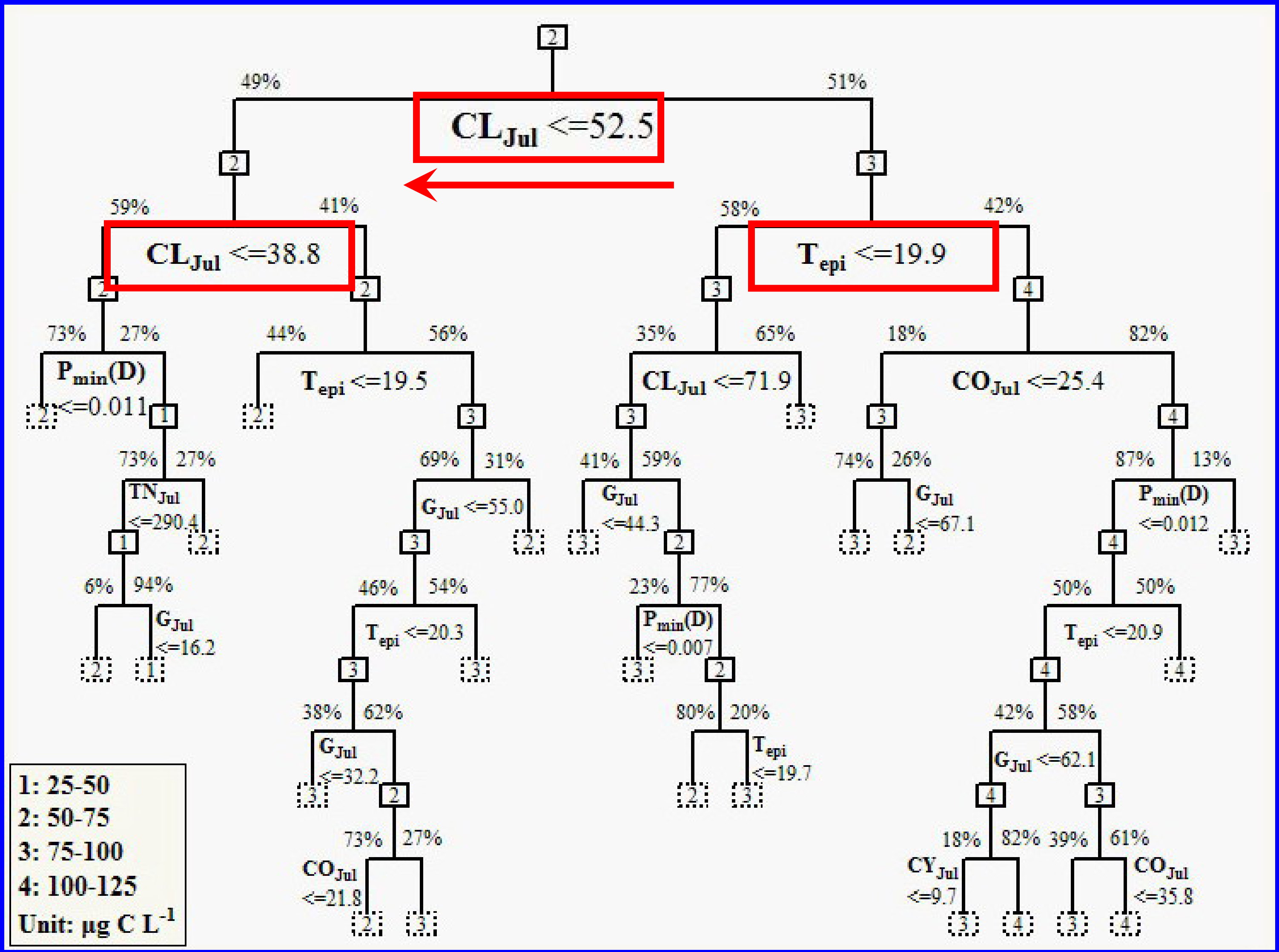


Diatoms



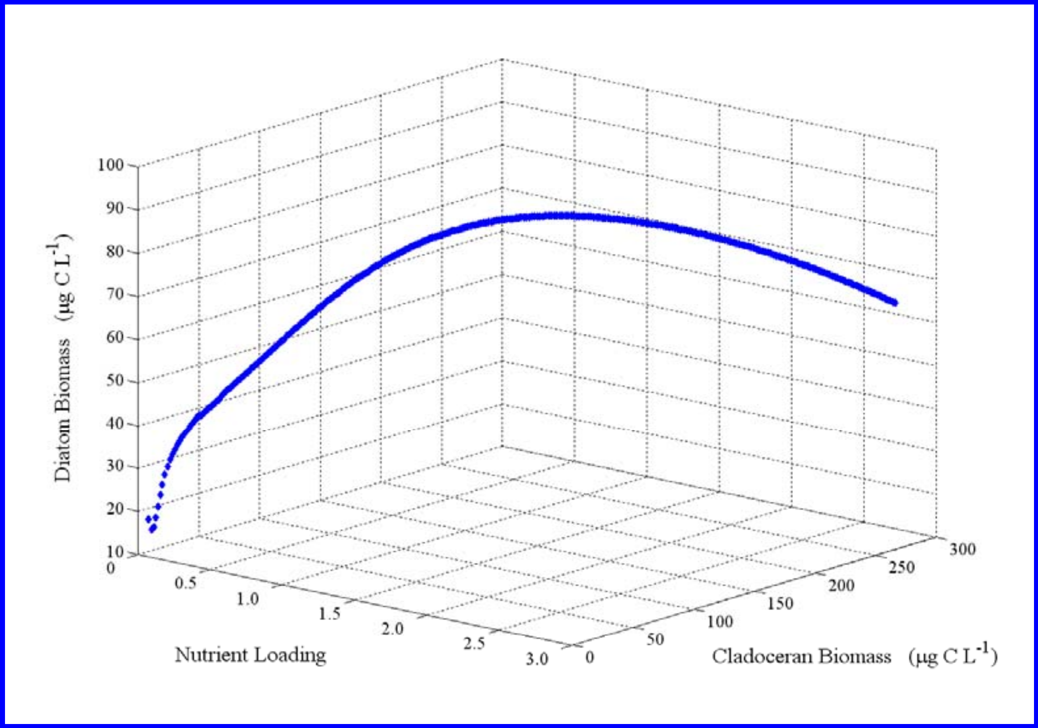
Minimum intracellular phosphorus storage
(Summer stratified period)
Luxury uptake
External nutrients
Maximum phosphorus uptake rate
Internal nutrients
Growth
Maximum intracellular phosphorus storage
(Eutrophic environments & winter period)
Phytoplankton cell

Diatoms



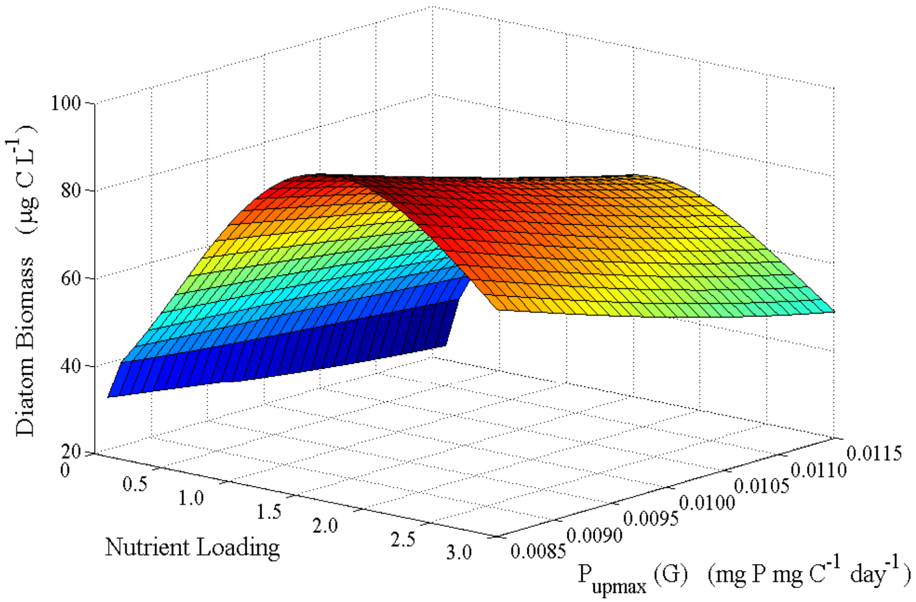
CL Jul <=52.5
49%
51%
CL Jul <=38.8
T epi <=19.9
P min(D) <=0.011
T epi <=19.5
CL Jul <=71.9
CO Jul <=25.4
TN Jul <=290.4
G Jul <=55.0
G Jul <=44.3
G Jul <=67.1
P min(D) <=0.012
G Jul <=16.2
T epi <=20.3
P min(D) <=0.007
T epi <=20.9
G Jul <=32.2
T epi <=19.7
G Jul <=62.1
CO Jul <=21.8
CY Jul <=9.7
CO Jul <=35.8
1: 25-50
2: 50-75
3: 75-100
4: 100-125
Unit: µg C L-1

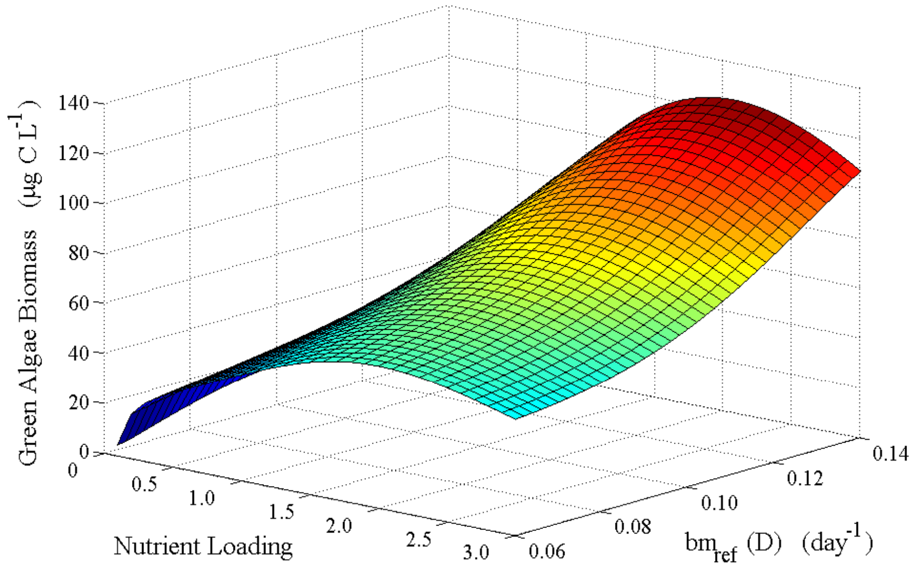
Diatoms



Tight connection and positive relationship between diatoms (fast-growing species with superior phosphorus competitors) and cladocerans (P-rich animals) that seems to reduce the grazing pressure exerted on the other residents of the phytoplankton community.

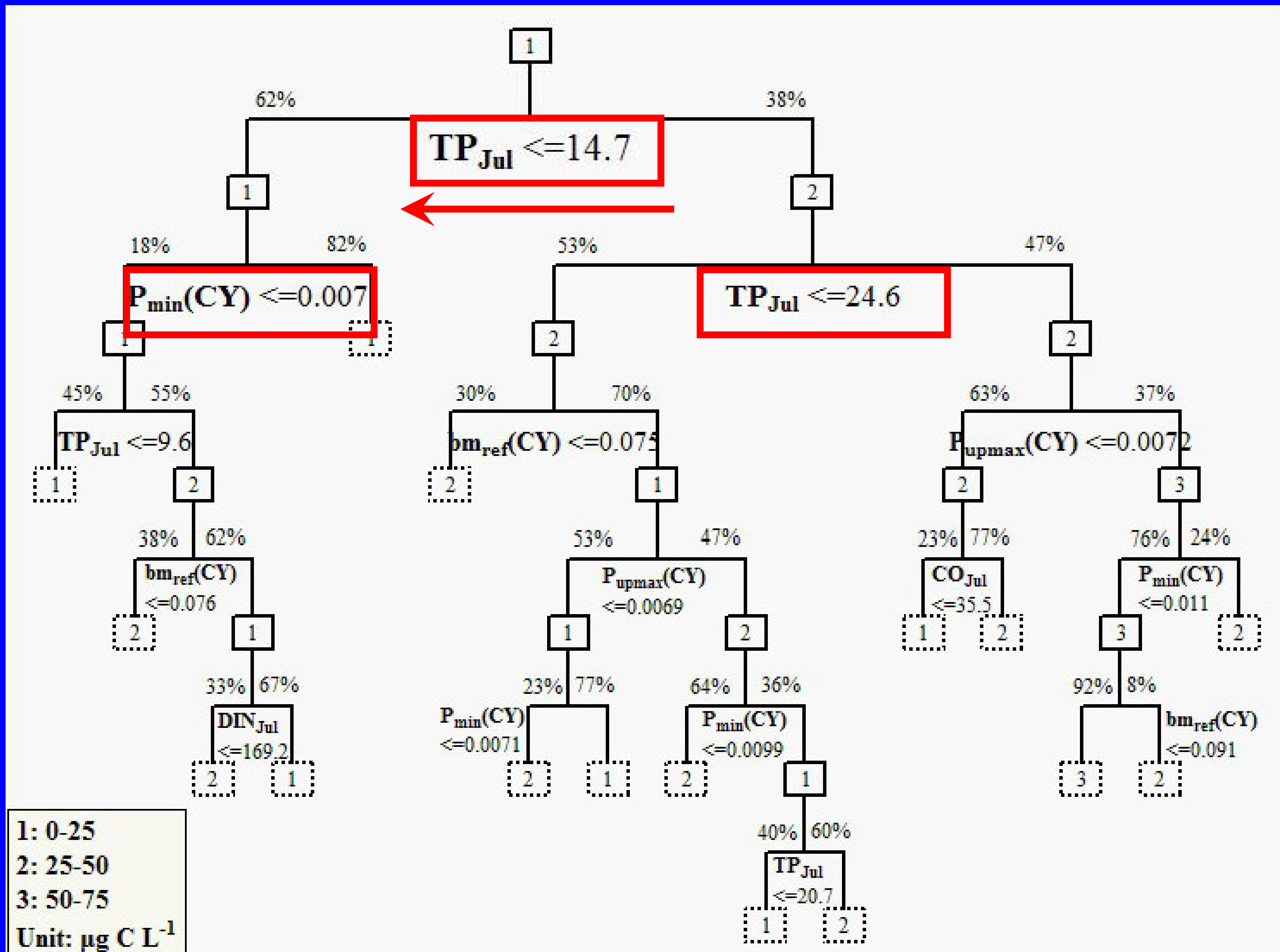
Diatoms



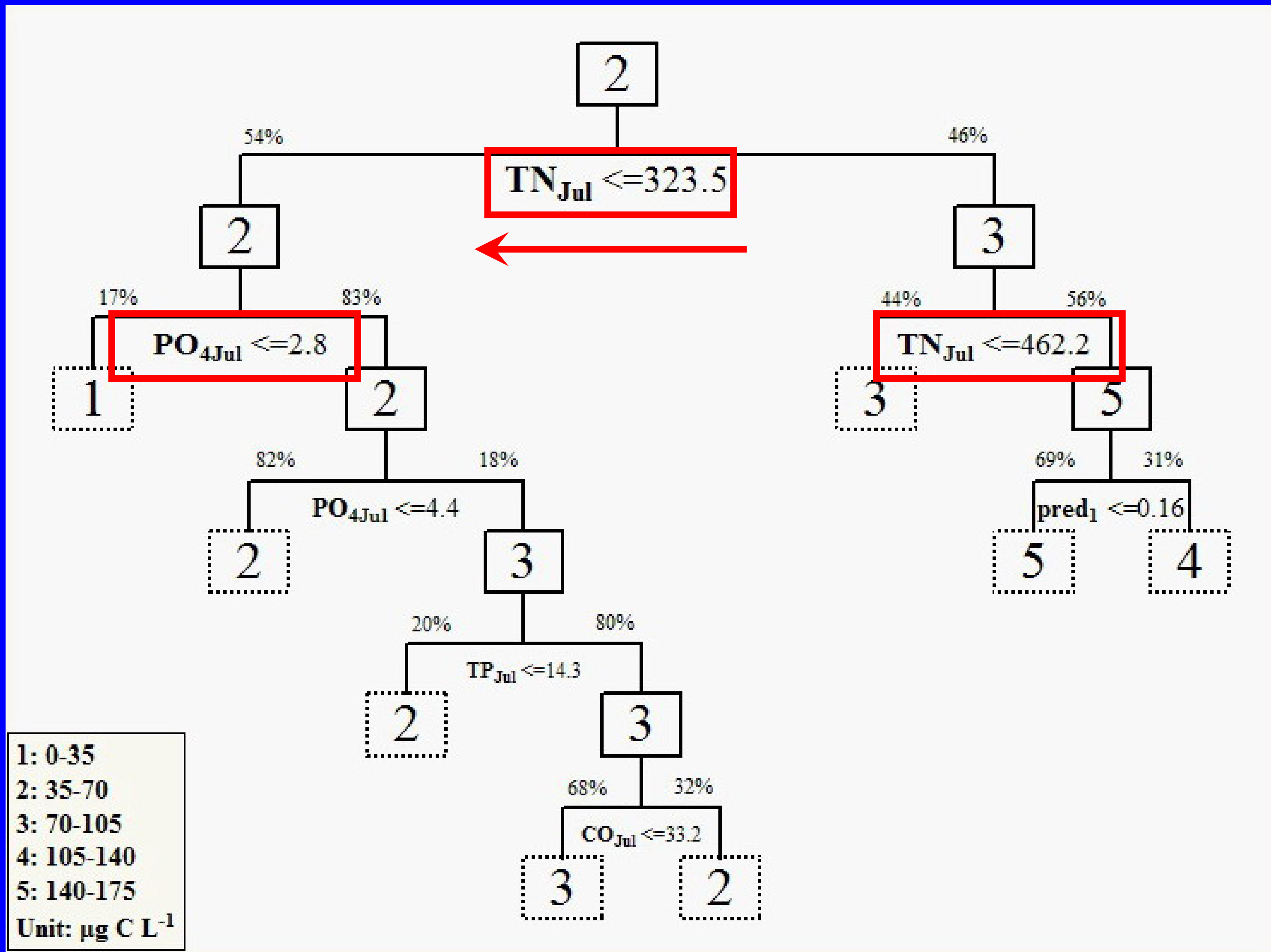


Diatoms and green algae directly compete against each other, as the one group's functional properties (growth rates, storage capacity, metabolic rates) and biomass levels can be significant predictors for the other one's dynamics.

Cyanobacteria



Cladocerans

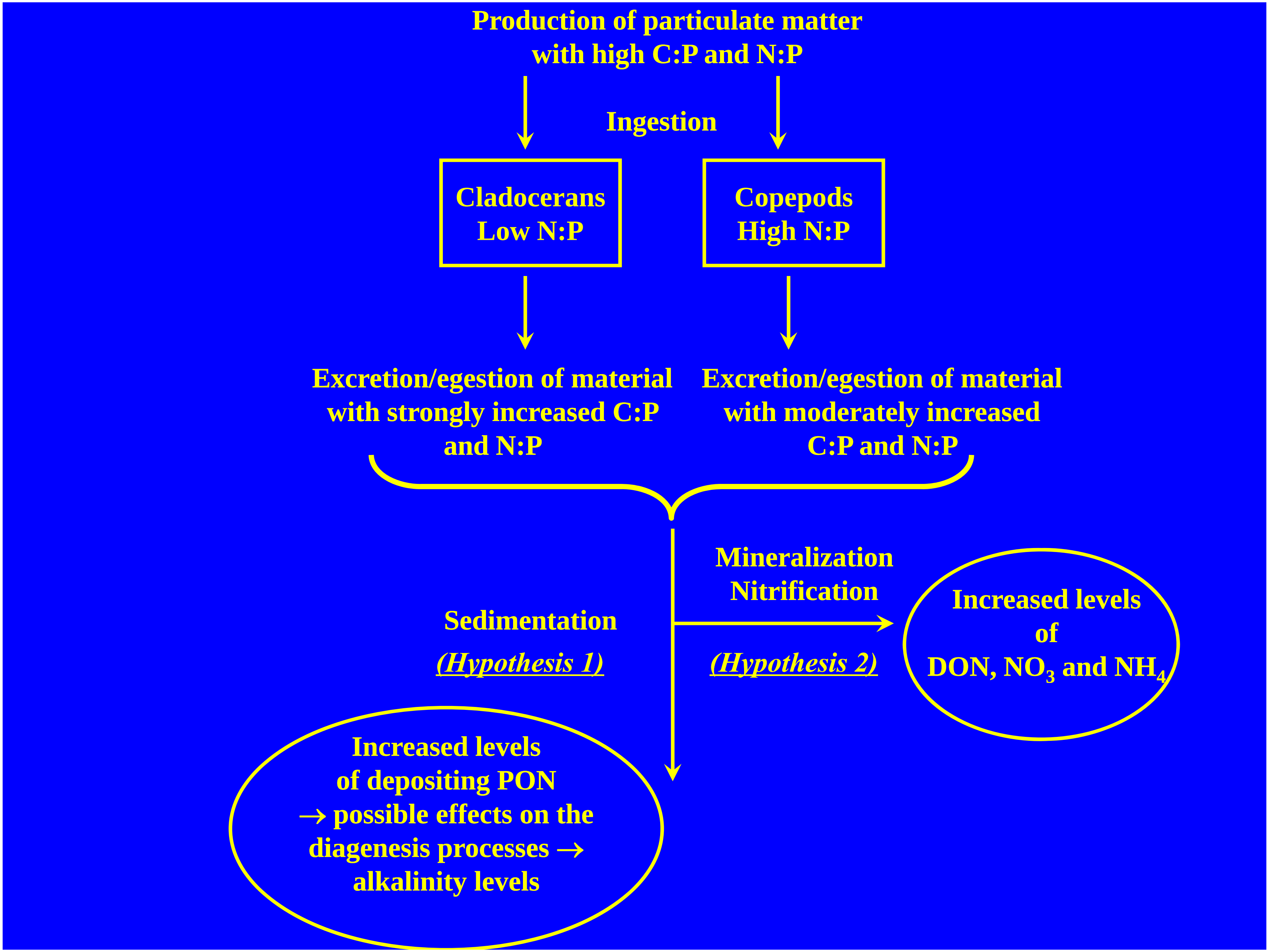


Cladocerans

• The P-rich animals (e.g., *Daphnia*) contribute a significant proportion of the excess carbon and nitrogen being recycled in the system.

• The large-bodied zooplankton grazers have the ability to reduce phytoplankton sensitivity to external perturbations.

• The reproduction of the seasonal succession zooplankton patterns is VERY sensitive to the assigned temperature requirements for attaining optimal growth.



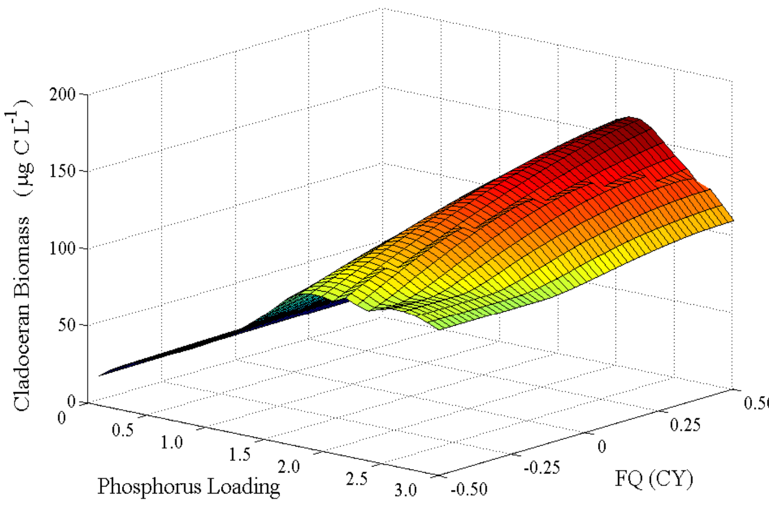
Production of particulate matter with high C:P and N:P
Ingestion
Cladocerans Low N:P
Copepods High N:P
Excretion/egestion of material with strongly increased C:P and N:P
Excretion/egestion of material with moderately increased C:P and N:P
Mineralization Nitrification
Sedimentation
(Hypothesis 1)
(Hypothesis 2)
Increased levels of DON, NO_3 and NH_4
Increased levels of depositing PON → possible effects on the diagenesis processes → alkalinity levels

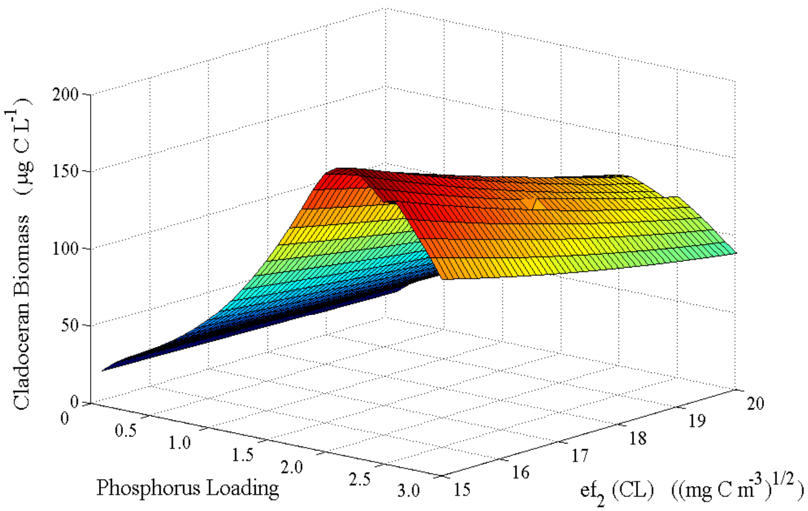
Homeostatic regulation of zooplankton stoichiometries

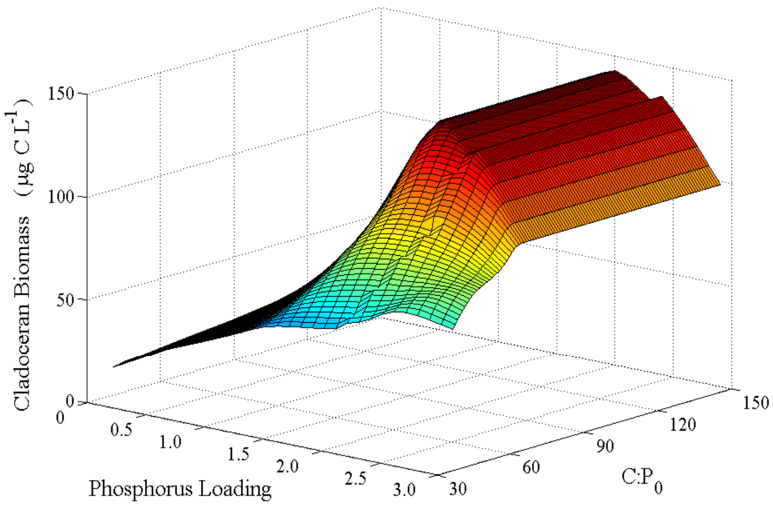
- **Hypothesis 1**: Processing during digestion and assimilation process (removing elements in closer proportion to their body ratio rather than to the element ratio in the food)

- **Hypothesis 2**: Post-assimilation processing and differential excretion of nutrients

The proposed food quality/quantity parameterization gives reasonable results!!







References

• **Zhao, J., M. Ramin, V. Cheng, and G.B. Arhonditsis. Application of mathematical modeling for examining plankton community patterns across a trophic gradient: What is the role of the zooplankton functional groups? *Ecological Research:* Submitted Manuscript**

• **Zhao, J., M. Ramin, V. Cheng, and G.B. Arhonditsis. Competition patterns among phytoplankton functional groups: How useful are the complex biogeochemical models? *Ecological Complexity*: Submitted Manuscript**