Acclimation of pigment content to light and nutrient limitation.

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http://mtlab.biol.tsukuba.ac.jp/WWW/PDB/Images/
Heterokontophyta/Centrales/Cyclotella/Cyclotella.jpg

Pigment content is high when cells grow under low light.

Pigment content declines
- as light increases
- at low temperature
- under nutrient limitation.

Pigment:biomass is highly variable.

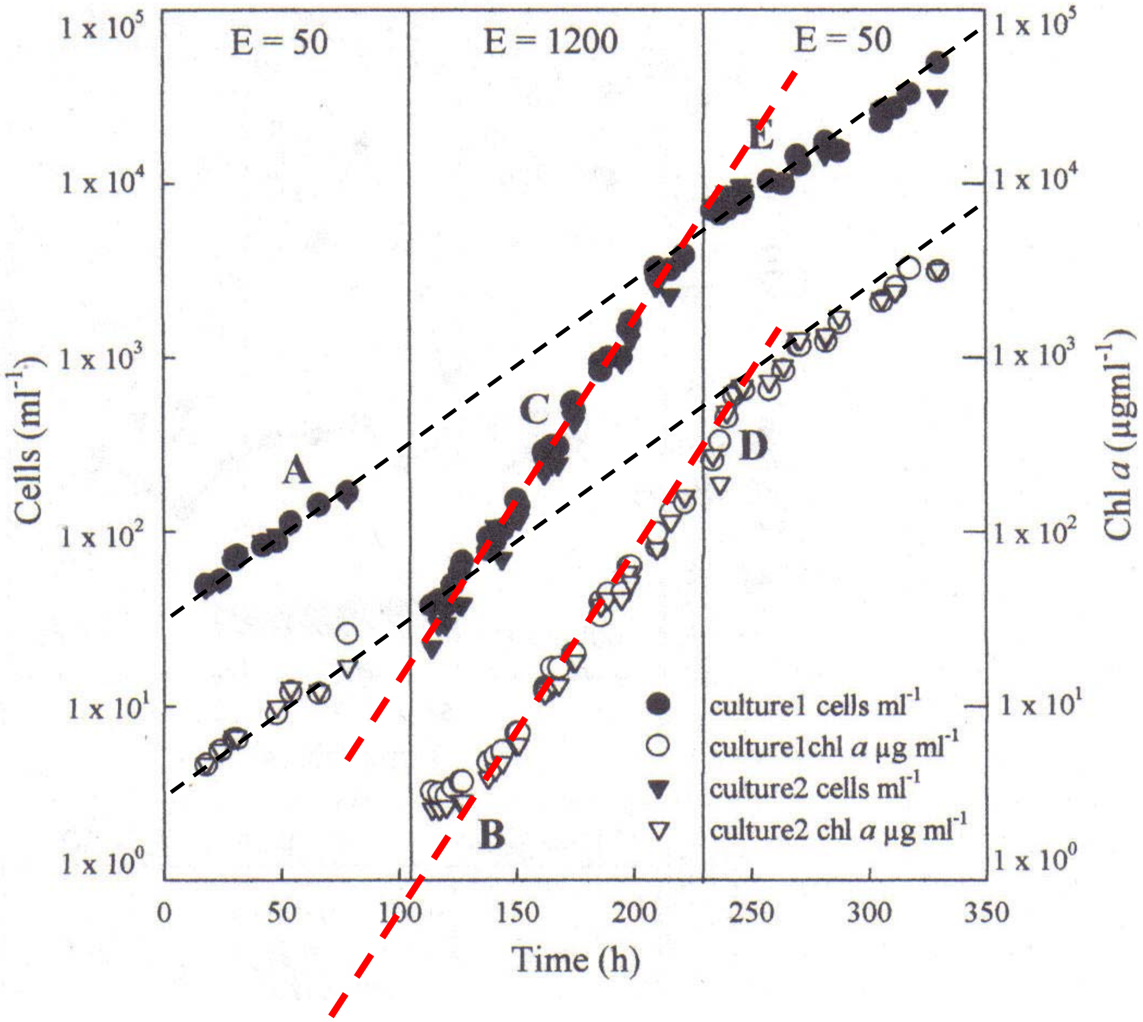
0.005 to 0.1g chl $(\text{g C})^{-1}$

10 to 200 g C $(\text{g chl})^{-1}$

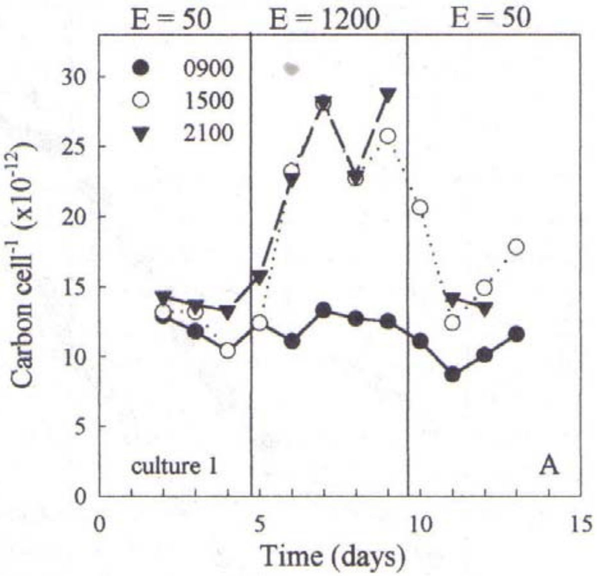
Outline

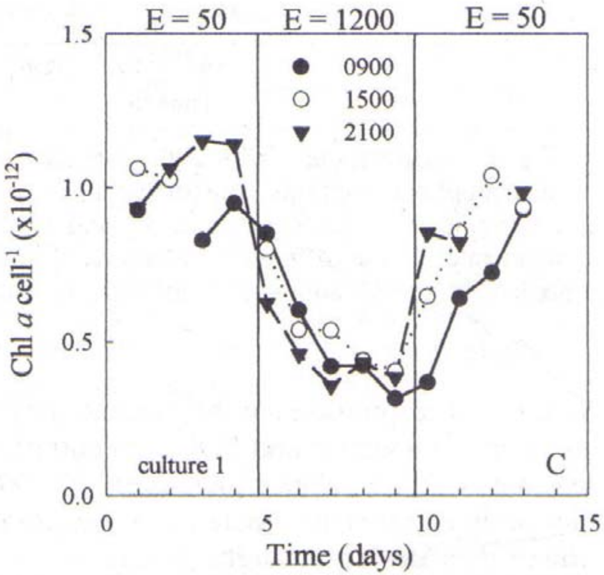
- Photoacclimation kinetics (Geider,Platt 1986)
- Pigment acclimation in *E huxleyi* (Harris, Scanlan, Geider)
- Pigment acclimation to light and nutrient limitation (Geider, MacIntyre, Kana 1996, 1997,1998)
- Pigment acclimation at BATS (Lefevre et al. 2002)

Skeletonema costatum

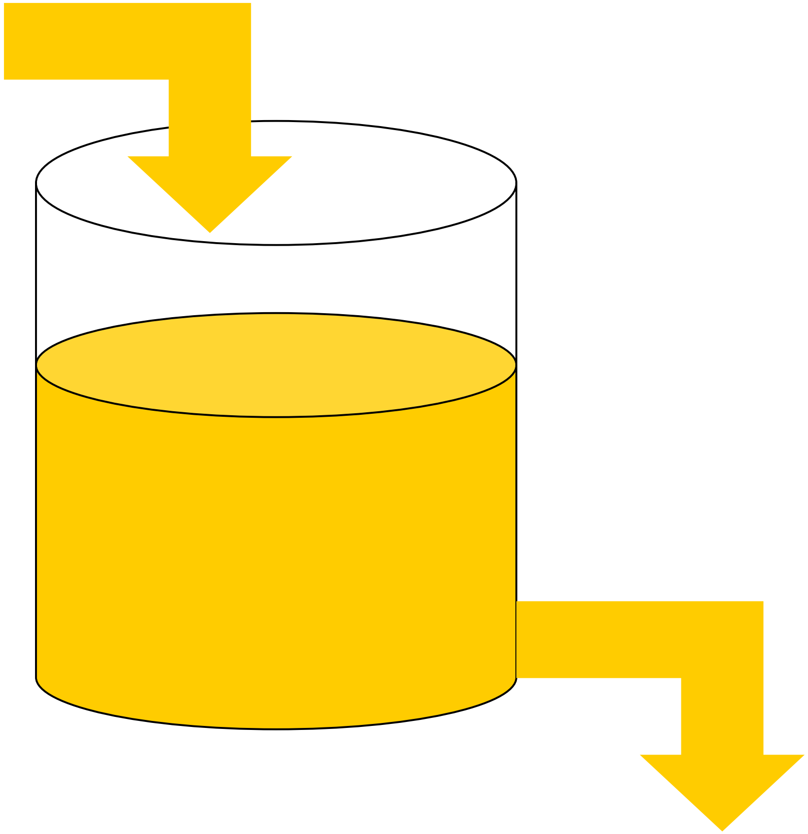


Anning et al. (2000) Limnol. Oceanogr. 45: 1807-1817





Anning et al. (2000) Limnol. Oceanogr. 45: 1807-1817



Photosynthesis (P)
adds organic
carbon.

Respiration (r)
removes organic
carbon.

Photosynthesis = Respiration

$$\frac{dC}{dt} = photosynthesis - respiration$$

$$\frac{dC}{dt} = P \cdot C - r \cdot C$$

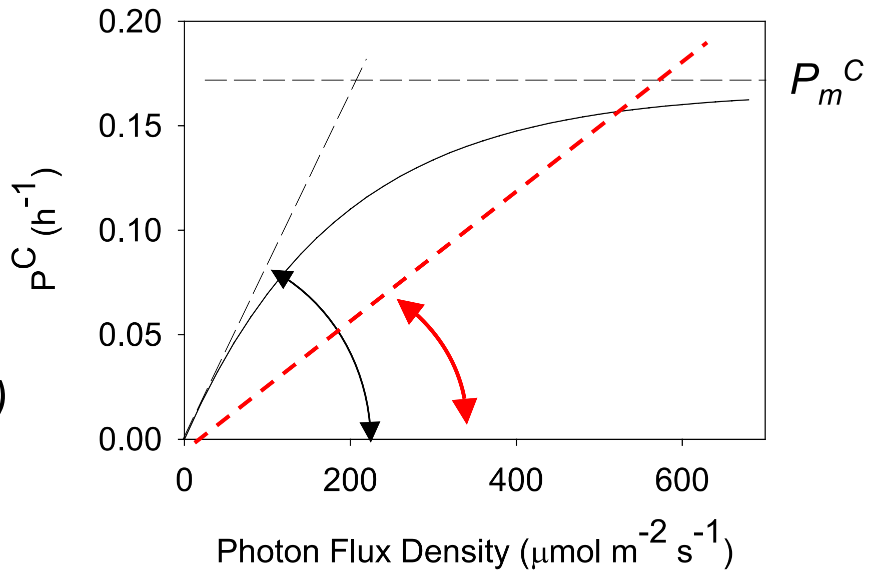
where P = *photosynthesis rate constant* (h^{-1})
r = *respiration rate constant* (h^{-1})

For light-limited photosynthesis

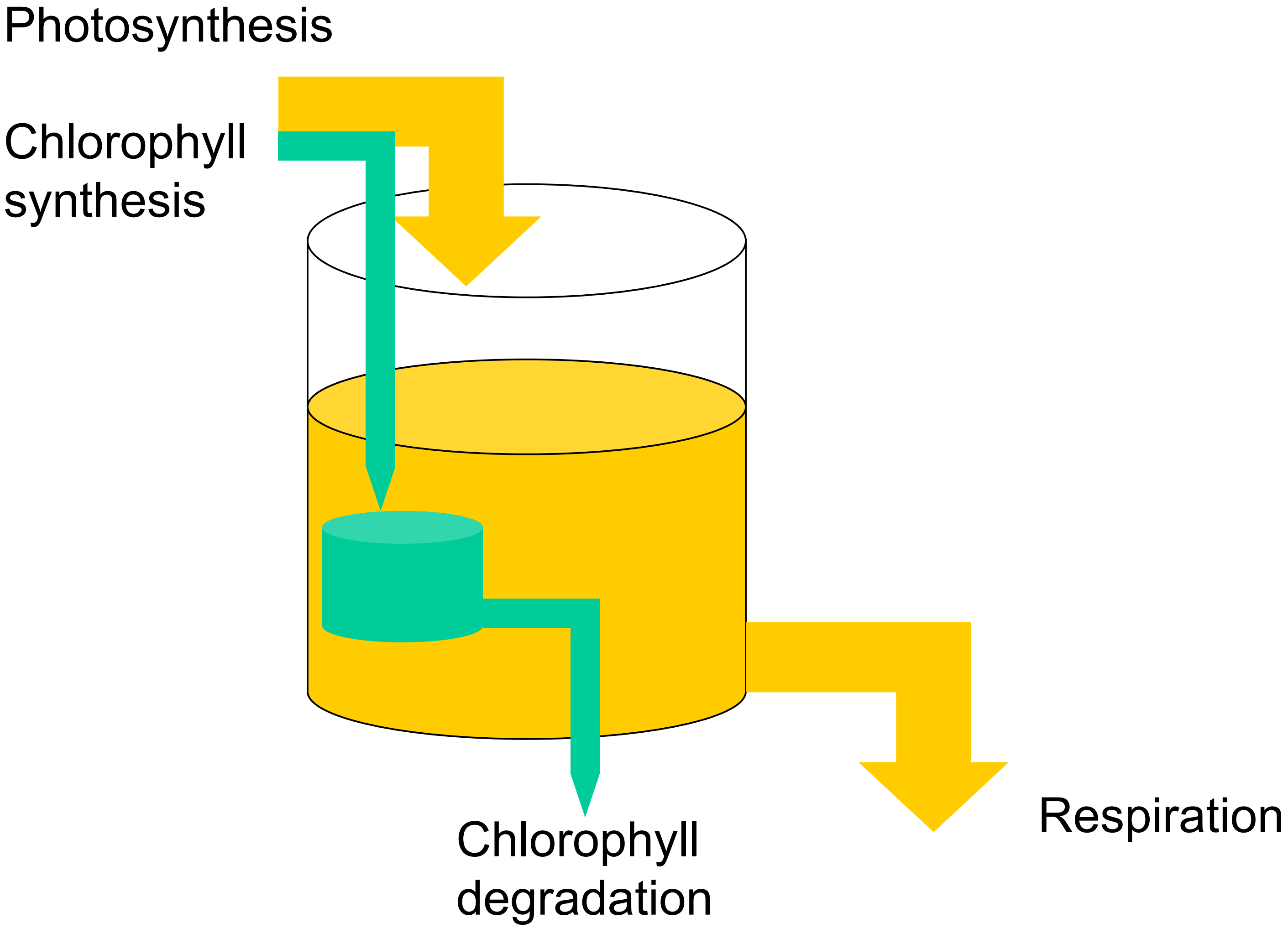
$$P = \alpha^{Chl} \cdot \frac{Chl}{C} \cdot E$$

For light-saturated photosynthesis

$$P = P_m^C$$

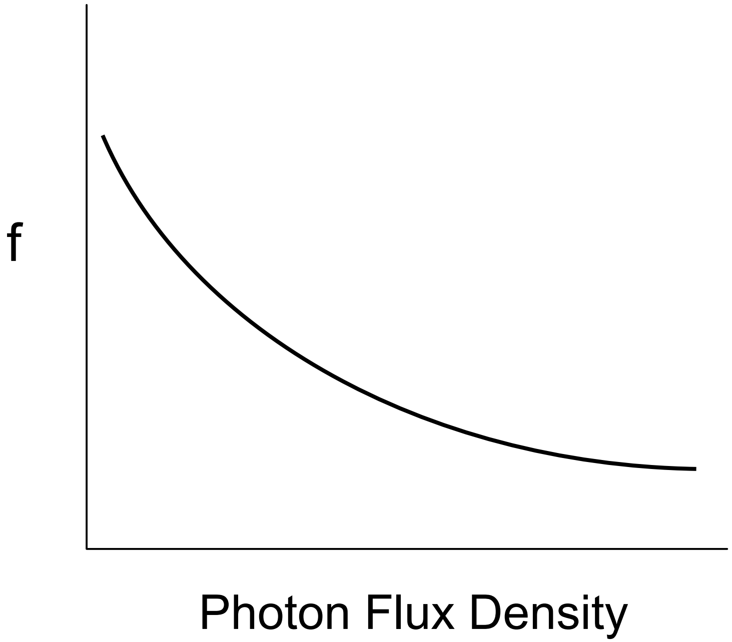


Geider & Platt (1986) MEPS 30: 85-92


Photosynthesis
Chlorophyll synthesis
Chlorophyll degradation
Respiration

$$\frac{dChl}{dt} = f \cdot P \cdot C - r \cdot Chl$$

where f = ratio of chlorophyll synthesis to carbon fixation



Geider & Platt (1986) MEPS 30: 85-92

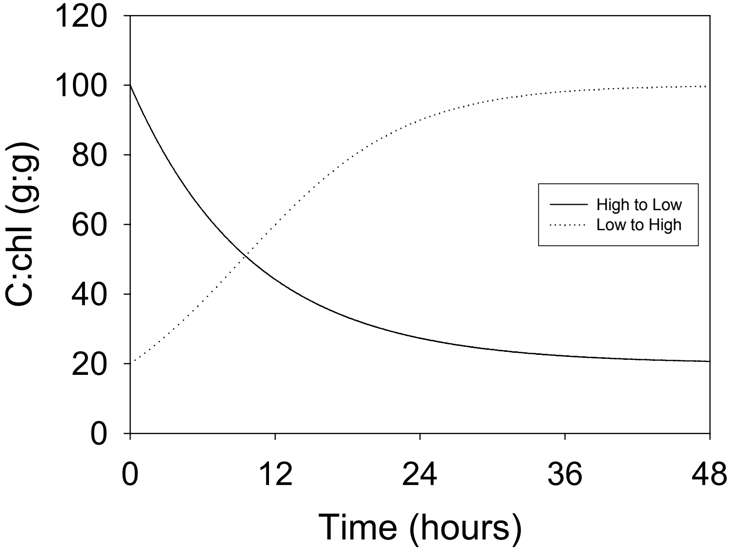
$$\frac{dC}{dt} = P \cdot C - r \cdot C$$

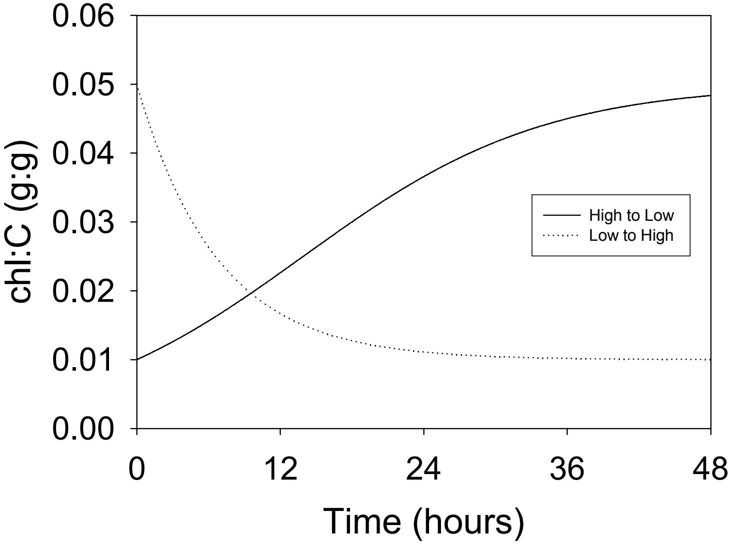
$$\frac{dChl}{dt} = f \cdot P \cdot C - r \cdot Chl$$

where f = ratio of chlorophyll synthesis to carbon fixation

Further assumptions:

- *chlorophyll synthesis depends on recently fixed carbon*
- *f changes instantaneously when E changes*
- *r has the same value for carbon and chlorophyll*





Geider & Platt (1986) MEPS 30: 85-92

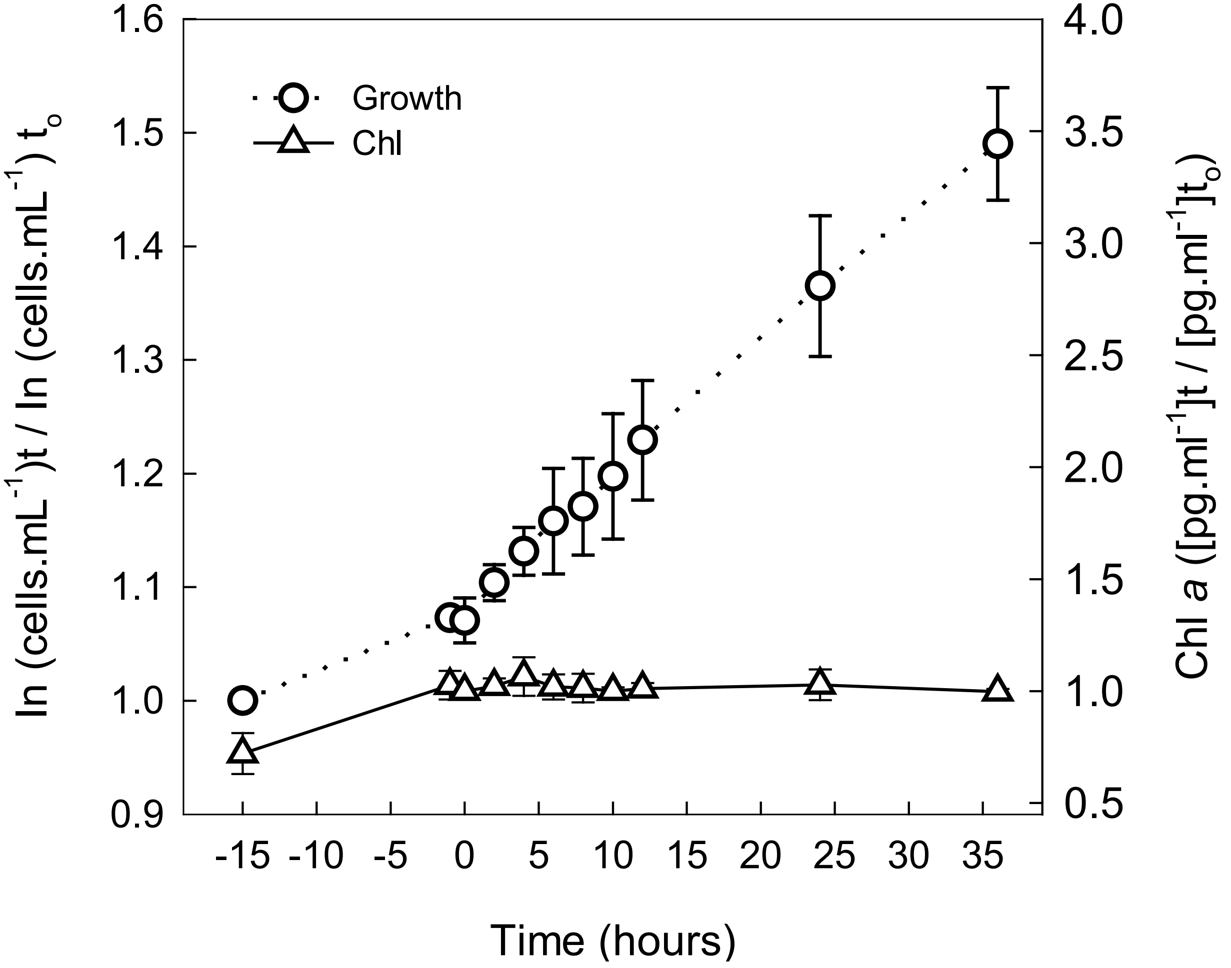
Cannot assume that photoacclimation follows first order kinetics,

or any other specific rate law.

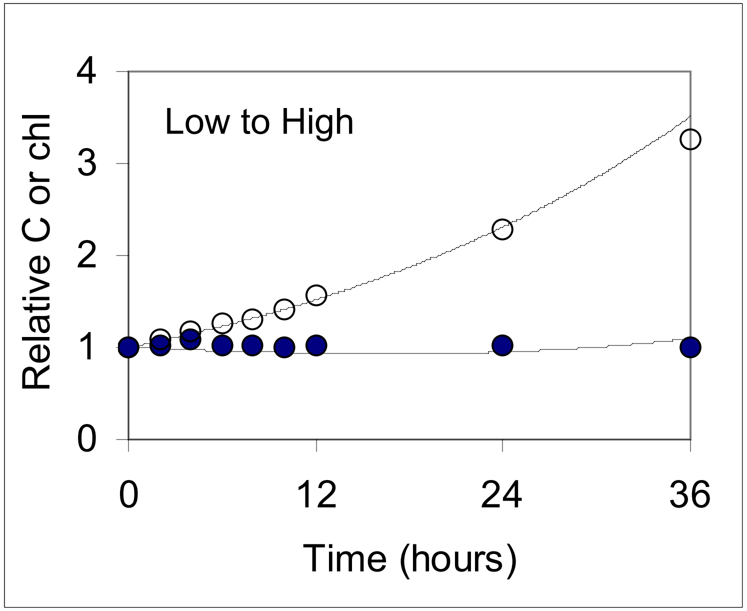
Model the underlying processes and the kinetics arise as a consequence of the model not as an assumption or constraint on the model.

Geider & Platt (1986) MEPS 30: 85-92

E huxleyi - continuous light - 50 to 800 μmol m^{-2} s^{-1}



Gayle Harris (unpublished)



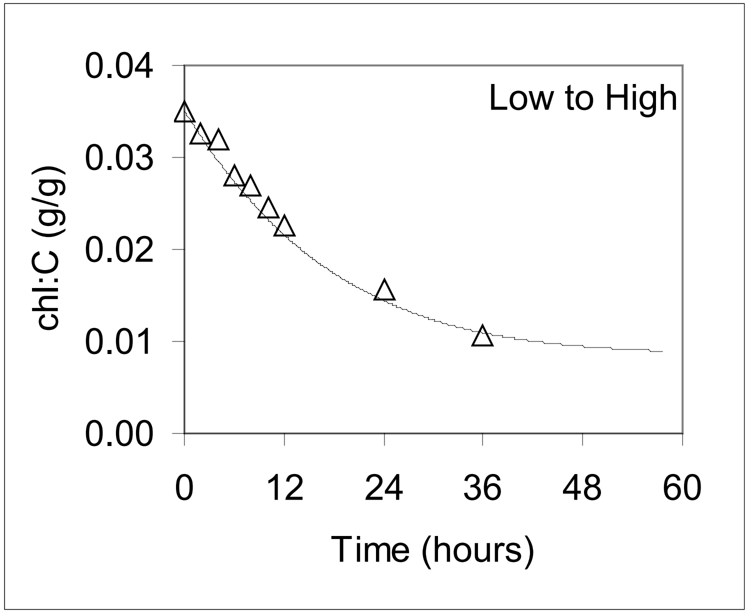
Emiliania huxleyi (5 pg C cell^{-1})

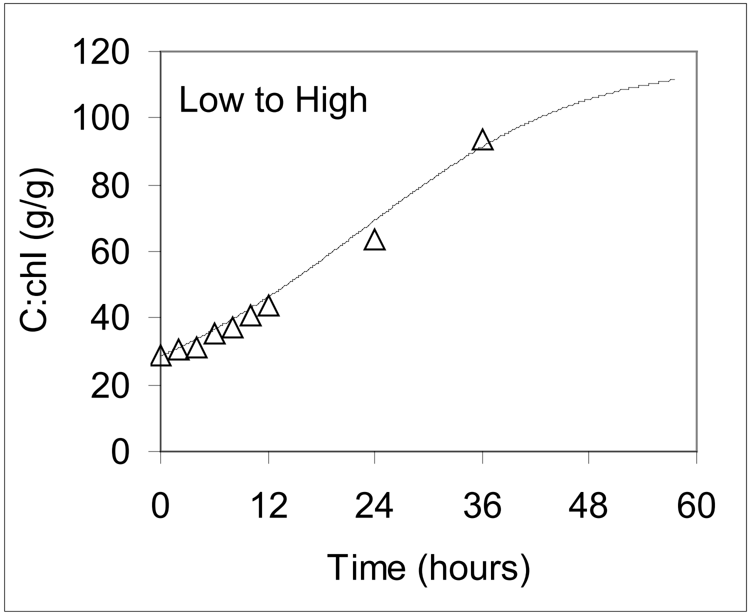
$P_m^C = 0.045\ h^{-1}$

$\alpha^{chl} = 10^{-5}$ g C m^{-2} μmol photons (g chl a)$^{-1}$

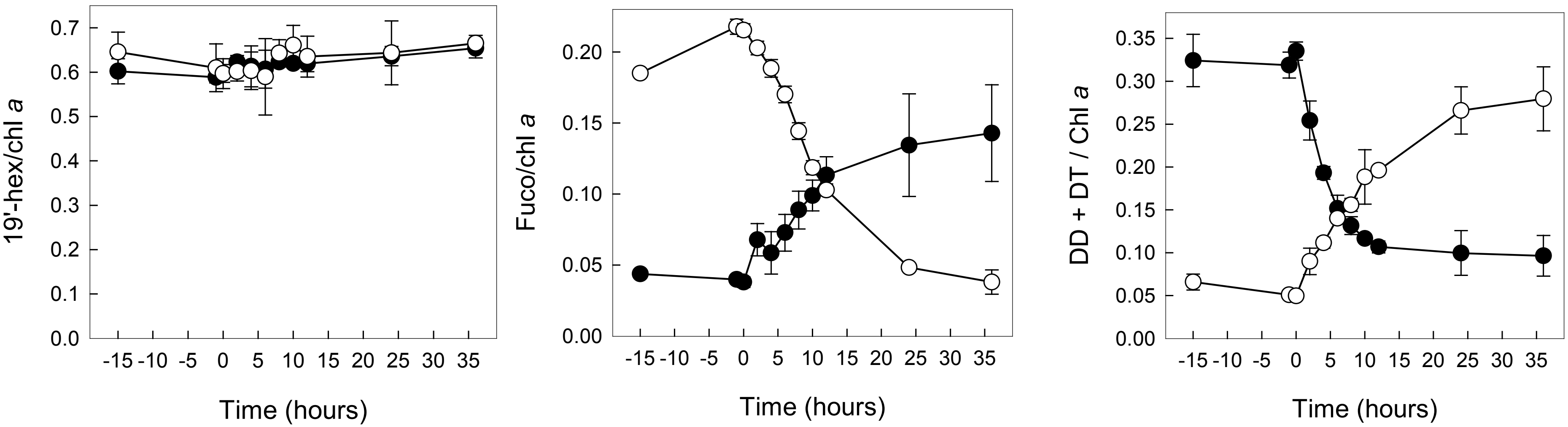
$Chl{:}C_{max} = 0.055$ g g^{-1}

$r = 0.01\ h^{-1}$





E huxleyi - reciprocal shifts
accessory pigments:chlorophyll *a*



Dynamic Regulatory Model

- phytoplankton are at the heart of models of upper ocean biogeochemistry
- currency of these models is nitrogen
- model performance is evaluated using observed chlorophyll *a*
- these models are used to evaluate role of ocean biota in the carbon cycle

Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694

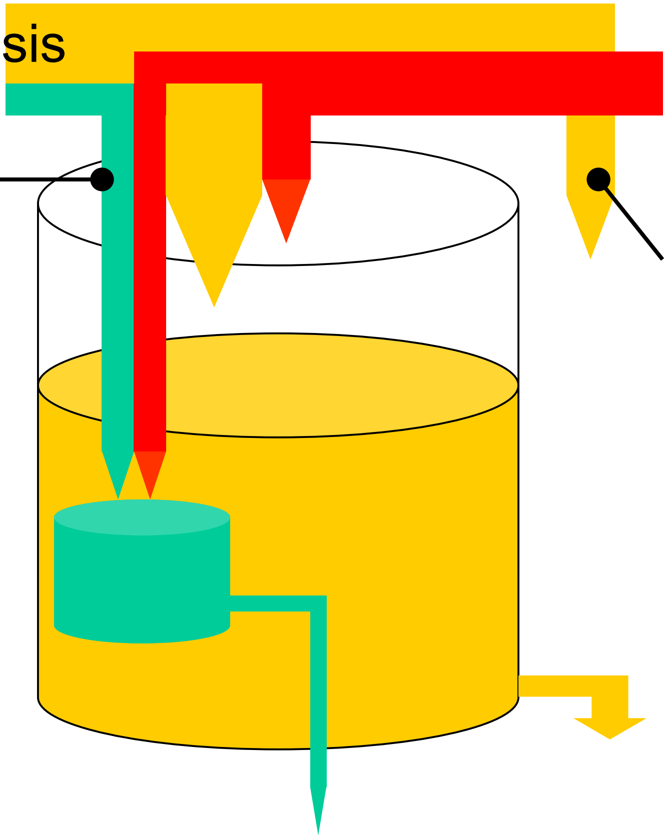
Objective

- Develop a model of phytoplankton growth that explicitly considers N, C and chlorophyll dynamics.

- Formulate the model in terms of processes that
  - can be measured and
  - are important to oceanographers

- These processes include
  - photosynthetic carbon fixation
  - inorganic nitrogen assimilation
  - respiration
  - chlorophyll *a* synthesis

Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694



Photosynthesis

Nitrogen assimilation

Chlorophyll synthesis

“Growth” Respiration

Maintenance Respiration

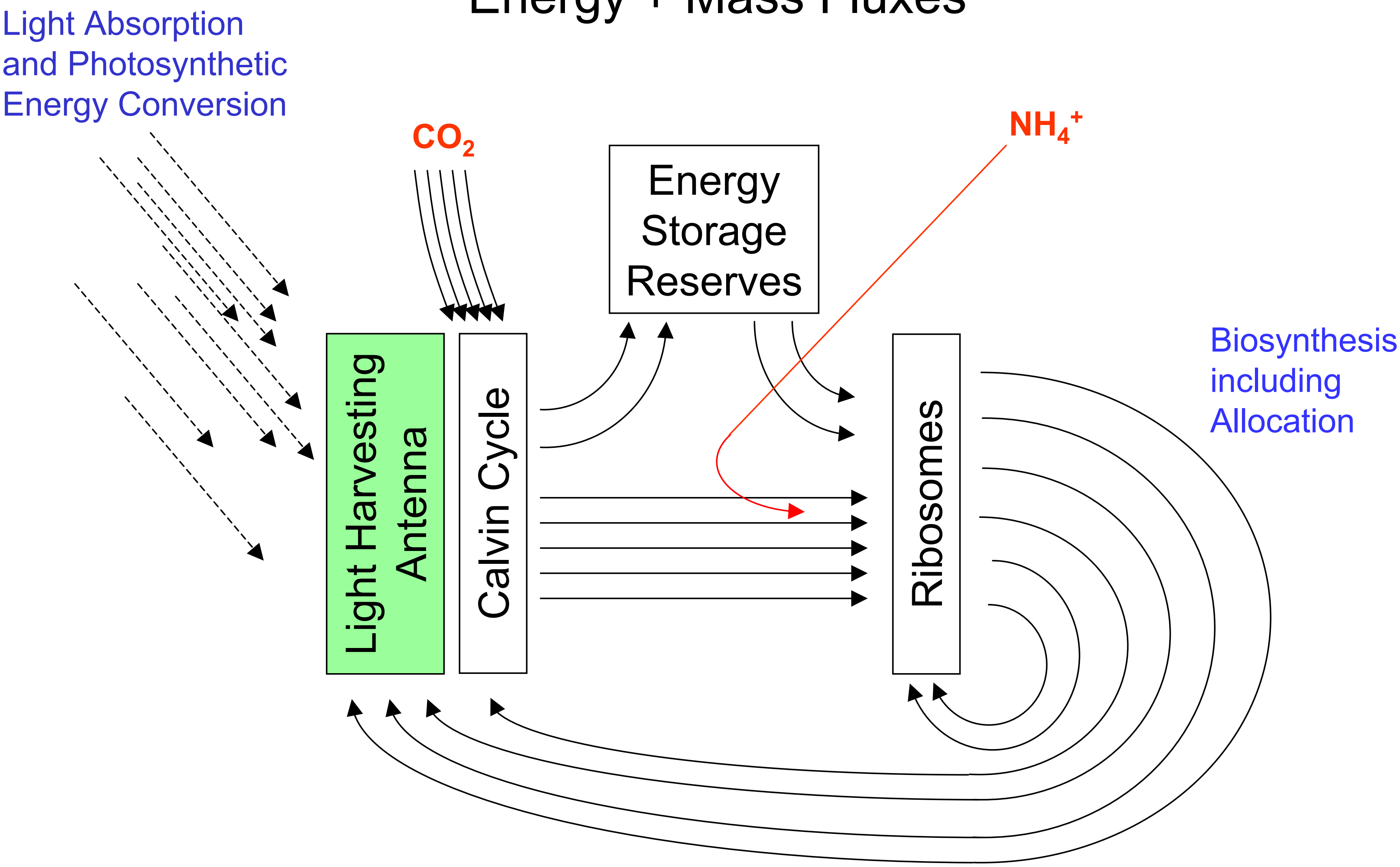
Chlorophyll degradation

Model Components

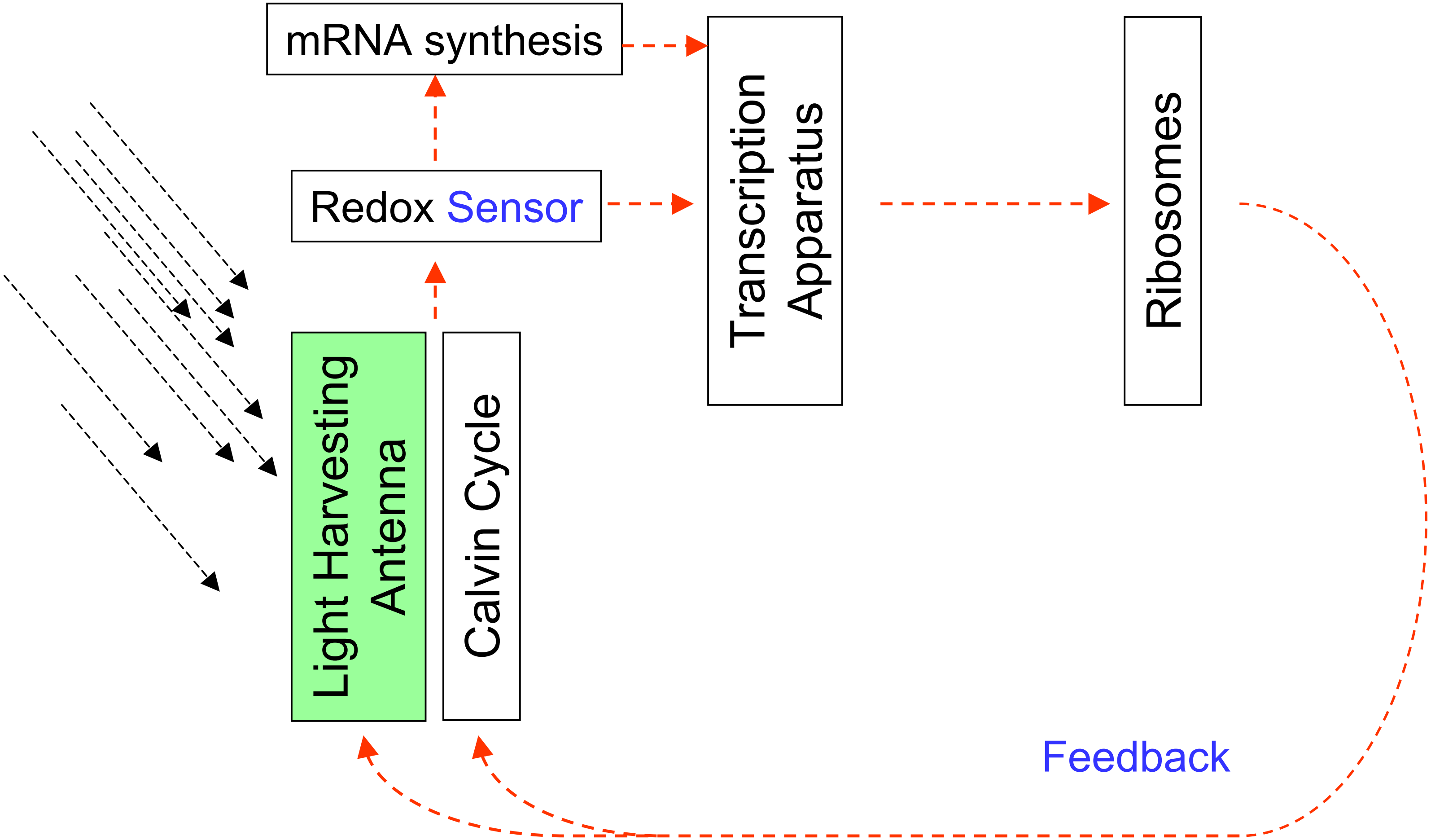
- Energy budget.
- Mass (C, N and chlorophyll) budgets.
- Information (signal) transduction.

Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694

Energy + Mass Fluxes

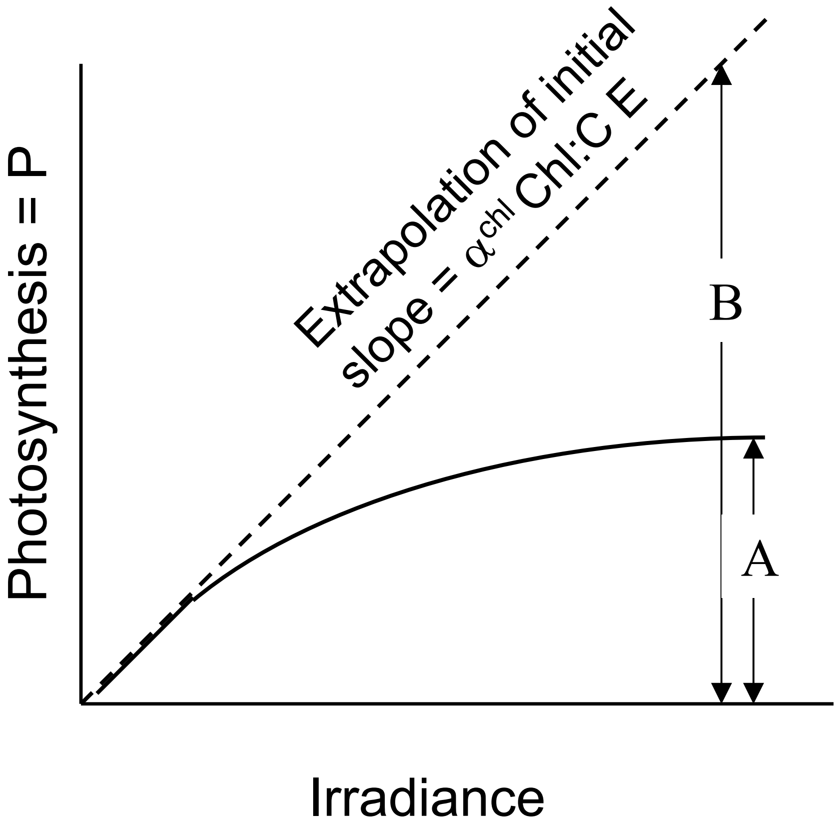


Information Flow



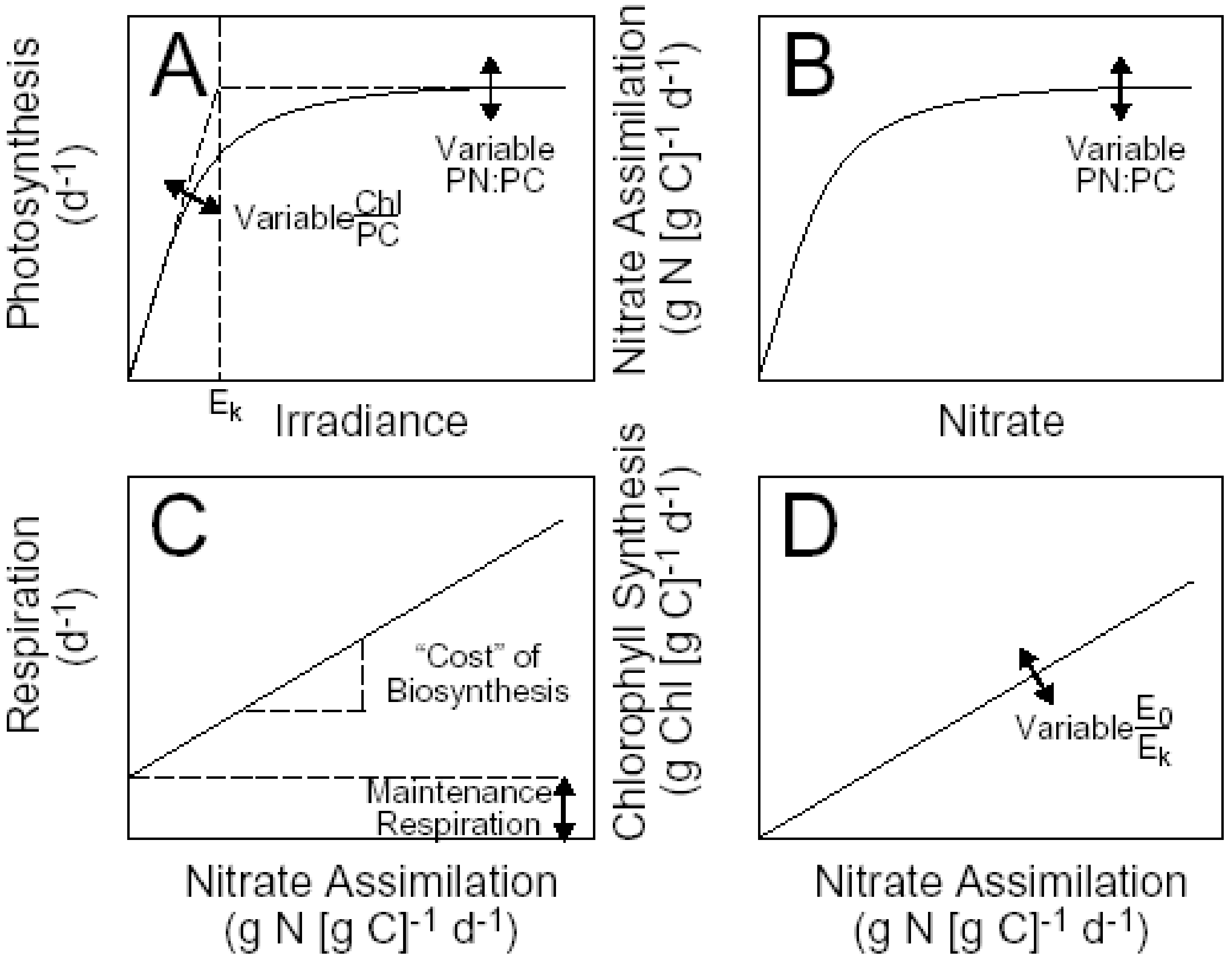
Information Flow

Down regulation of pigment synthesis is proportional to the **imbalance** between energy supplied by **light harvesting** and the **energy demand** for growth and photosynthesis.



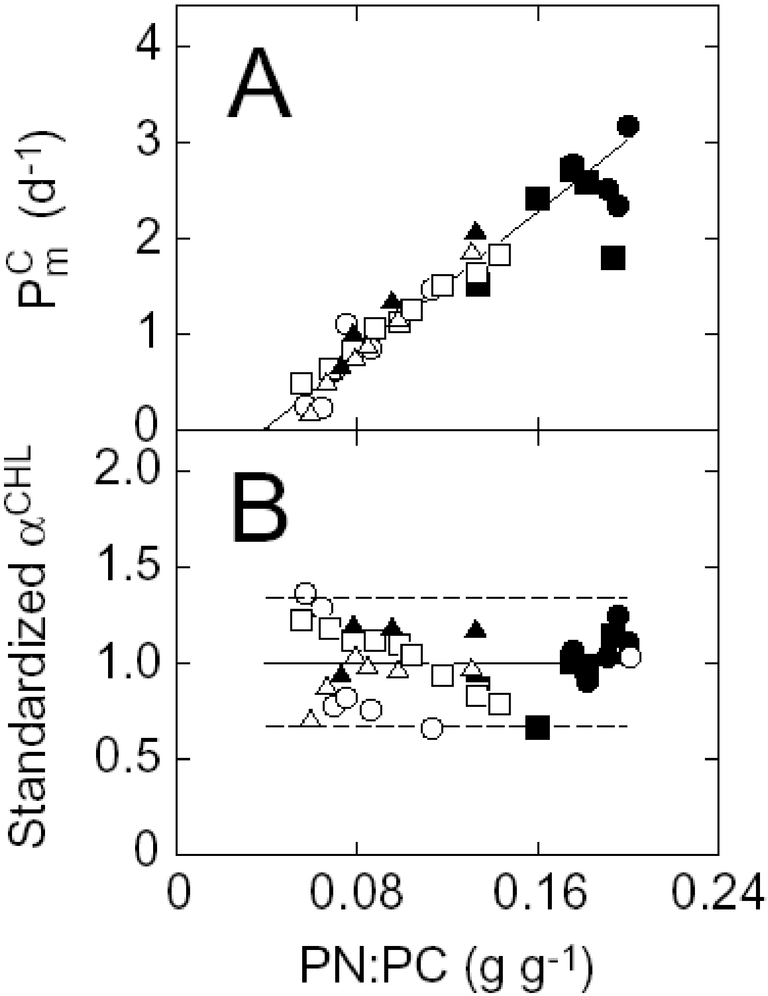
$$\frac{\mathrm{A}}{\mathrm{B}} = \frac{P^C}{\alpha^{chl} \frac{Chl}{C} E}$$

Physiological acclimation model structure.



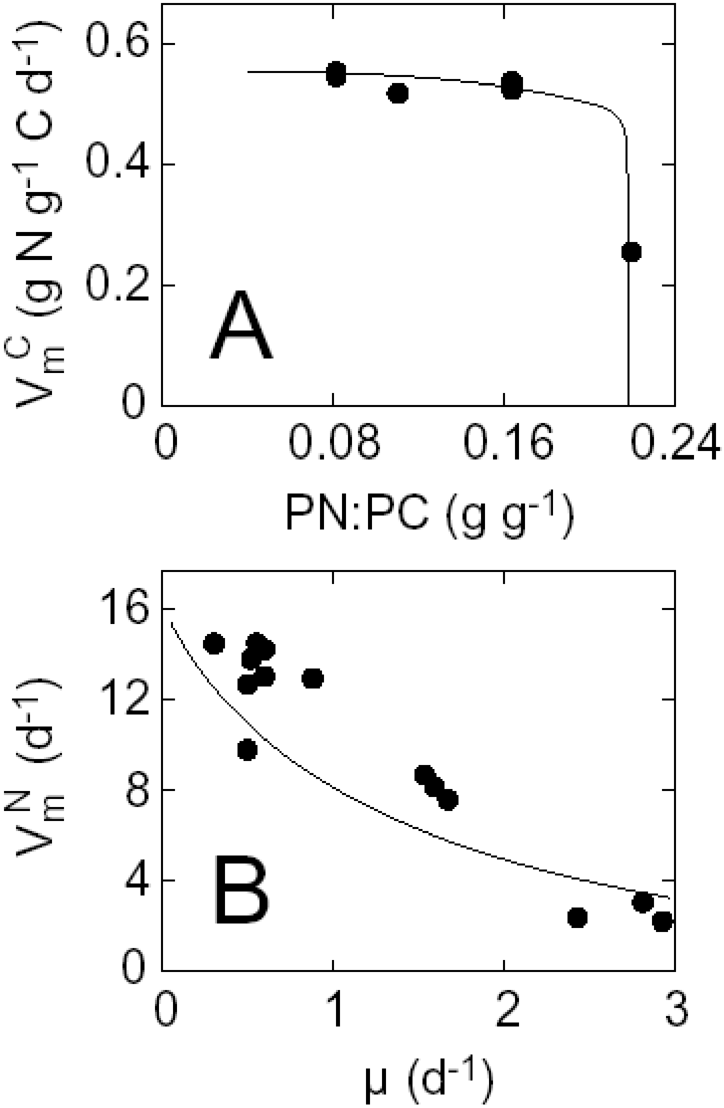
Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694

Model Calibration



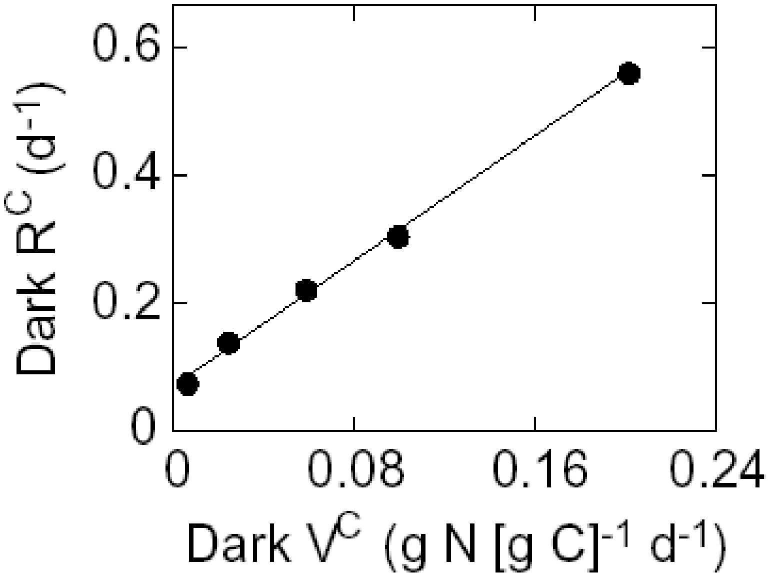
Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694

Model Calibration



Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694

Model Calibration



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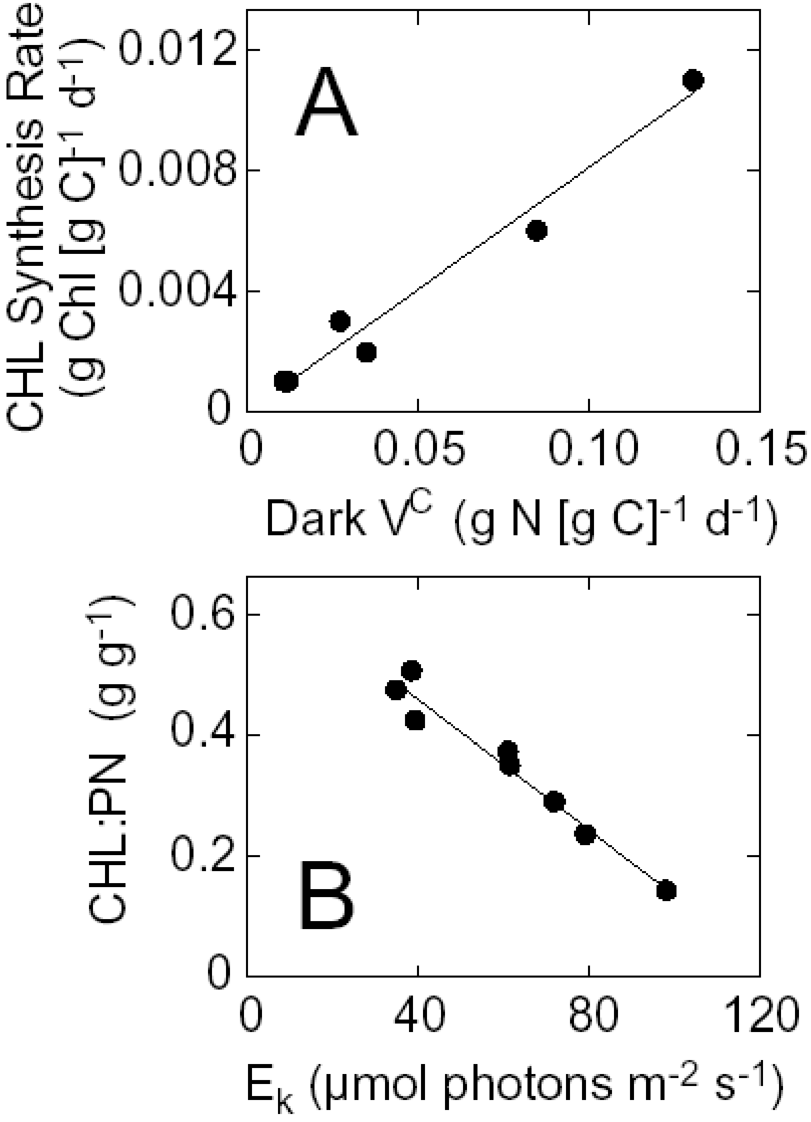
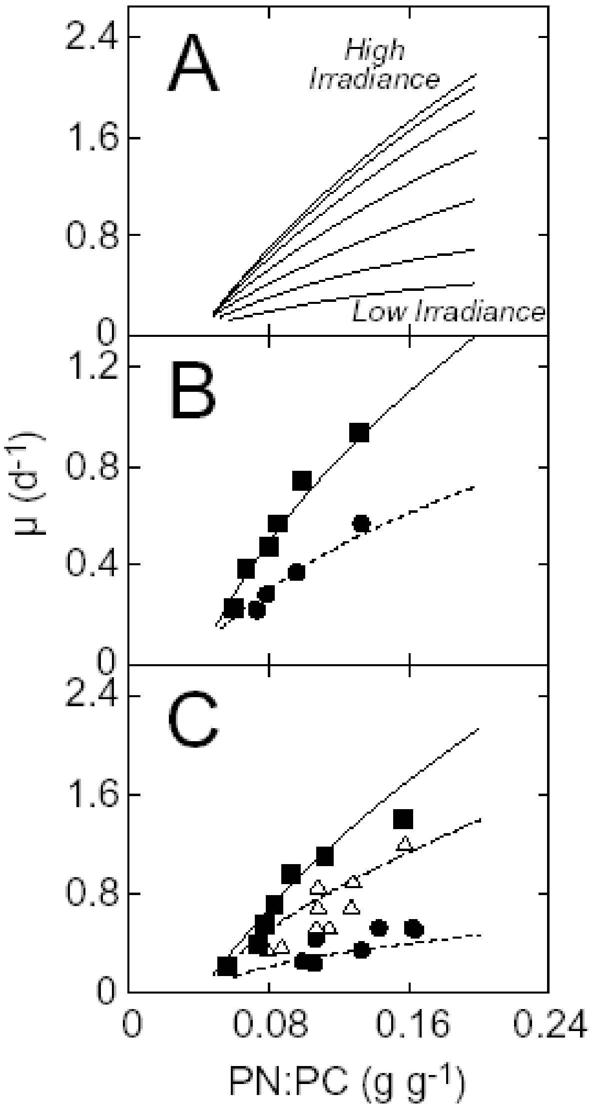
Model Calibration

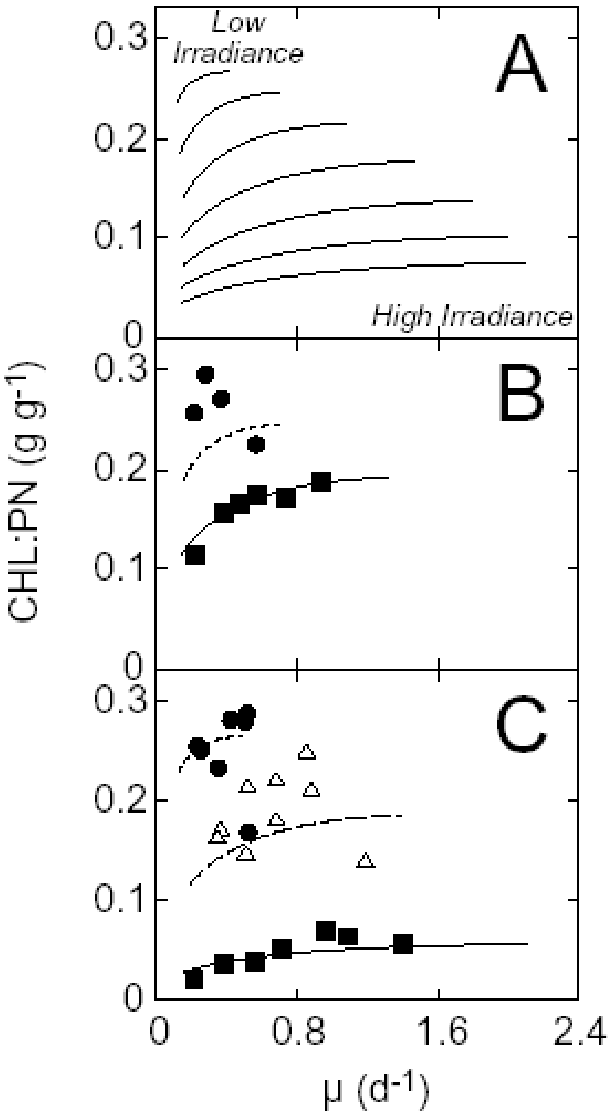


Geider, MacIntyre, Kana (1998) Limnol. Oceanogr. 43: 679-694

Model Verification

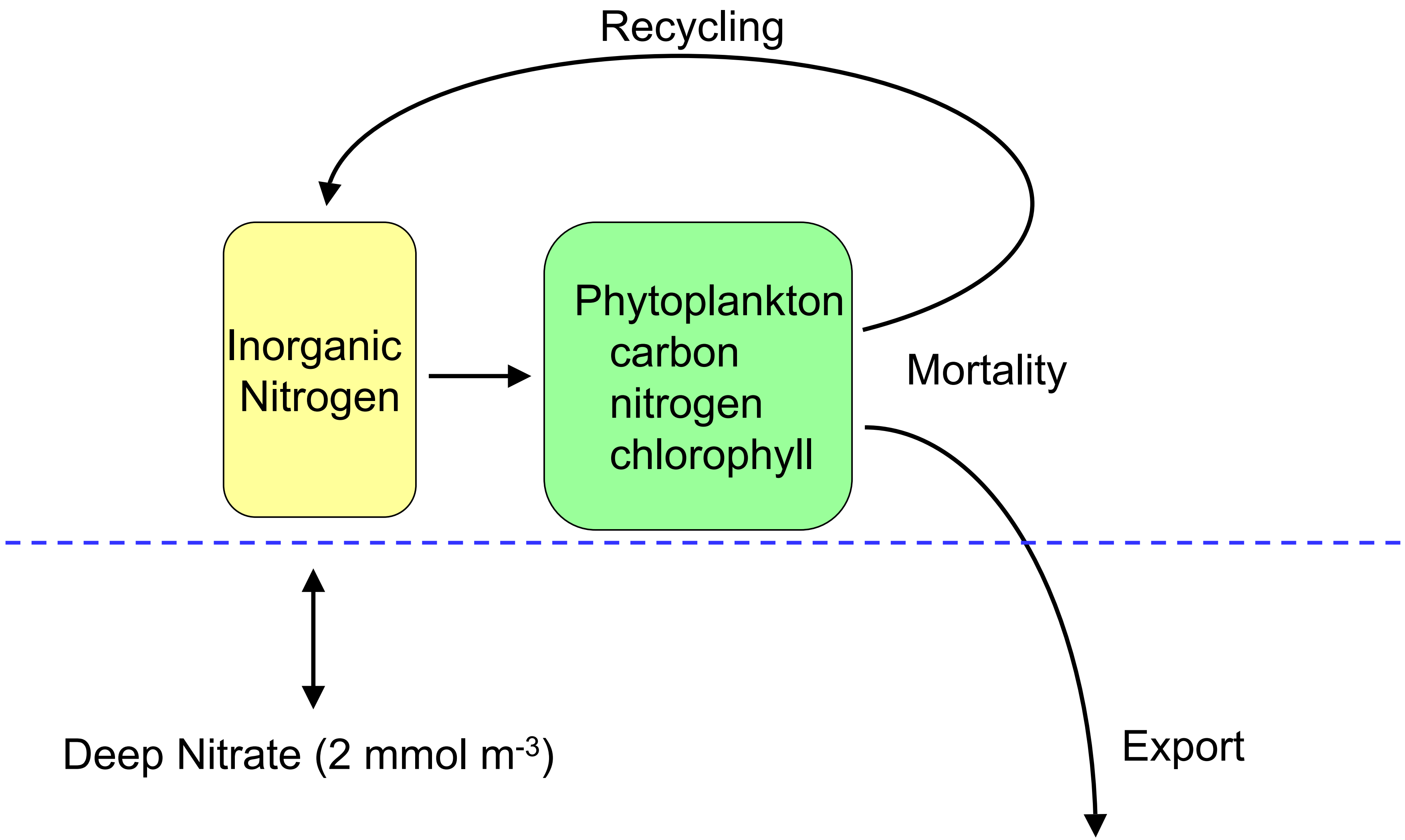


Cell Quota (Droop) Model



Photoacclimation

Two Component Phytoplankton Model for Subtropical Atlantic (Sargasso Sea)



Recycling

Inorganic Nitrogen

Phytoplankton
carbon
nitrogen
chlorophyll

Mortality

Deep Nitrate (2 mmol m^{-3})

Export

Lefevre et al. (2002) Limnol. Oceanogr. 48: 1796-1807

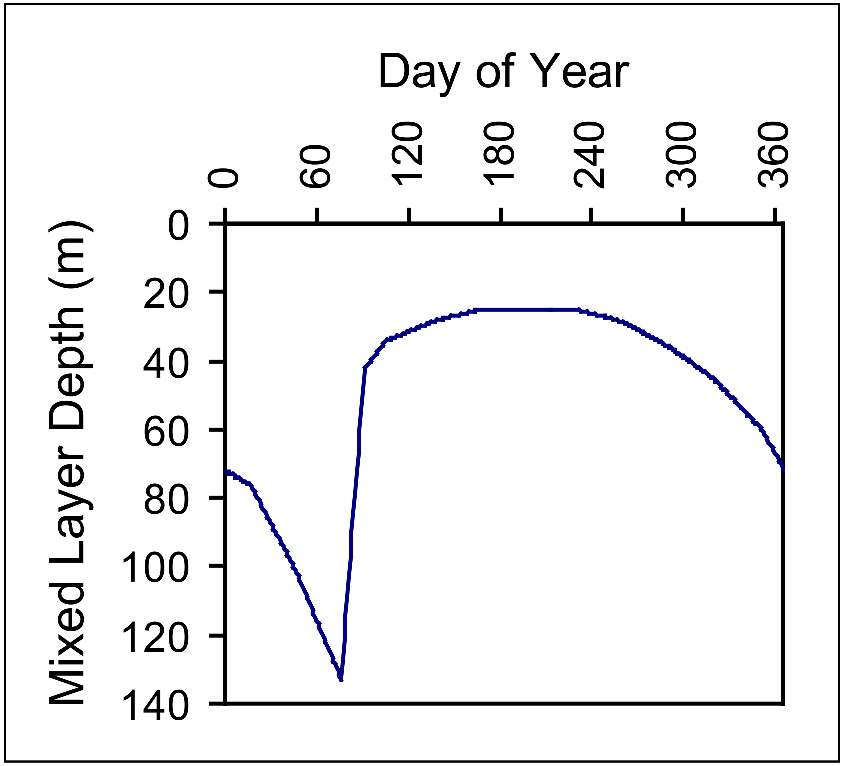
Physical Setting

One dimensional (0-200 m) with vertical resolution of 4 m.

Fixed nitrate concentration at 200 m.

Prescribed seasonal cycles of
    solar radiation,
    mixed layer depth,
    mixed layer temperature.

Fixed vertical diffusivity of $0.0002\ m^2\ s^{-1}$ with mixed layer homogenized daily

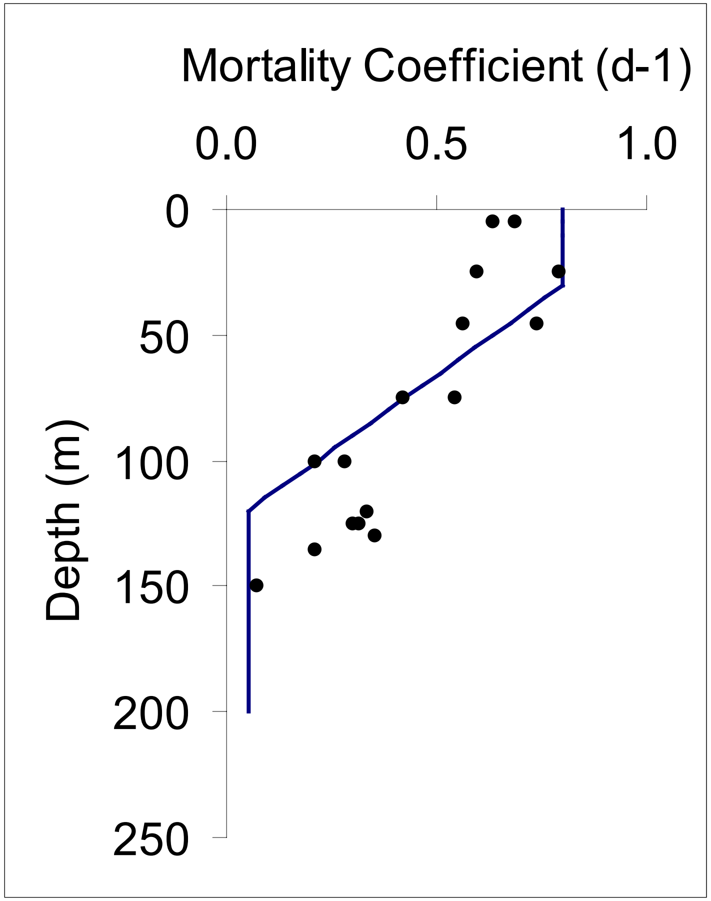


Phytoplankton Mortality

$$\frac{\partial X}{\partial t} = (\mu - m)X$$

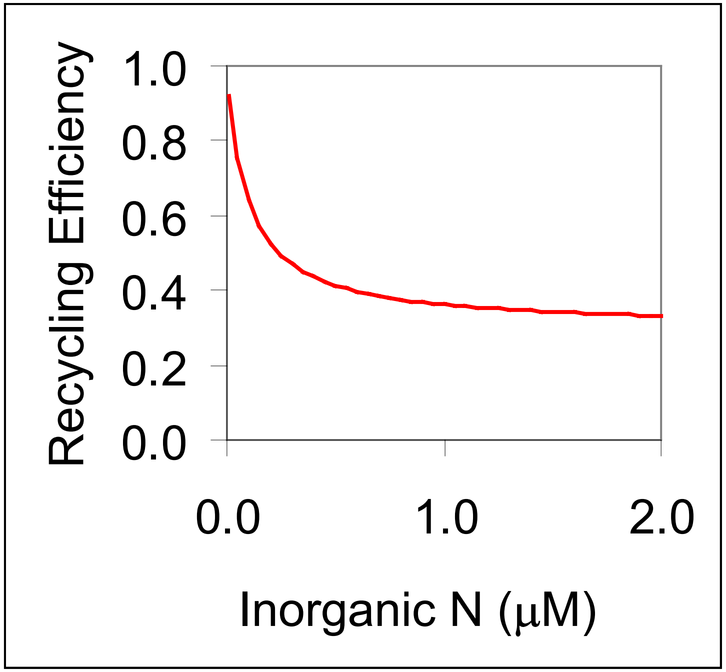
where *X* is phytoplankton biomass (C, N , Chl*a*),
μ is the growth rate, and
m is the mortality coefficient

Data for *Prochlorococcus* at ALOHA from Liu, Nolla & Campbell (1997) *Aquatic Microbial Ecology,* 12: 39-47)

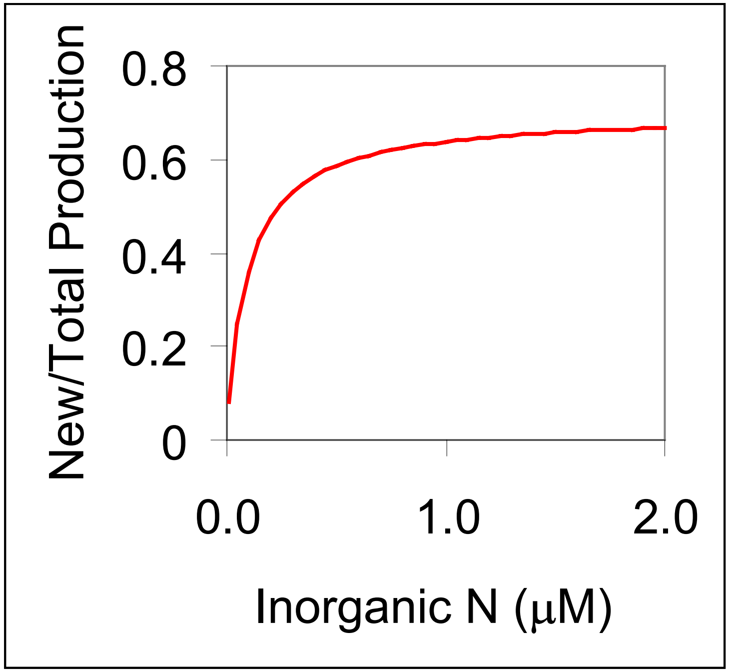


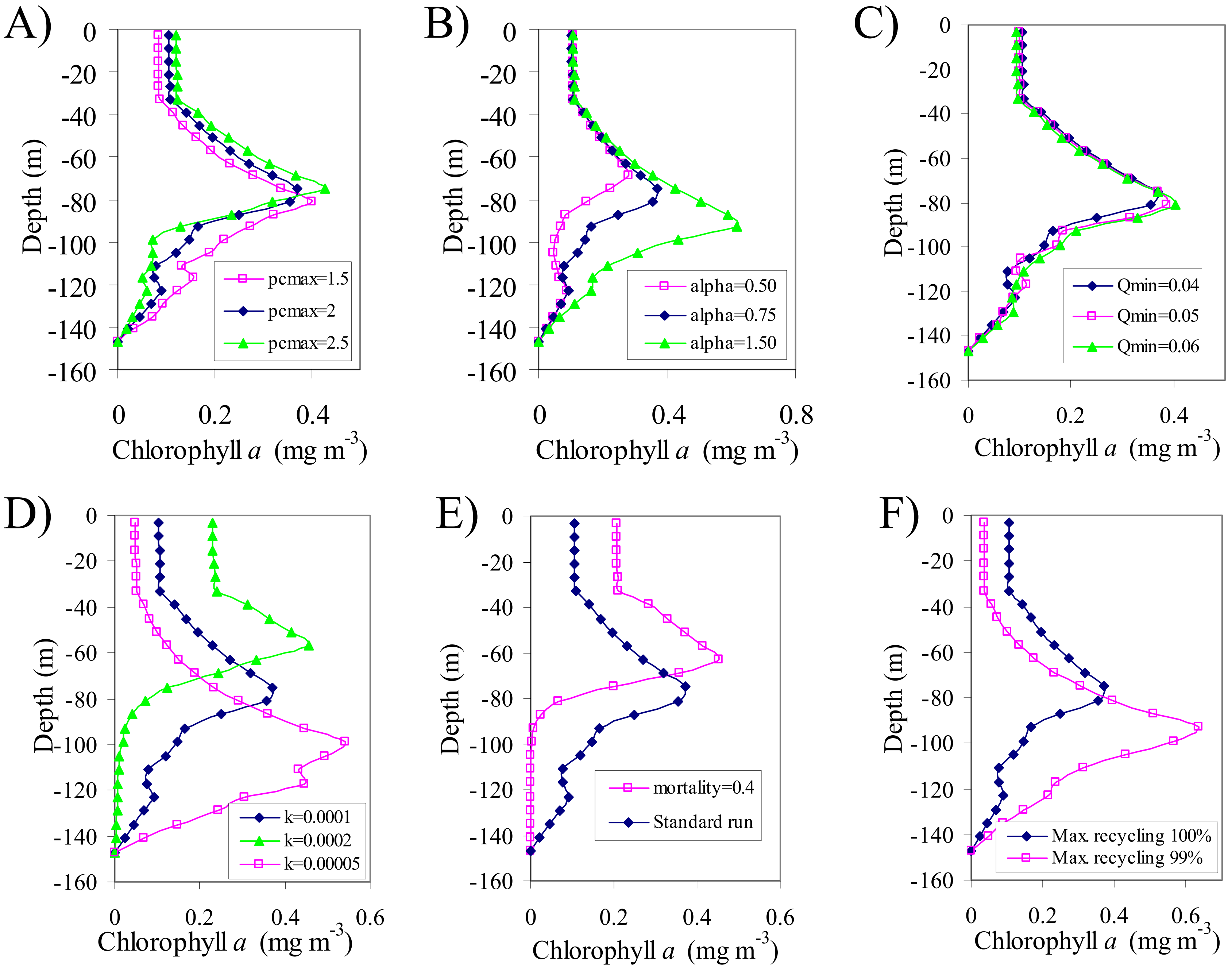
Recycling Efficiency (ε) and the F-ratio

$$\varepsilon = 0.3 + \frac{(\varepsilon_{\max} - 0.3)K_N}{N + K_N}$$

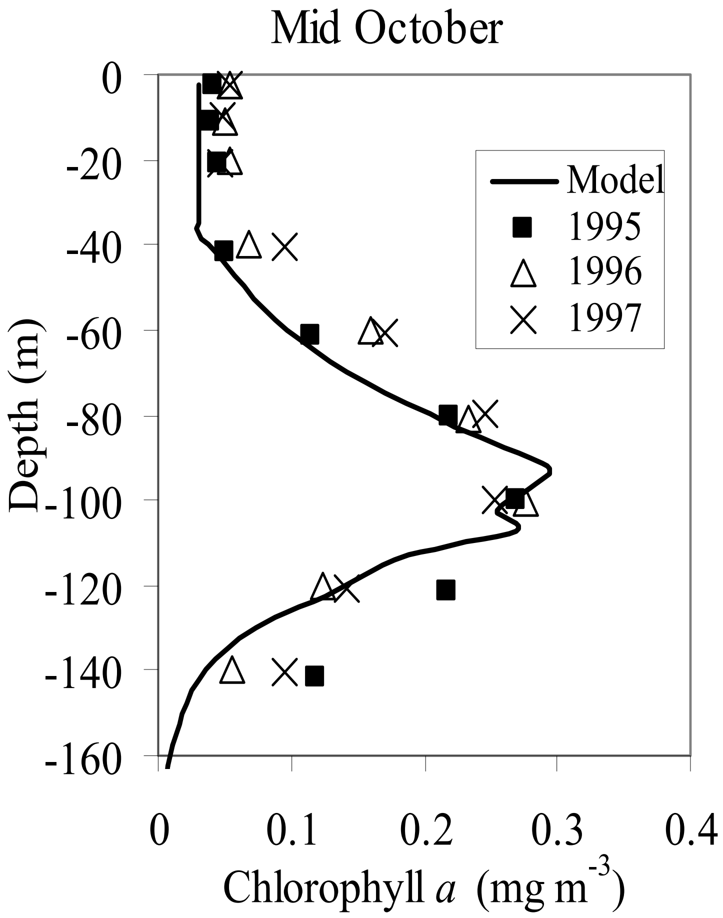


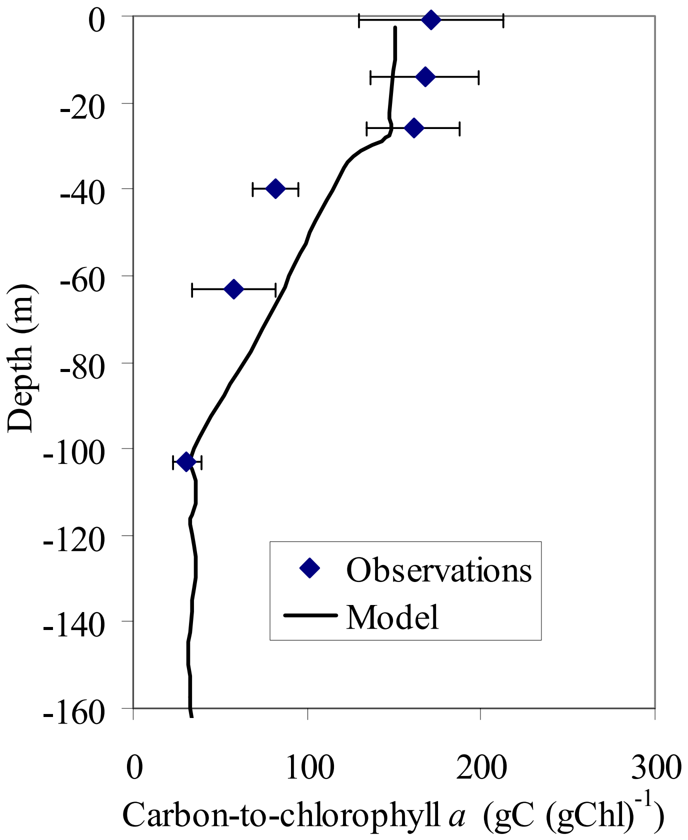
“Steady-State” F-ratio

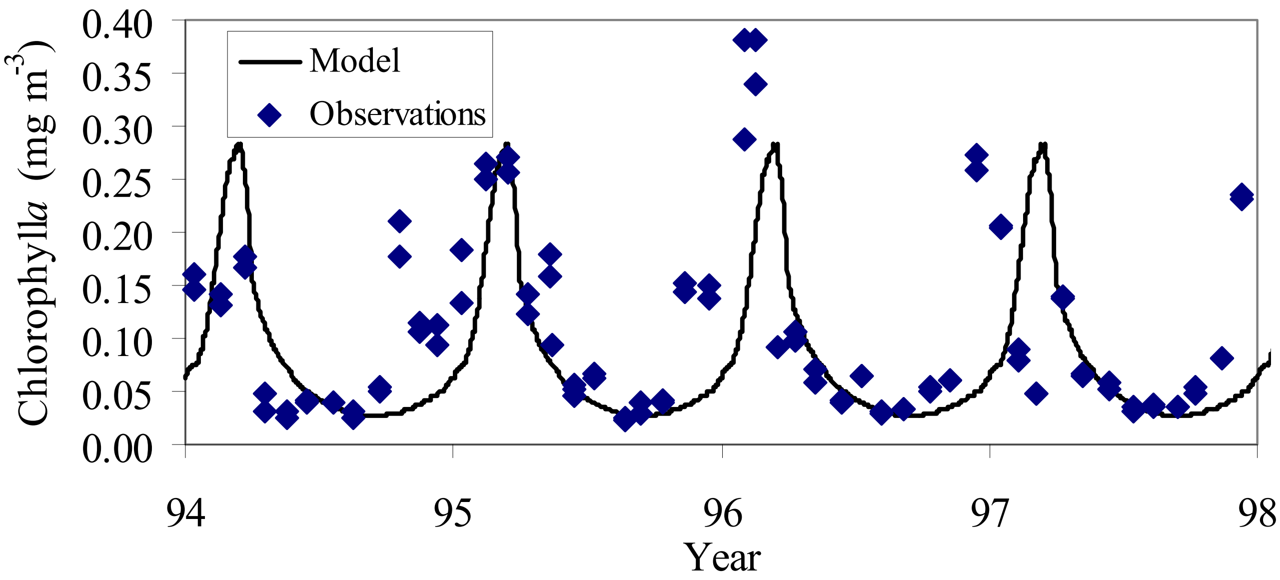


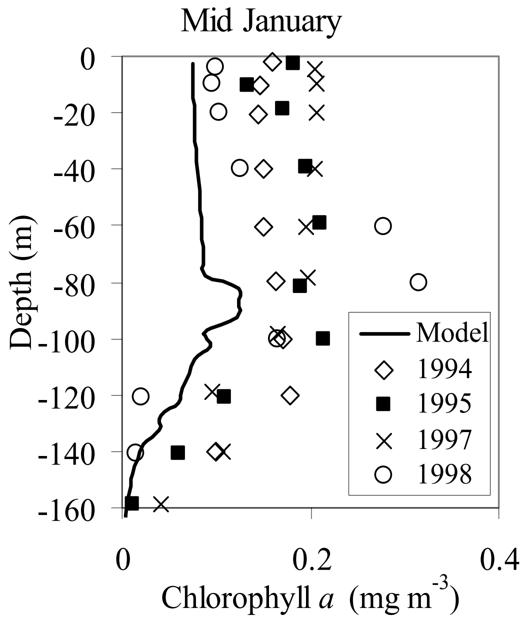

A)
B)
C)
D)
E)
F)
Depth (m)
Chlorophyll *a* (mg m^{-3})
0
-20
-40
-60
-80
-100
-120
-140
-160
0
0.2
0.4
0.6
0.8
pcmax=1.5
pcmax=2
pcmax=2.5
alpha=0.50
alpha=0.75
alpha=1.50
Qmin=0.04
Qmin=0.05
Qmin=0.06
k=0.0001
k=0.0002
k=0.00005
mortality=0.4
Standard run
Max. recycling 100%
Max. recycling 99%

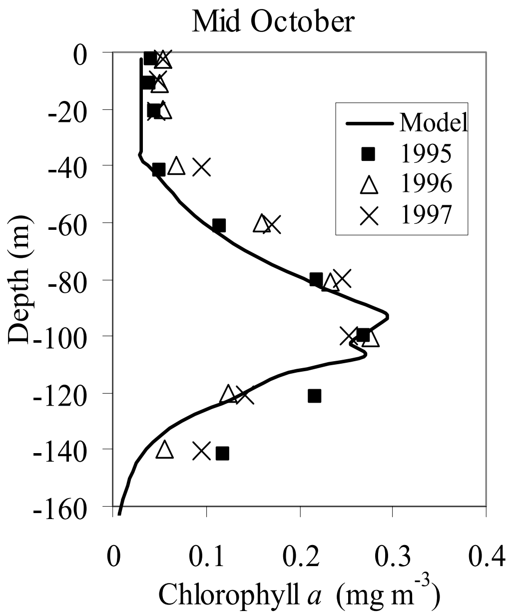
Simulating the seasonal cycle of primary productivity in the Sargasso Sea requires that photoacclimation be included.

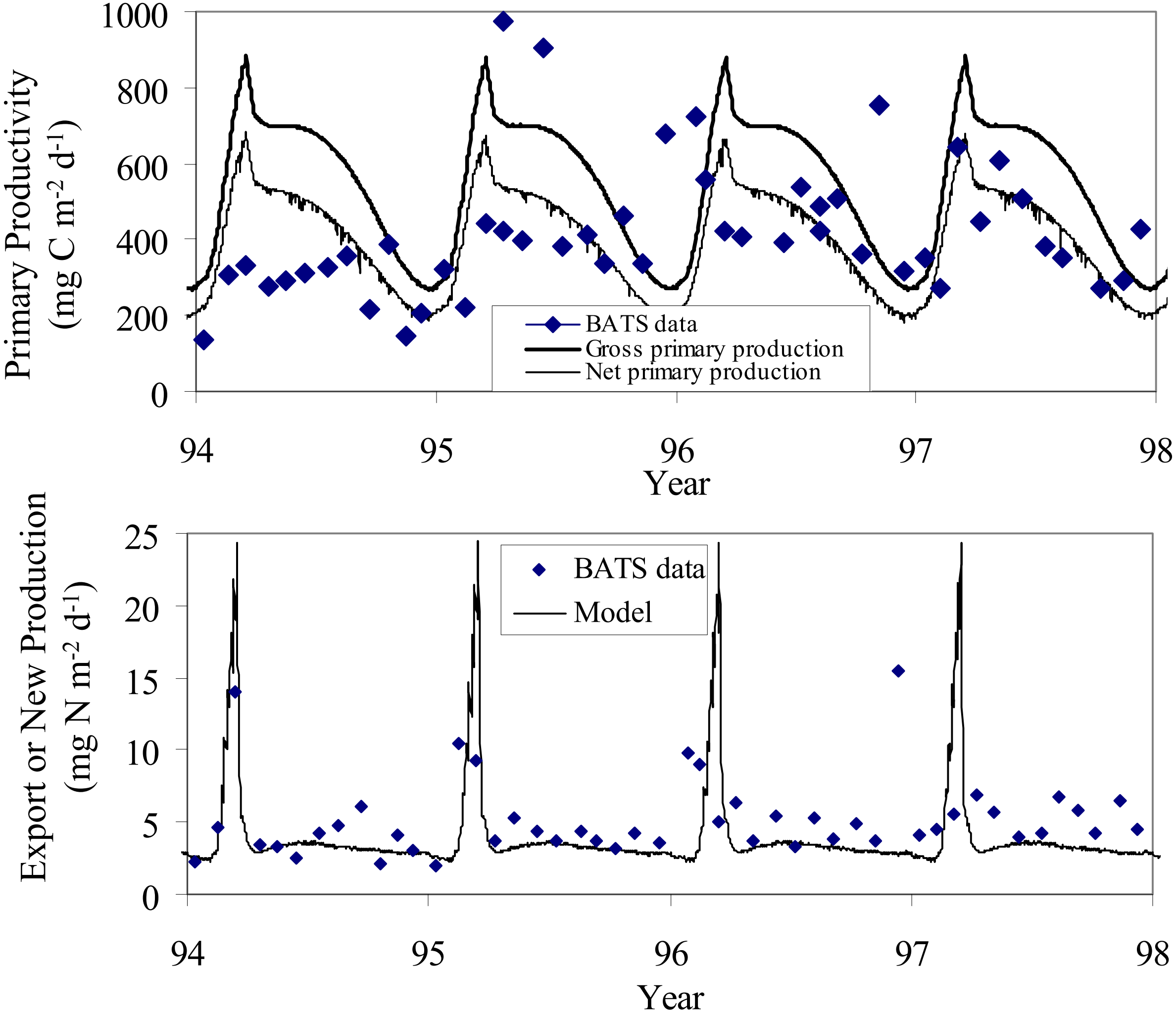





Model
Observations
Chlorophyll *a* (mg m^{-3})
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
94
95
96
97
98
Year


Mid January
Depth (m)
0
-20
-40
-60
-80
-100
-120
-140
-160
0
0.2
0.4
Chlorophyll *a* (mg m^{-3})
Model
1994
1995
1997
1998


Mid October
Depth (m)
0
-20
-40
-60
-80
-100
-120
-140
-160
0
0.1
0.2
0.3
0.4
Chlorophyll *a* (mg m^{-3})
Model
1995
1996
1997


Primary Productivity
(mg C m^{-2} d^{-1})
1000
800
600
400
200
0
BATS data
Gross primary production
Net primary production
94
95
96
97
98
Year
Export or New Production
(mg N m^{-2} d^{-1})
25
20
15
10
5
0
BATS data
Model
94
95
96
97
98
Year

Conclusion

- Mass and energy balances, when appropriately formulated, can provide the basis for models of the light, nutrient and temperature dependencies of algal growth rate and pigment acclimation.

- Such models can be calibrated from measurements of component processes, and
- validated by comparison of predictions of growth rate and pigment:biomass with independent observations.

What have I learned from the MAG workshop?

- Cell cycle should not be neglected.
- Photoinhibition may also be an important driver of photosynthetic physiology.
- Energy and reductant fluxes may need to be separated from carbon fluxes.
- Through entrainment of cell division to a 24 h light:dark cycle, basic cell biology may constrain pelagic ecosystem function and biogeochemistry.