Biological Sciences
at the University of Essex

NATURAL
ENVIRONMENT
RESEARCH COUNCIL

Acclimation of pigment content and photosynthesis in microalgae.

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Outline

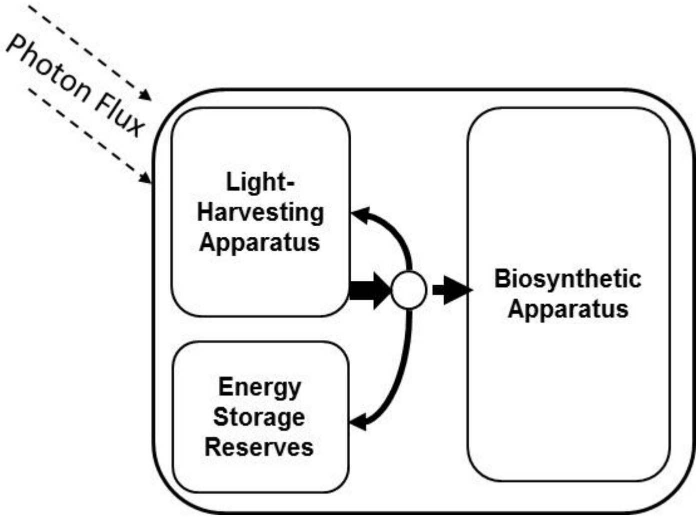
- Simple models of links amongst photosynthesis, respiration, nitrogen assimilation and chlorophyll synthesis.
  - Geider, Kana & MacIntyre (GKM 1998)
  - Ross & Geider (2009)
- Acclimation of photosynthetic rates and photosynthetic proteins to light- and nutrient-limitation in *Emilania huxleyi*
  - McKew *et al.* (2013)
  - McKew *et al.* (2015)
- Conclusions

Alternative hypotheses to explain variability of chlorophyll-to-carbon ratio

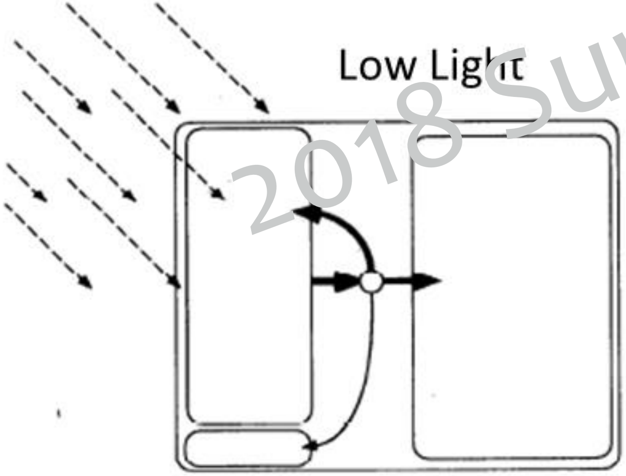
Physiological regulation: Pigment content is regulated by excitation pressure to reduce the susceptibility of cells to photooxidative stress in high light.

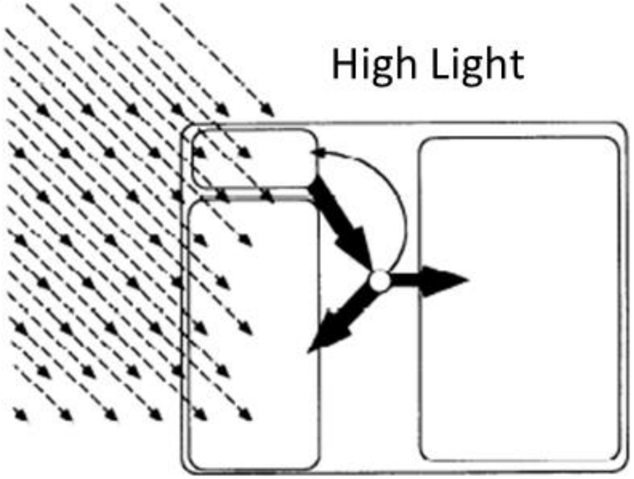
Optimal allocation model: Growth rate is maximized by changing the allocation of biomass between the pigments that absorb light and the catalysts that use light energy for photosynthesis and biosynthesis.

Light Limitation - GKM (1996) model



- Down-regulation of chlorophyll synthesis is determined by excitation pressure.
- Organic carbon not used for synthesis of light harvesting apparatus is stored as an energy reserve.





Geider, Kana, MacIntyre (1996) A dynamic model of photoadaptation in phytoplankton. *Limnology & Oceanography* 41: 1-15

Light- and Nitrogen-limitation - GKM98

Photosynthesis – Respiration

$$\mu = \frac{1}{C}\frac{dC}{dt} = \left(P^C - \zeta \cdot V_N^C - R_0^C\right)$$

Nitrogen Uptake – Remineralisation

$$\frac{1}{C}\frac{dN}{dt} = V_N^C - R_0^N \cdot Q$$

Chlorophyll Synthesis – Degradation

$$\frac{1}{C}\frac{dChl}{dt} = \rho_{Chl} \cdot V_N^C - R_0^{Chl} \cdot \theta^C$$

C = organic carbon

N = organic N

Chl = chlorophyll

θ^C = Chl:C ratio

Q = N:C ratio

P^C = C-specific photosynthesis

V_N^C = C-specific N assimilation

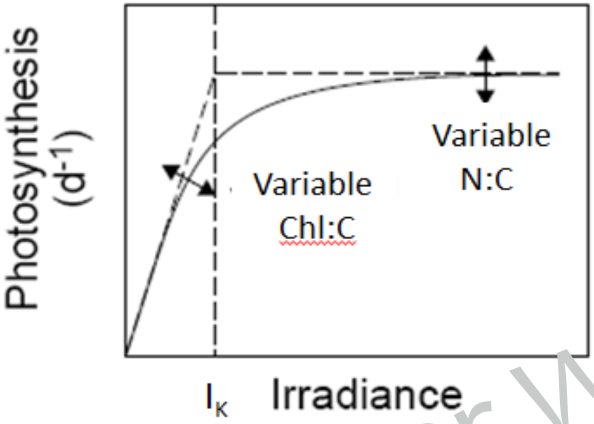
ζ = Cost of biosynthesis

R_0^C, R_0^N, R_0^{Chl} = Maintenance Metabolic Rates

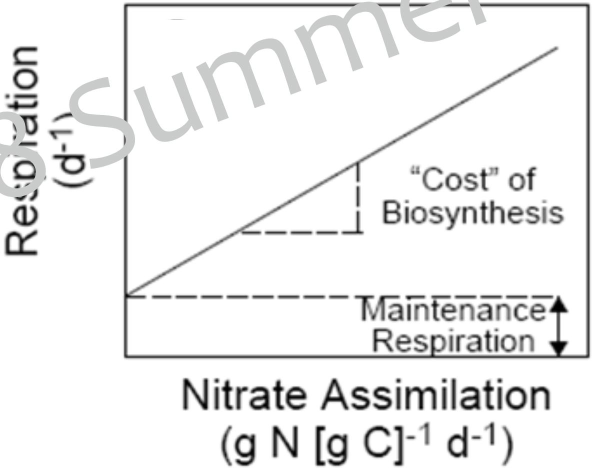
ρ_{Chl} = regulation of chlorophyll synthesis

Geider, Kana, MacIntyre (1998) A dynamic regulatory model of phytoplanktonic acclimation to light, nutrients, and temperature. *Limnology & Oceanography* 43: 679-694

Light- and Nitrogen-limitation - GKM98



$$P_m^C = P_{max}^C \cdot \left(\frac{Q - Q_{min}}{Q_{max} - Q_{min}} \right)$$



$$R^C = R_0^C + \zeta \cdot V_N^C$$

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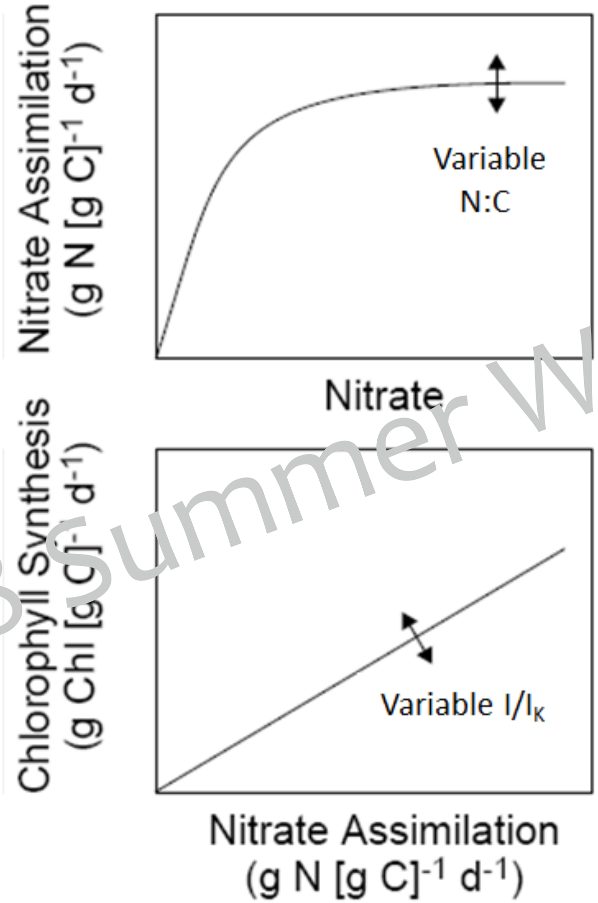
Light- and Nitrogen-limitation - GKM98



$$V_m^N = V_{max}^N \cdot \left(\frac{Q_{max} - Q}{Q_{max} - Q_{min}}\right)^n$$

$$\rho_{Chl} = \theta_{max}^N \cdot \frac{I_k}{I} \cdot \left[1 - exp\left(\frac{I}{I_k}\right)\right]$$

Geider, Kana, MacIntyre (1998) A dynamic regulatory model of phytoplanktonic acclimation to light, nutrients, and temperature. *Limnology & Oceanography* 43: 679-694

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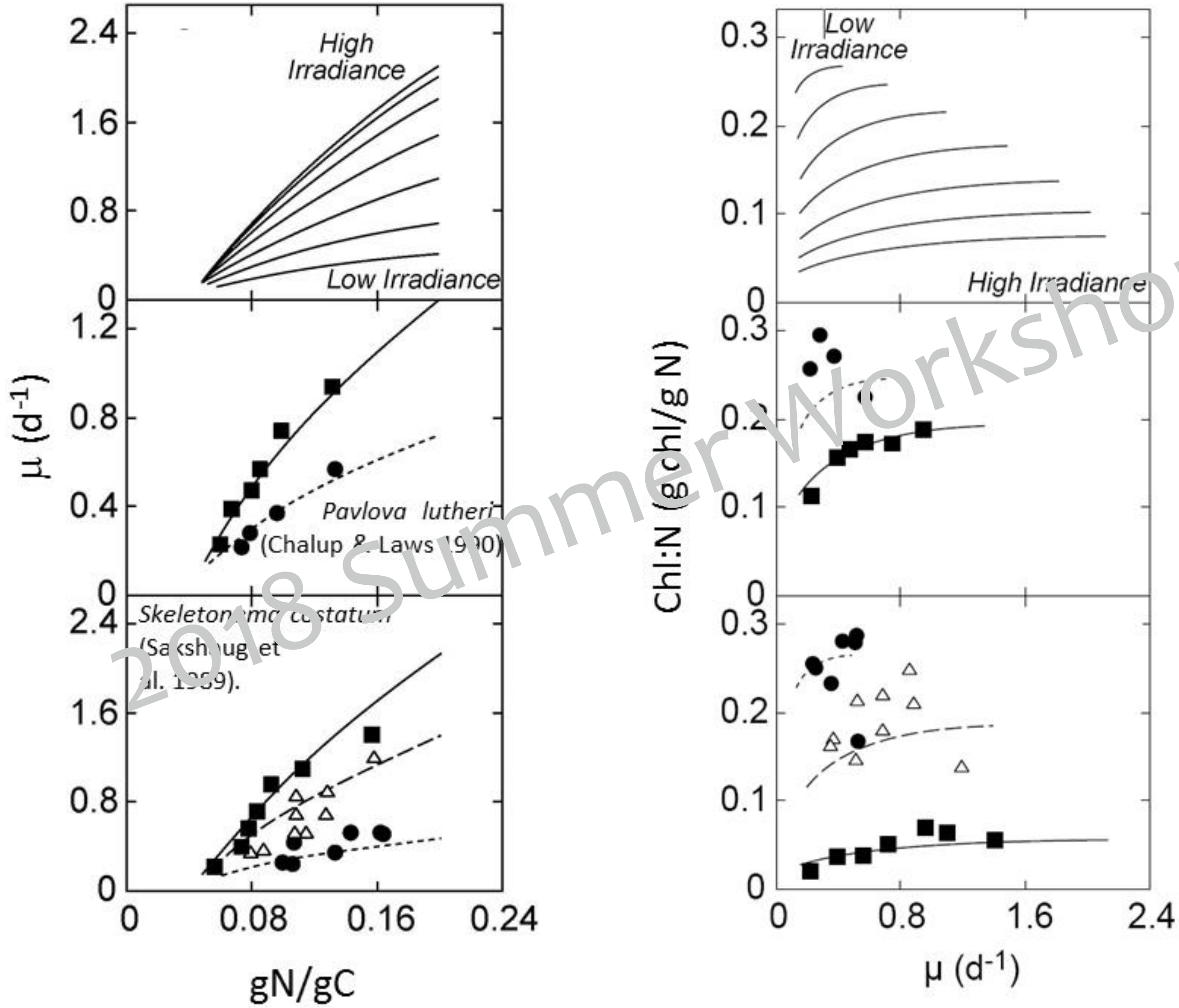

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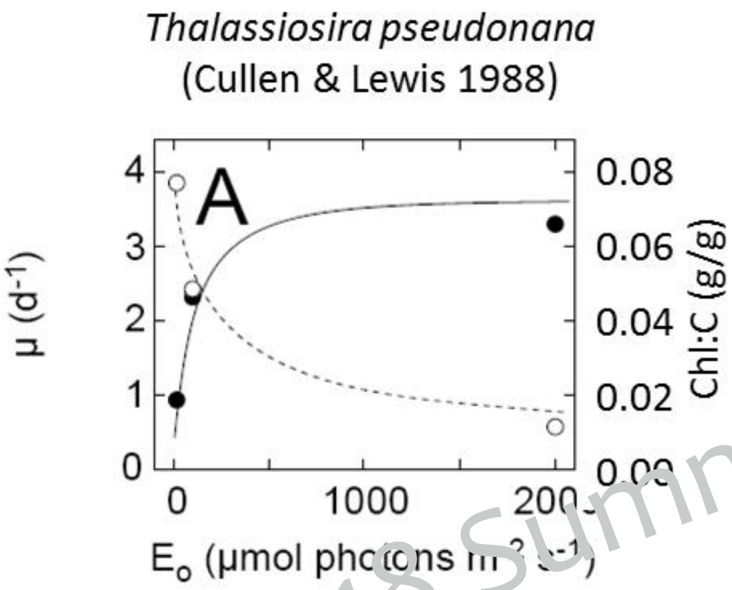
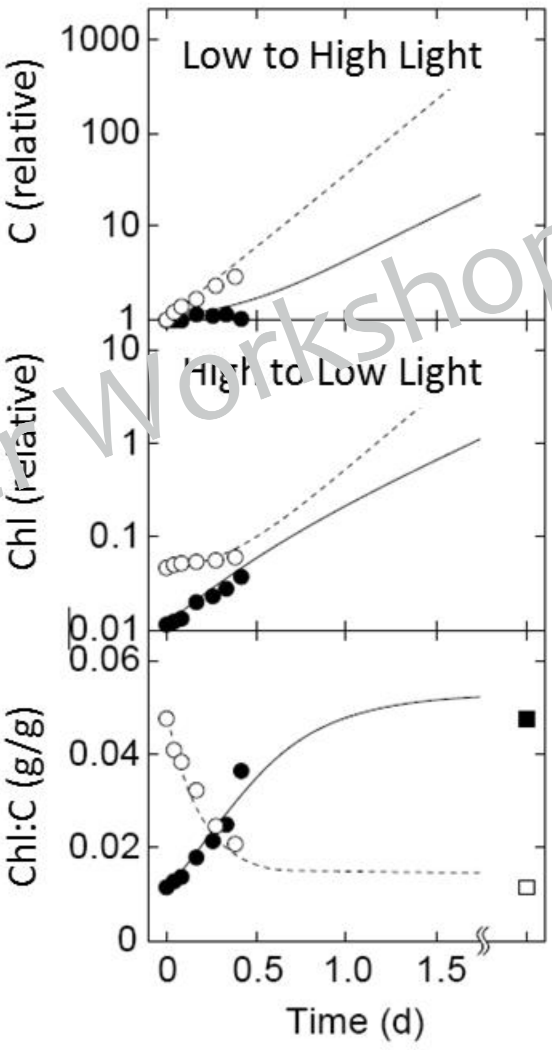
Kinetics of Photoacclimation - GKM98





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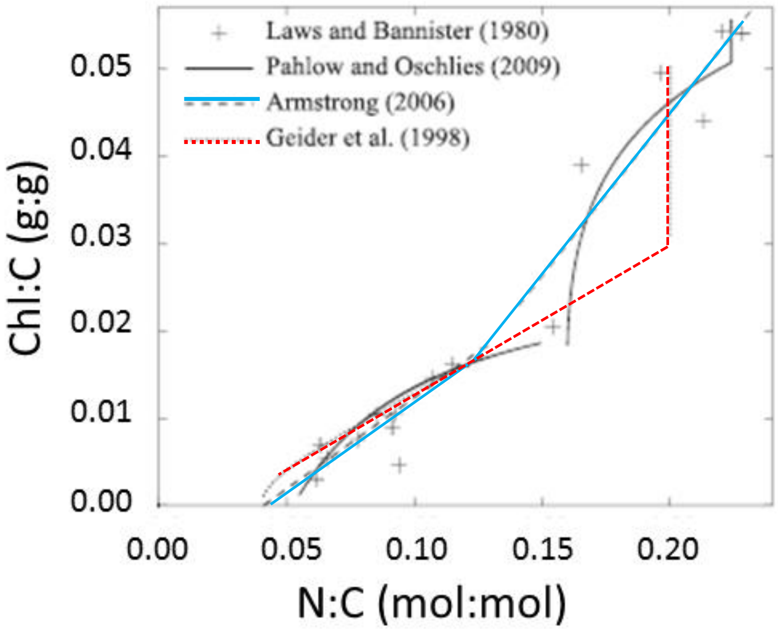
Optimality Models of Photoacclimation as alternatives to GKM98.

optimality models “explain the down-regulation of Chl:C at intermediate to high irradiance levels as a consequence of **a negative relation between the light harvesting and biosynthetic apparatuses**.”

“optimal-growth models can reproduce the relationship between N:C and Chl :C ratios for light limited growth”

whereas “the model of Geider et al. (1998) predicts almost constant N:C” under light limitation



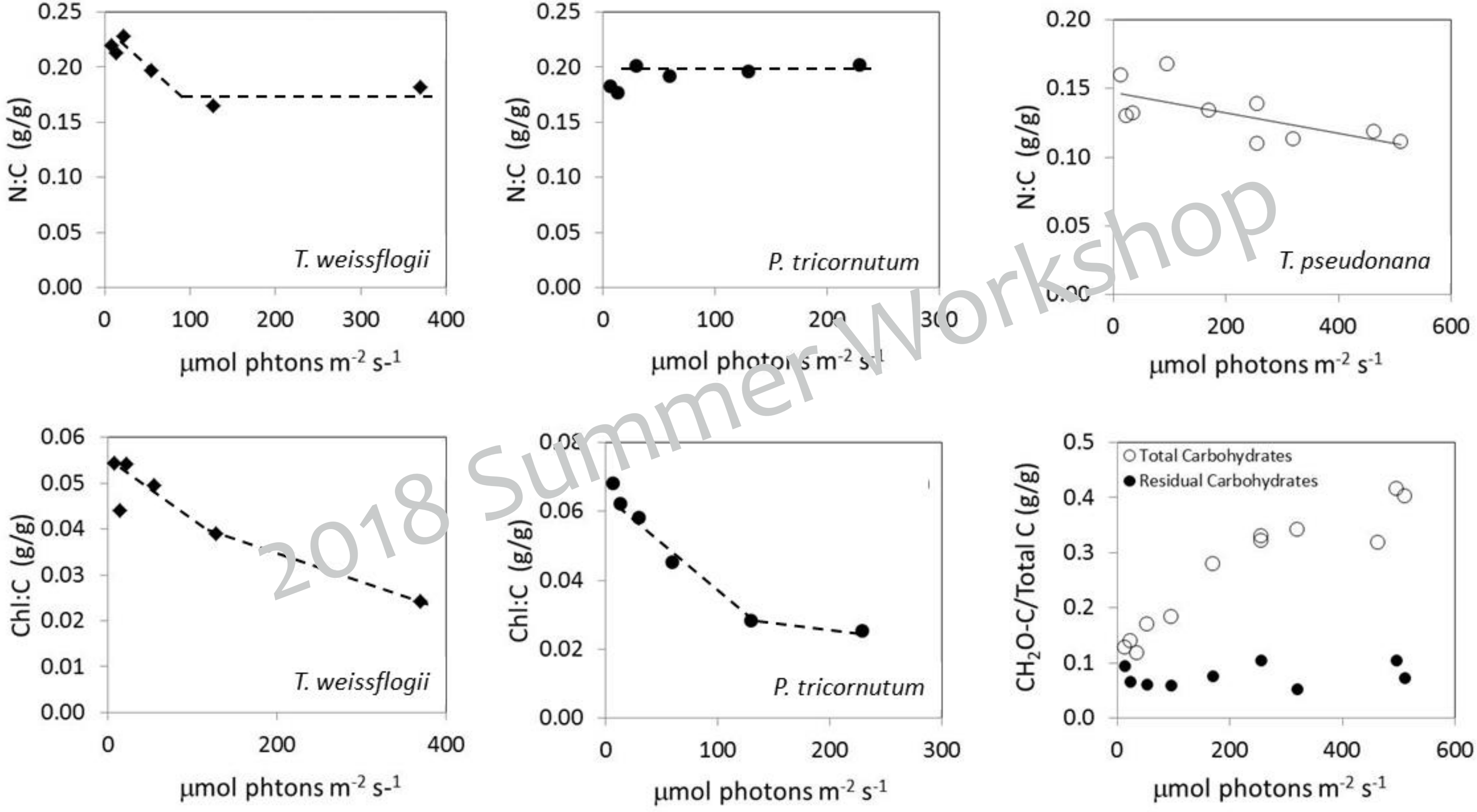
Data from Laws & Bannister (1980). Limnol Oceanogr 25: 457-473.

Pahlow (2005) Mar Ecol Prog Ser 287: 33-43.

Armstrong (2006) Deep-Sea Research II 53: 513-531.

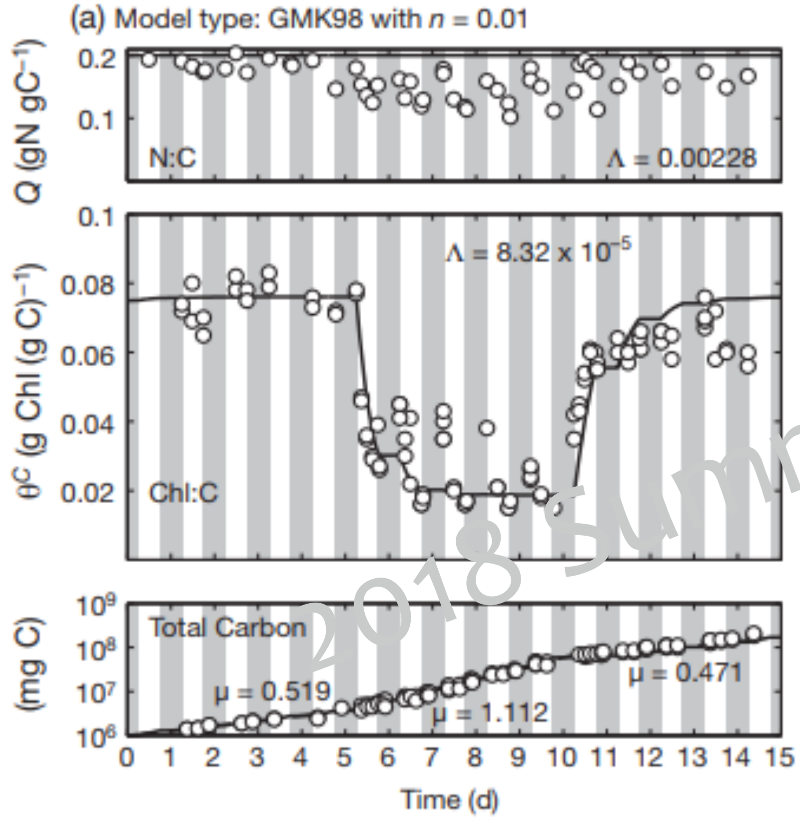
Smith, Pahlow, Merico & Wirtz (2011) Optimality-based modeling of planktonic organisms. *Limnology & Oceanography* 56: 2080-2094

N:C and Chl:C in light-limited, nutrient replete conditions



Laws & Bannister (1980) data for *Thalassiosira weissflogii*
Original data data for *Phaeodactylum tricornutum* & *Thalassiosira pseudonana*

Light-limited Growth on a Light-Dark Cycle
Ross-Geider (2009) Model



Ross & Geider (2009) New cell-based model of photosynthesis and photo-acclimation: accumulation and mobilisation of energy reserves in phytoplankton. *Marine Ecology Progress Series* 383: 53-71
Observations from Anning et al. (2000) Photoacclimation in the marine diatom *Skeletonema costatum*. *Limnology & Oceanography* 45: 1807-1817.

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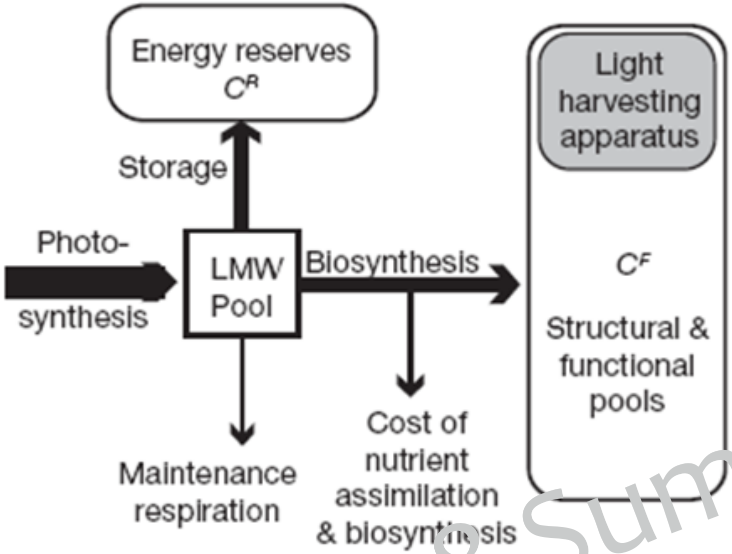

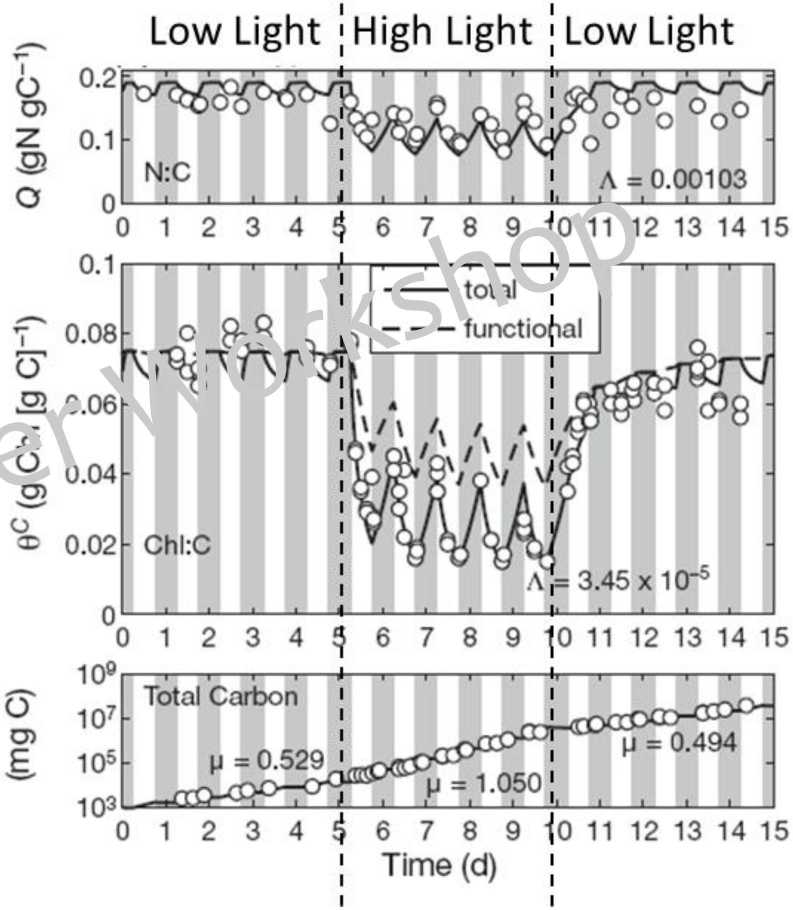

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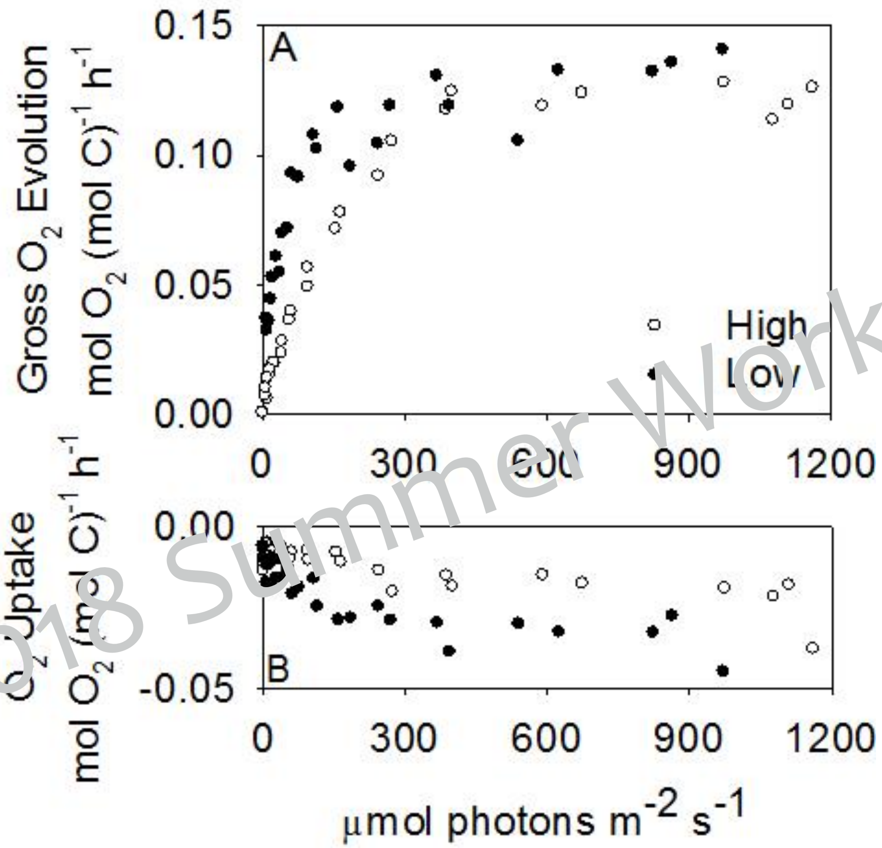
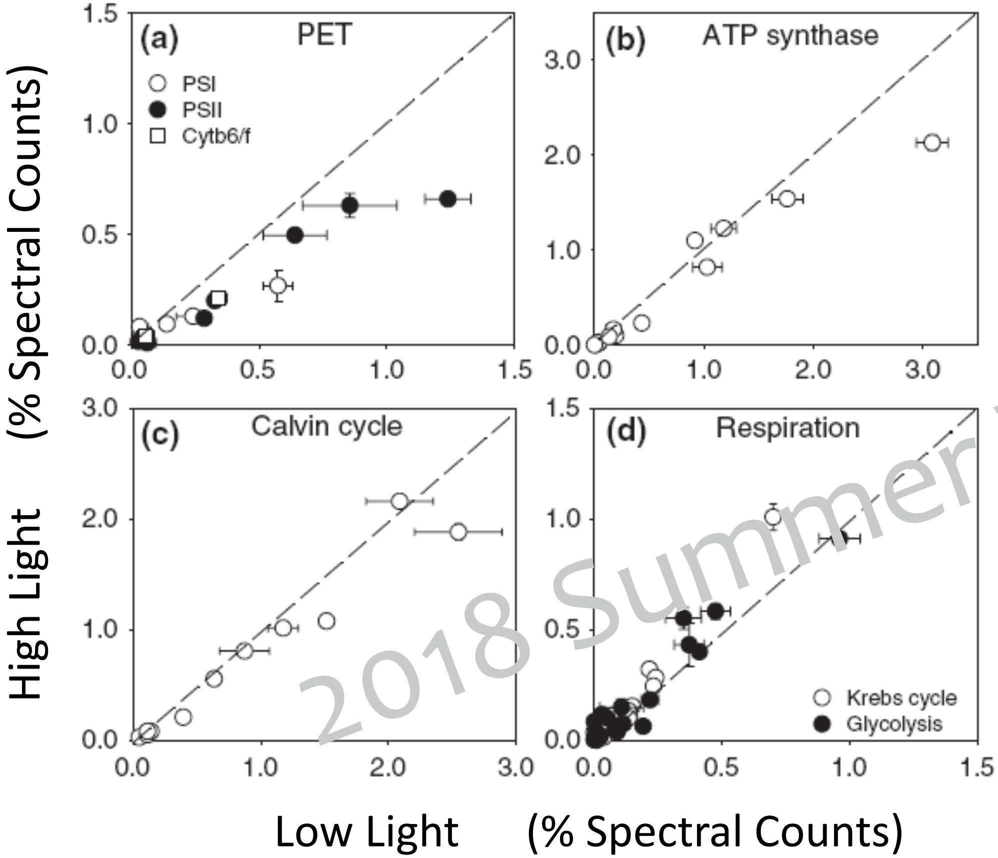
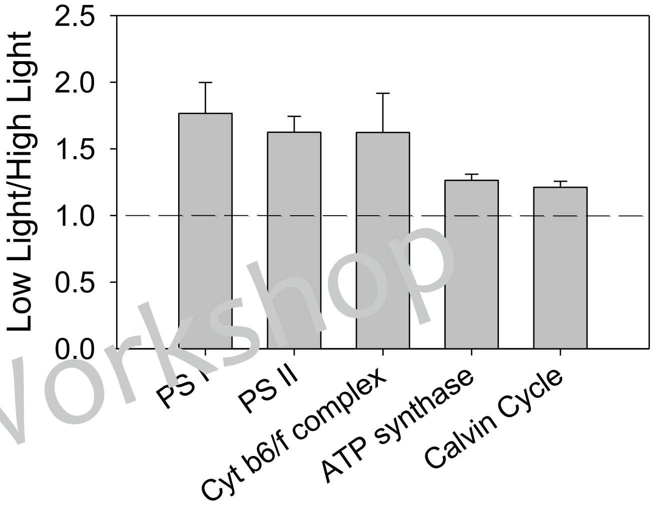
Light Acclimation of *Emiliania huxleyi* Photosynthesis



McKew et al. (2013) The trade-off between the light-harvesting and photoprotective functions of fucoxanthin-chlorophyll proteins dominates light acclimation in *Emiliania huxleyi* (clone CCMP 1516). *New Phytologist* 200: 74-85. doi: 10.1111/nph.12373

Light Acclimation of *Emiliania huxleyi* Proteome





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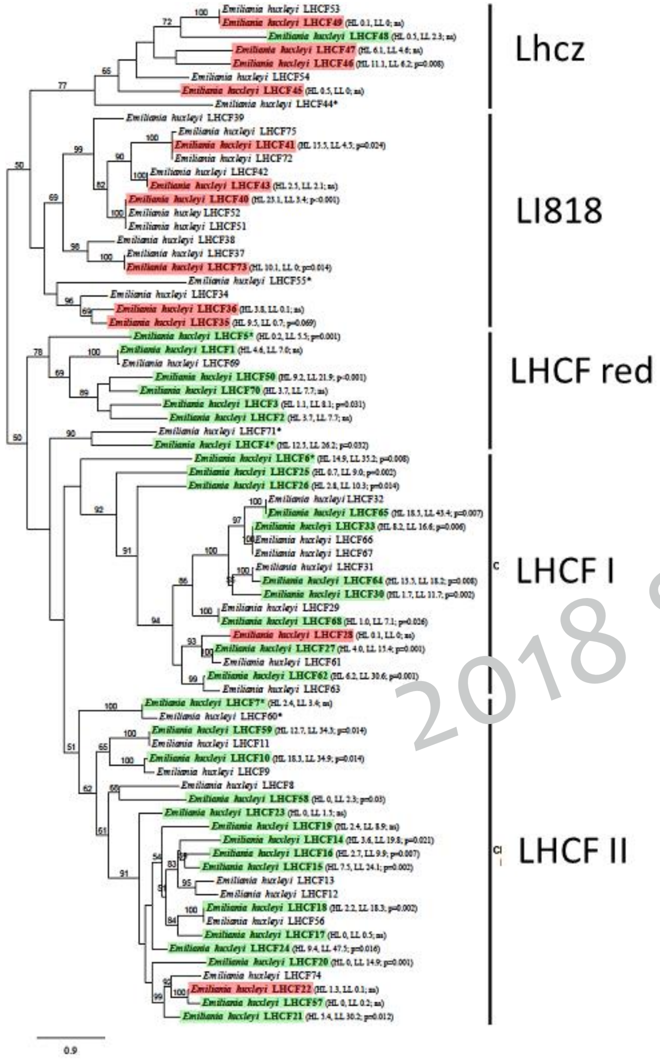

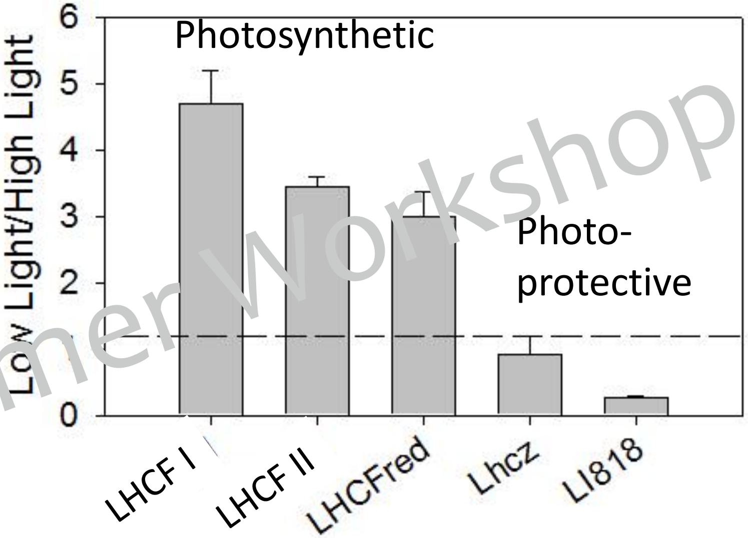

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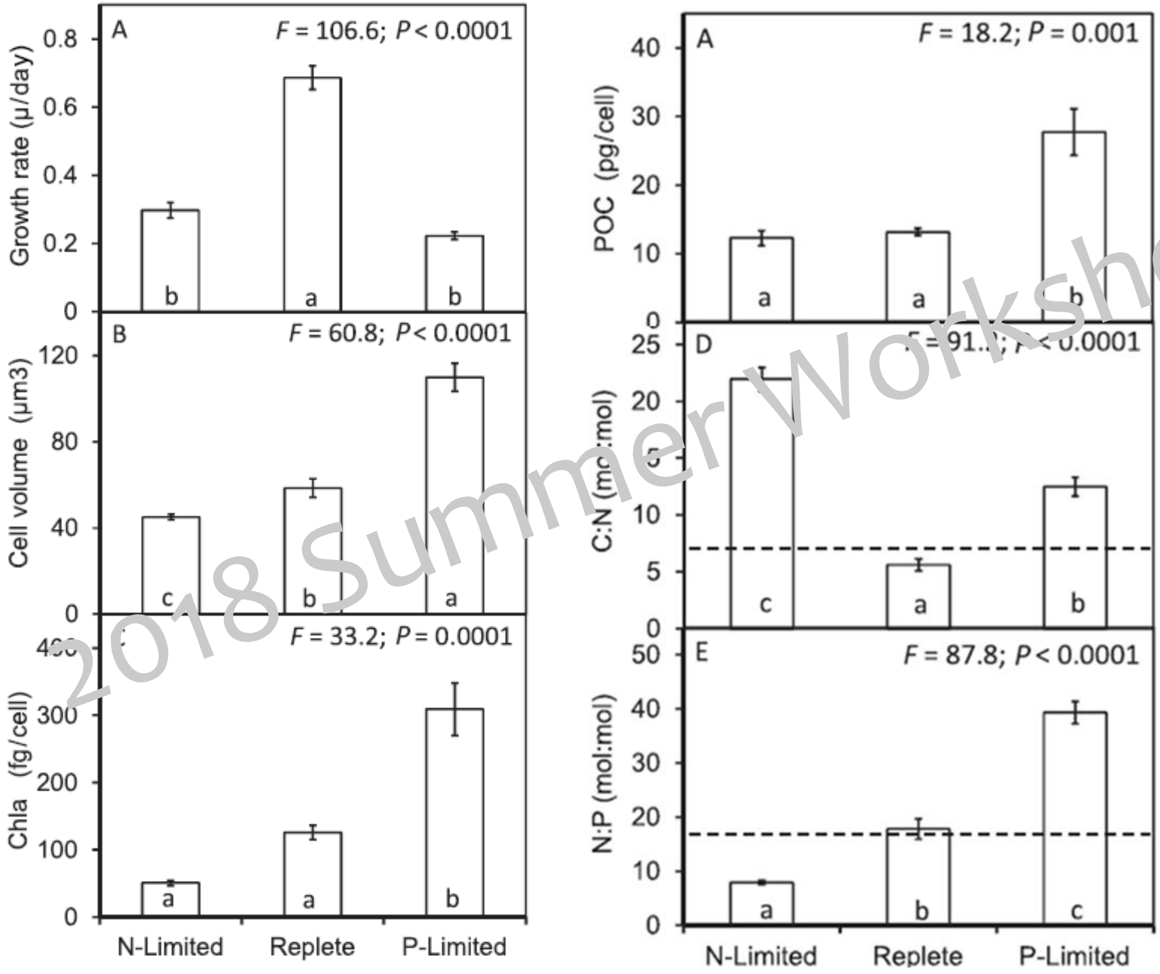
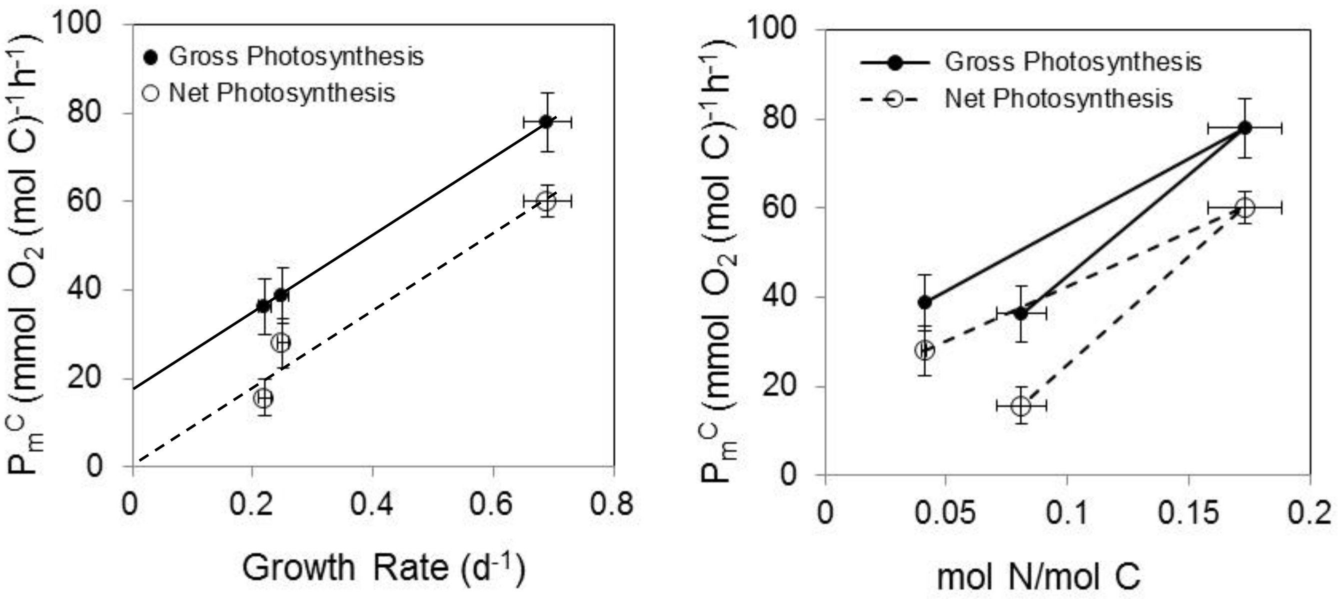
P-limitation and N-limitation in *Emilania huxleyi*



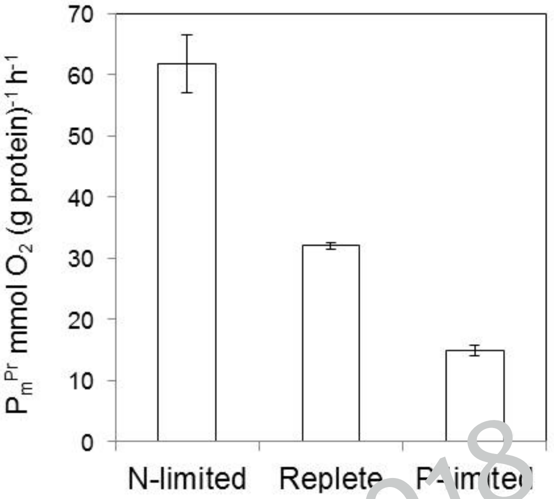
McKew et al. (2015) Acclimation of *Emiliania huxleyi* (1516) to nutrient limitation involves precise modification of the proteome to scavenge alternative sources of N and P. *Environmental Microbiology* 17: 4050-4062.

P-limitation and N-limitation of photosynthesis in *Emilania huxleyi*

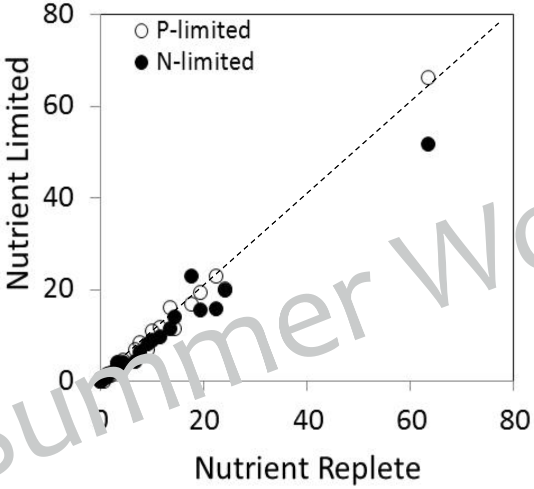


Original unpublished data of McKew et al.

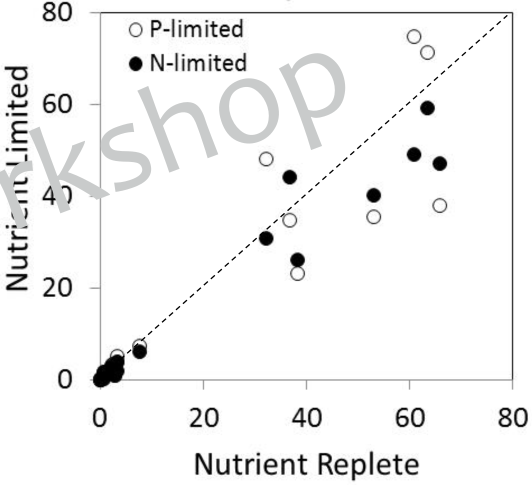
P-limitation and N-limitation of photosynthesis in *Emilania huxleyi*



Light saturated gross photosynthesis per unit cell protein



Spectral Counts of Photosynthetic Electron Transfer Proteins



Spectral counts of Calvin Cycle Enzymes

Original unpublished data of McKew et al.

Conclusions

- Down-regulation of pigment synthesis can be parameterised using an index of excitation pressure.
- Catalytic rates of enzymes are regulated by cellular nutrient and light status.
- This regulation is likely to be as important in controlling how phytoplankton use light and nutrients as is allocation of resources (C, N, P) amongst these catalysts.
- Energy (organic carbon) and nutrient storage pools, which allow episodic variability of resources (light, N, P, Fe) to be exploited, contribute to variability in phytoplankton elemental stoichiometry.

Design considerations for the photosynthetic apparatus.

- Capital costs (e.g., C, N) of synthesizing the structural and functional components of the cell.
- Energetic and catalytic efficiencies of CO_2 fixation, nutrient acquisition and biosynthesis.
- Running costs associated with cell maintenance.
- Costs of preventing, repairing, or failing to repair photooxidative damage.
- Opportunity costs associated with exploiting (or failing to exploit) variability in the environment.