Revisiting Seasonal Plankton Cycles in the Subarctic Atlantic and Pacific

Ocean Color Research Team Meeting 2007

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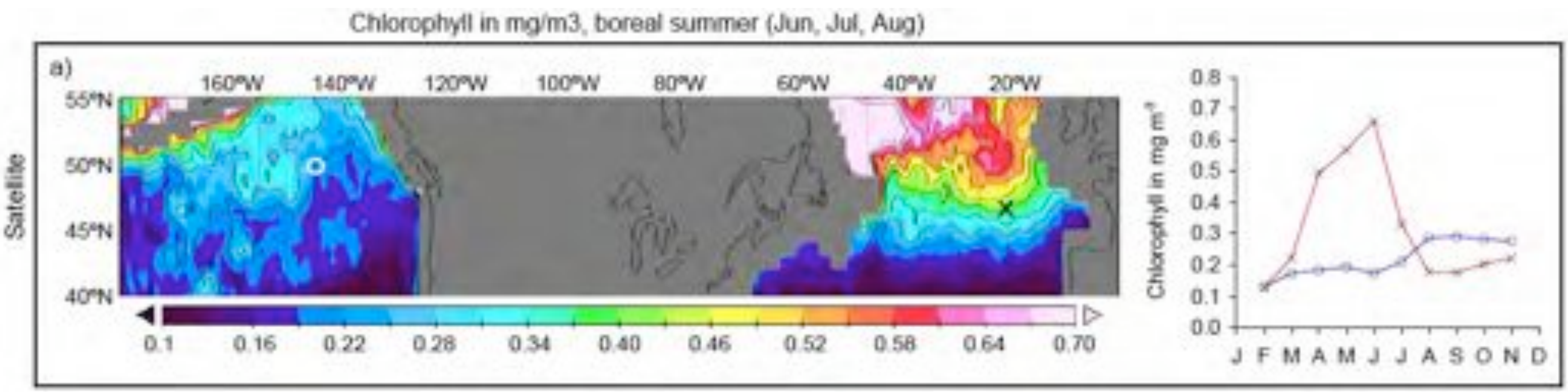
Seasonal Chlorophyll Cycles

- "In the North Atlantic, there is a marked increase in the standing stock of phytoplankton as measured by Chlorophyll a (...); in contrast, at Station P average values vary over a narrow range (...)" (Parsons & Lalli, 1988)
- "Based on the quantity of Chlorophyll a (…), there is virtually no seasonal variation in phytoplankton standing stock at Station P." (Frost, 1991)
- "Chlorophyll a at Station P is nearly constant year around (…) the key feature of the North Pacific is that the phytoplankton population is low and hardly changes with season." (Sarmiento & Gruber, 2006)



So what?

- Cellular pigmentation (Chl:C) varies in response to
  - Light
  - Temperature
  - Nutrient Limitation
  - Iron Deficiency

- Subarctic Atlantic and Pacific differ with respect to
  - Light
  - Temperature
  - Nutrient Limitation
  - Iron Deficiency

Two Approaches

Satellite chlorophyll

Chl:C ratio
(photoacclimation model)

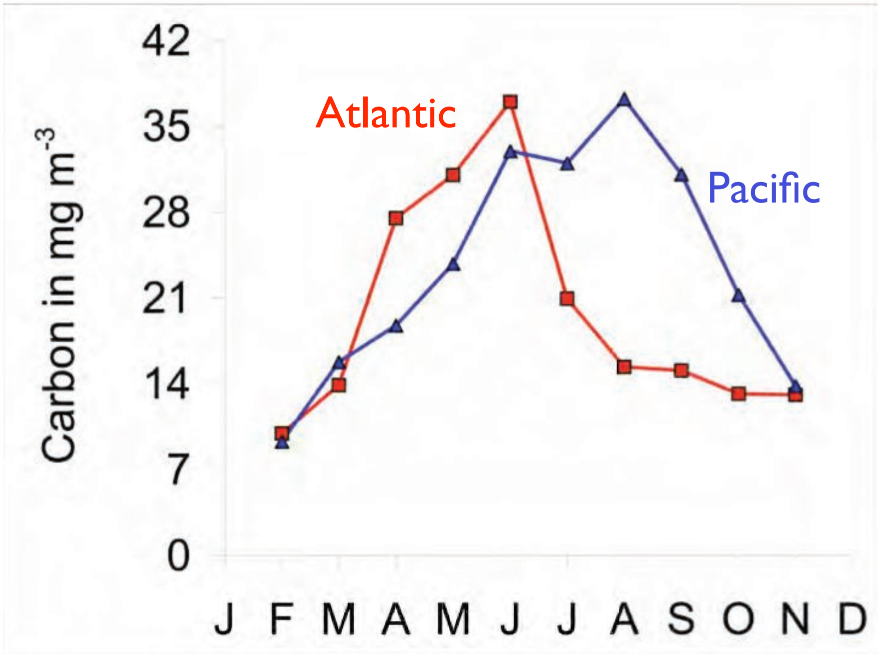
Satellite particulate
backscattering

Behrenfeld et al.
(2005)

Phytoplankton
carbon biomass

Conclusions

- Phytoplankton biomass in the Northeast Pacific varies seasonally.
- Maximum biomass concentrations are similar to the North Atlantic.



Phytoplankton Physiology

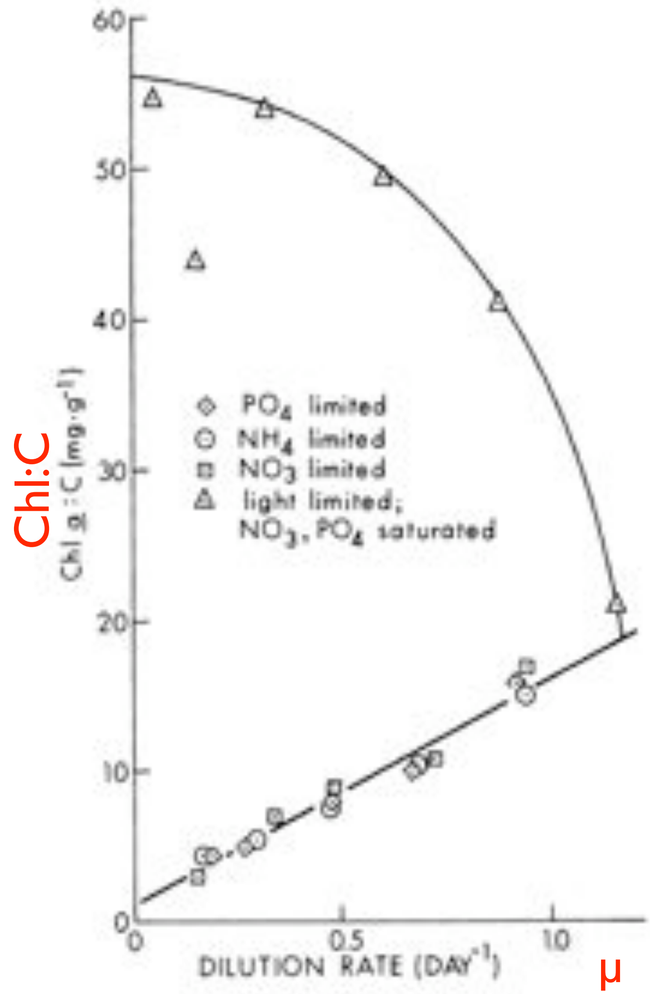
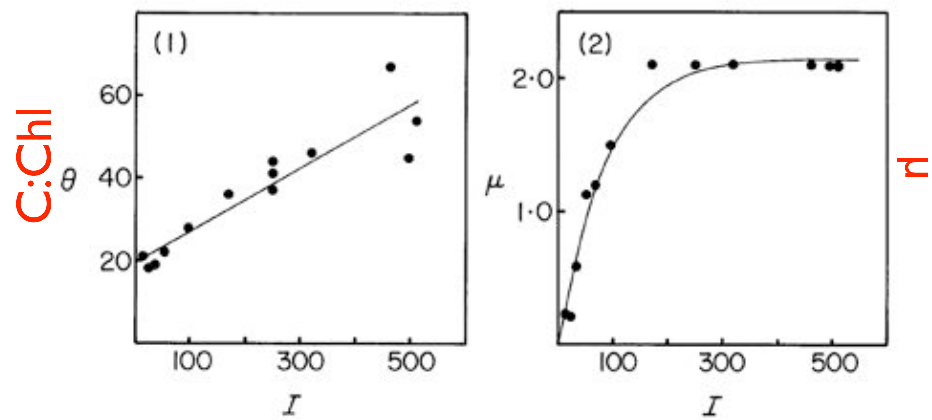
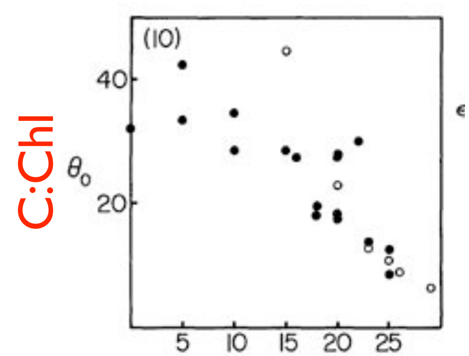


Fig. 5. Smooth curve to light-limited data from Bannister's model. Regression to nutrient-limited data, Chl *a*:C = 1.14 + 15.1 μ.





Laws & Bannister (1980)

Light- and nutrient-limited growth of *Thalassiosira fluviatilis*

R. Geider (1987)

Light- and temperature-limited growth *Thalassiosira pseudonana*

Phytoplankton Physiology

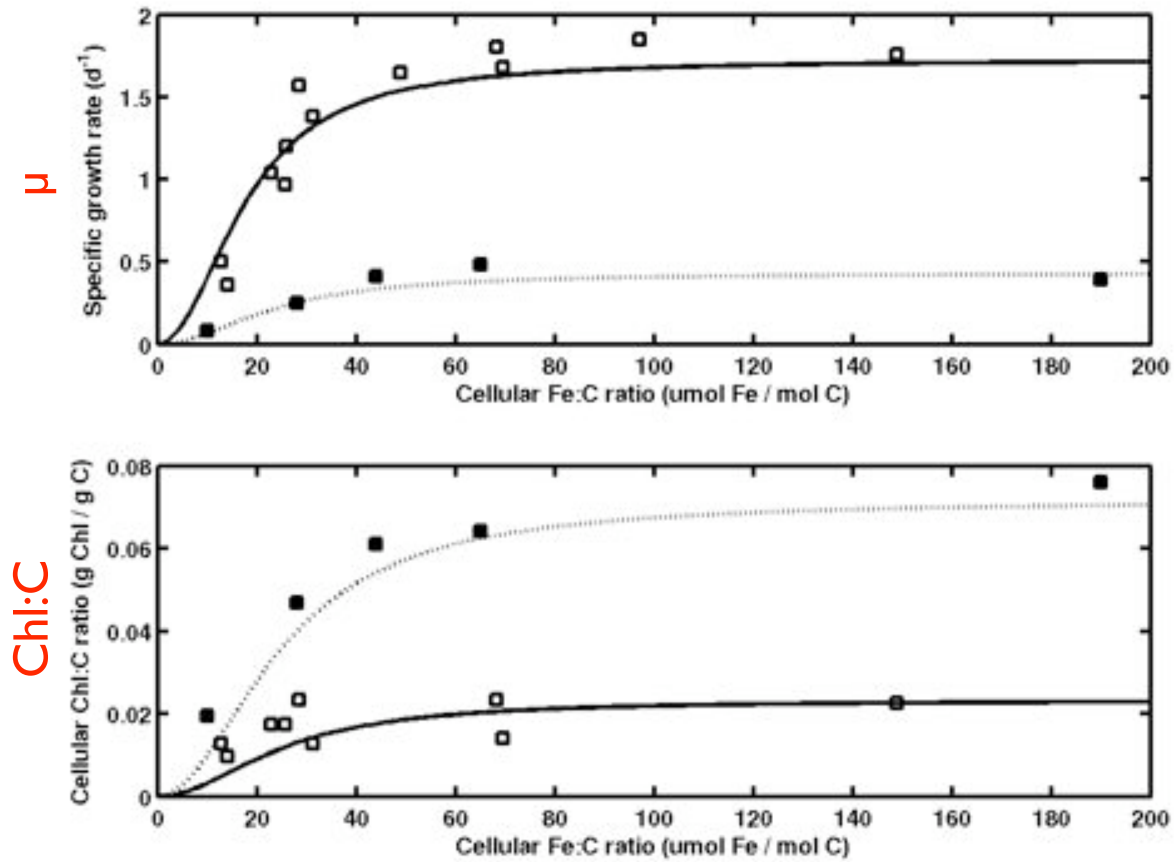


Figure S2 - Model fit to *Sunda* [1997]. Chl:C ratio (gChl gC^{-1}) and specific growth rate data (d^{-1}) for *Thalassiosira Pseudonana* under high light (open) and low light (filled) as a function of iron content. P^C_m = 2.9E-05 s^{-1}, α = 3.5 gC gChl^{-1} m^2 Watts^{-1} s^{-1}, $Fe{:}N_{irr}$ = 25 µmolFe molC^{-1}, T = 20 ºC, ϑ_{max} = 0.08 gChl gC^{-1}, κ = 0.063 ºC^{-1}. Values were fit for ϑ_{max}, α, $Fe{:}N_{irr}$ and the low light irradiance (24 Einstein m^{-2} s^{-1}), the last of which was adjusted from the value given in *Sunda* [1997] (50 Einstein m^{-2} s^{-1}) for the best fit.

Sunda (1997)

Effect of iron on growth rate and Chl:C ratio of *Thalassiosira pseudonana*

Photoacclimation Model

- “Bastardized” version of GFDL global ocean biogeochemistry model
- Based on Geider (1997), but modified to account for
  - Co-limitation by nitrate, phosphate, silicate
  - The direct physiological effect of iron deficiency
  - Two size classes (“large” and “small”)

$$\vartheta_i = \vartheta_{\min,i} + \frac{\left(\vartheta_{\max,i} - \vartheta_{\min,i}\right) \cdot \dfrac{\left[Fe/N\right]_i^2}{k_{Fe} + \left[Fe/N\right]_i^2}}{1 + \vartheta_{\max,i}^{Fe} \cdot \alpha_i \cdot E \Big/ \left(2 \cdot P_{\max,i}^{C} \cdot \Lambda_{N,i} \cdot \exp(\kappa \cdot T)\right)} \qquad i \in \left[Lg, Sm\right]$$

Geider (1997), Dunne et al. (2006), Sunda (1997), Sunda & Huntsmann (1997)

Photoacclimation Model

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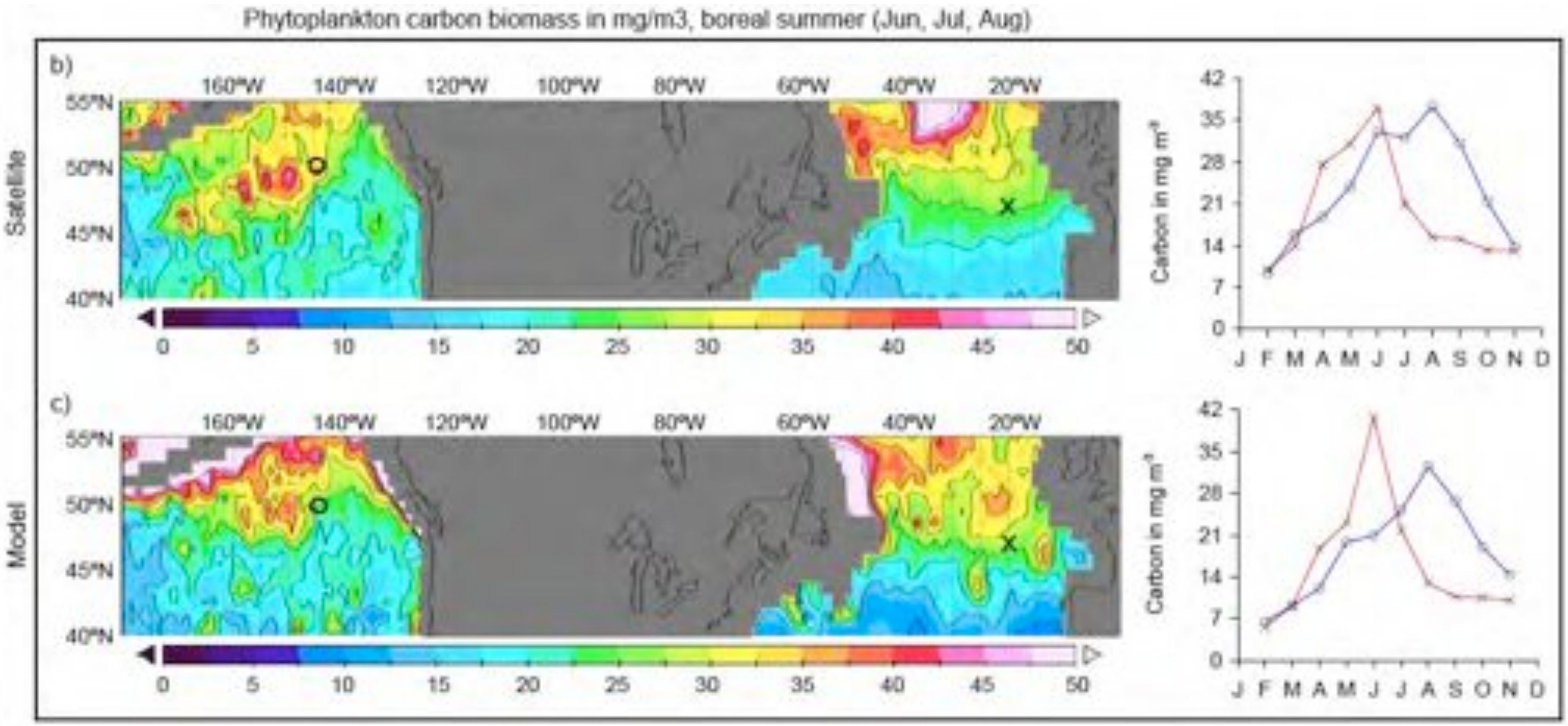
  - Two size classes ("large" and "small")

- Community Chl:C ratio = weighted average of "large" and "small" Chl:C

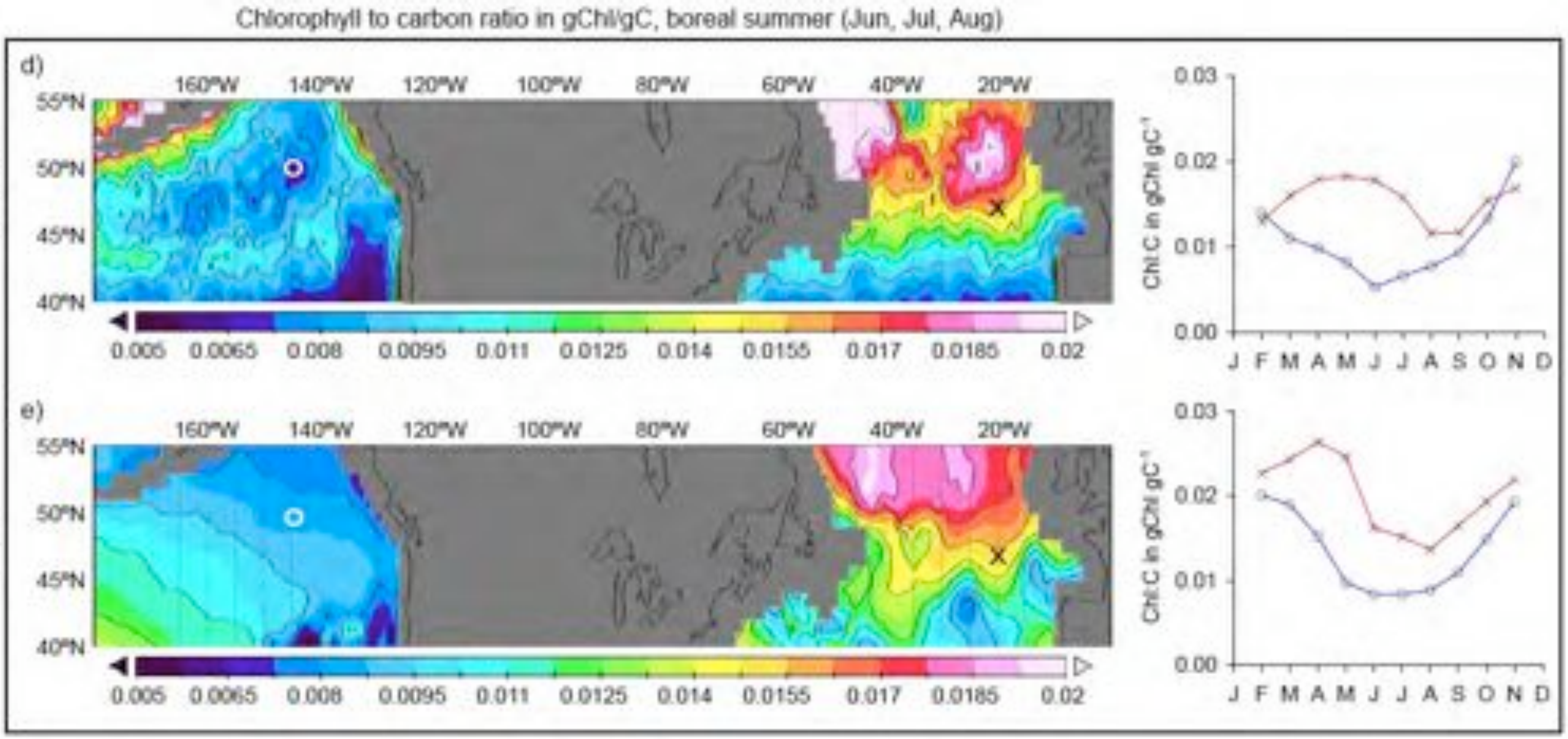
$$\vartheta = f_{Lg} \cdot \vartheta_{Lg} + \left(1 - f_{Lg}\right) \cdot \vartheta_{Sm}$$

Armstrong (1999), Dunne et al. (2005)

Phytoplankton Carbon Biomass

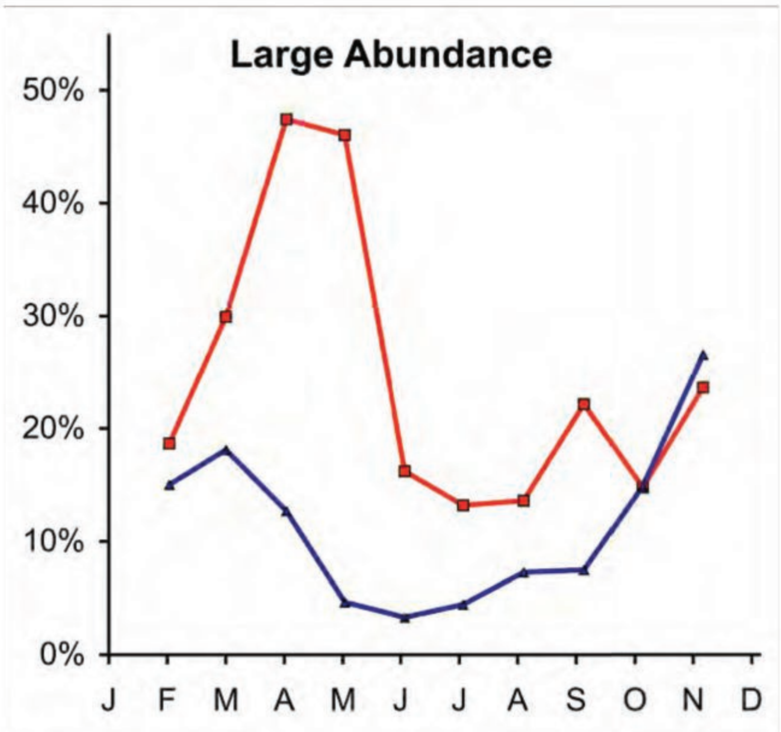


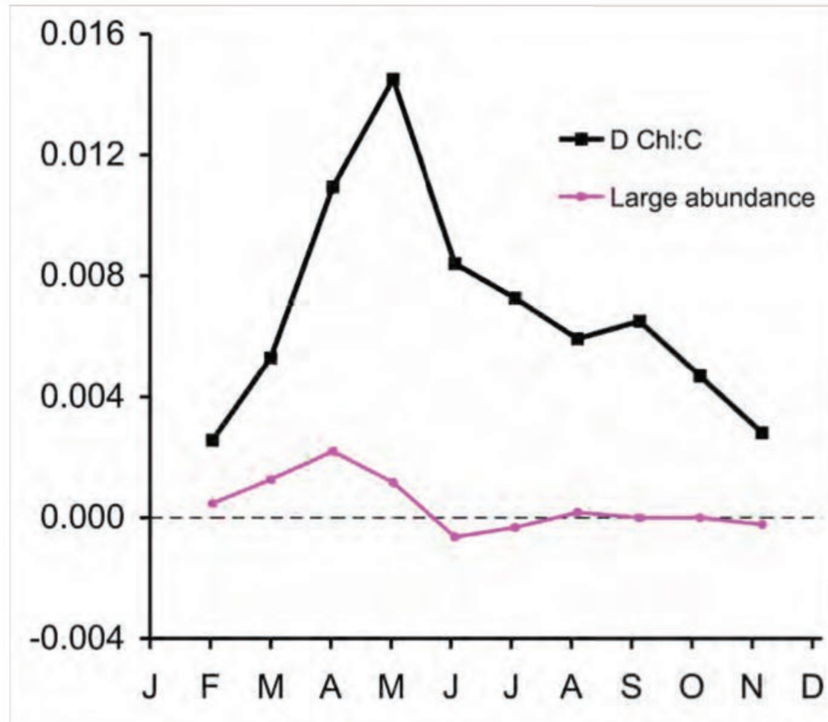
Chl:C Ratio



$$\Delta\vartheta \approx \sum_X \left(\frac{\partial \vartheta}{\partial X} \cdot \Delta X \right) \qquad X \in \left[f_{Lg}, T, E, \Lambda_N, Q_{Fe} \right]$$

Decomposing the Chl:C Ratio





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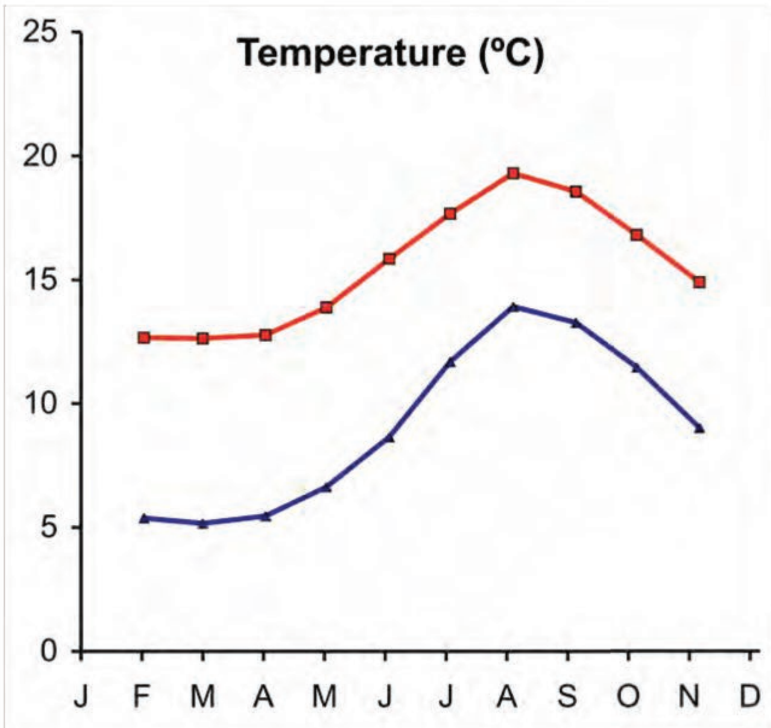

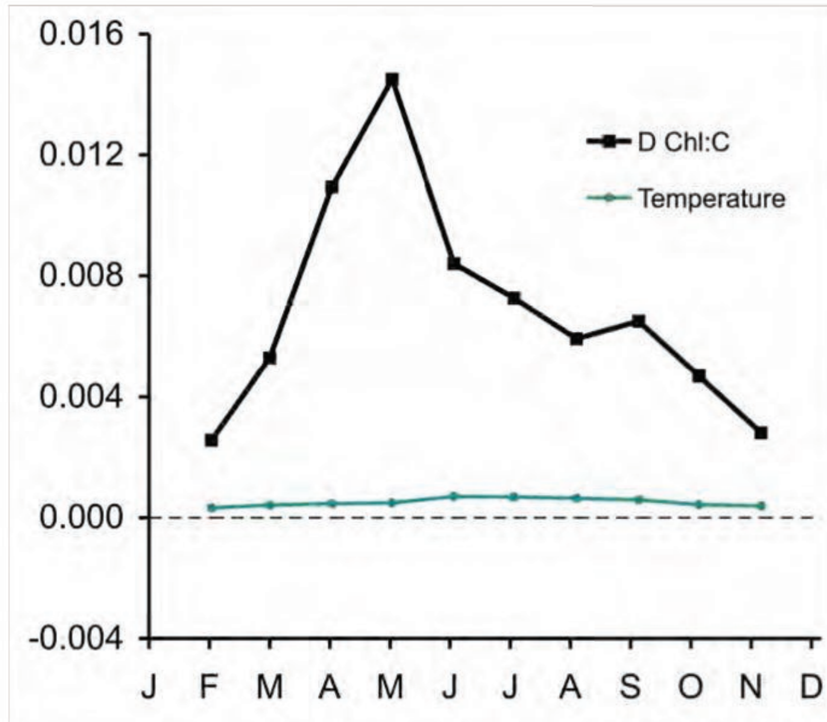

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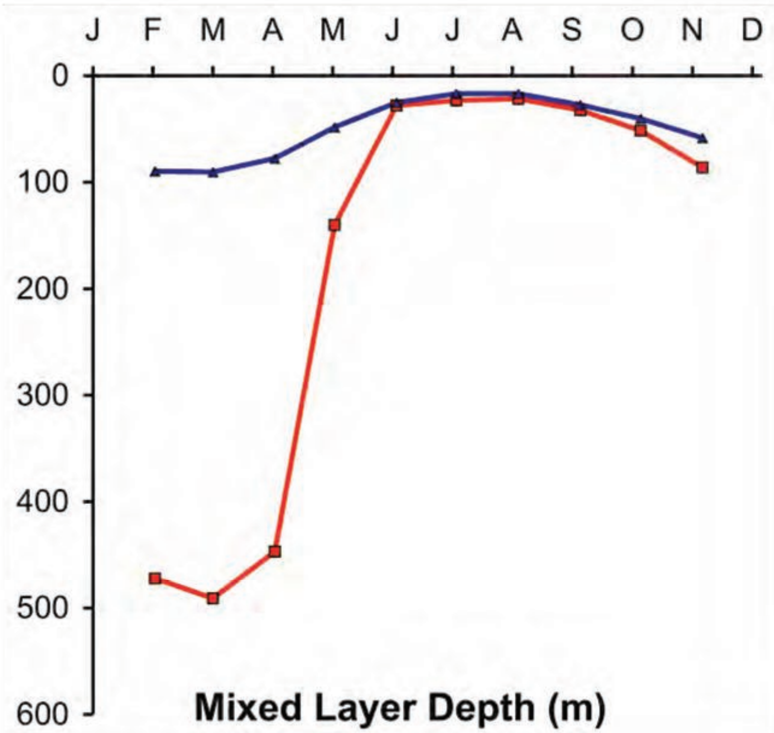

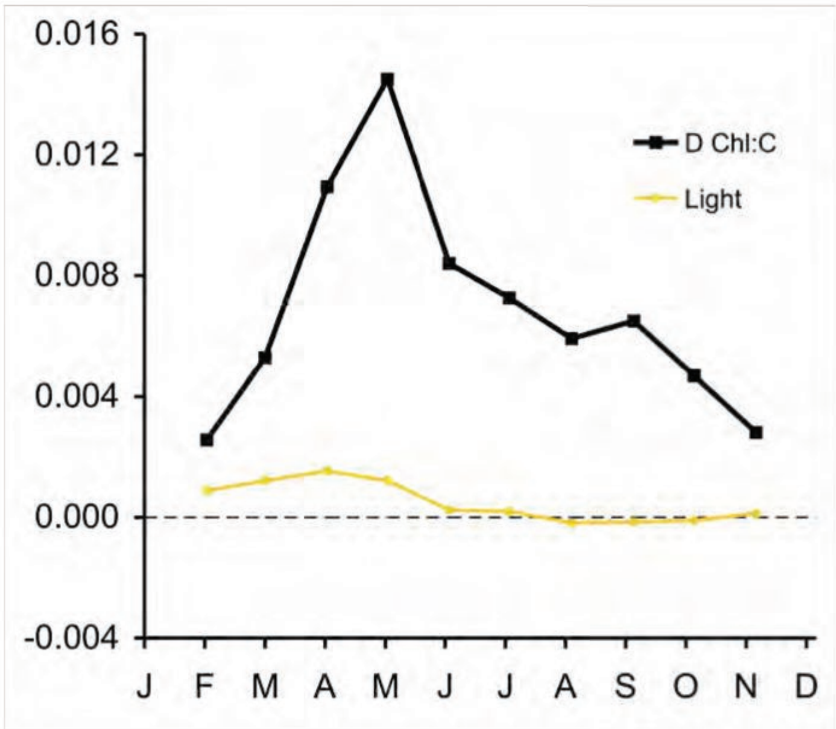

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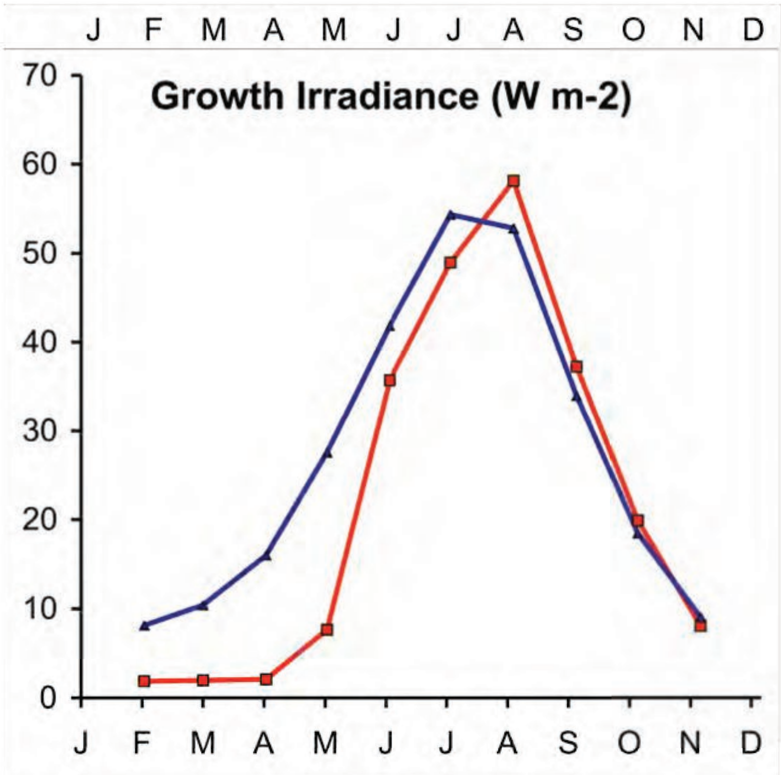

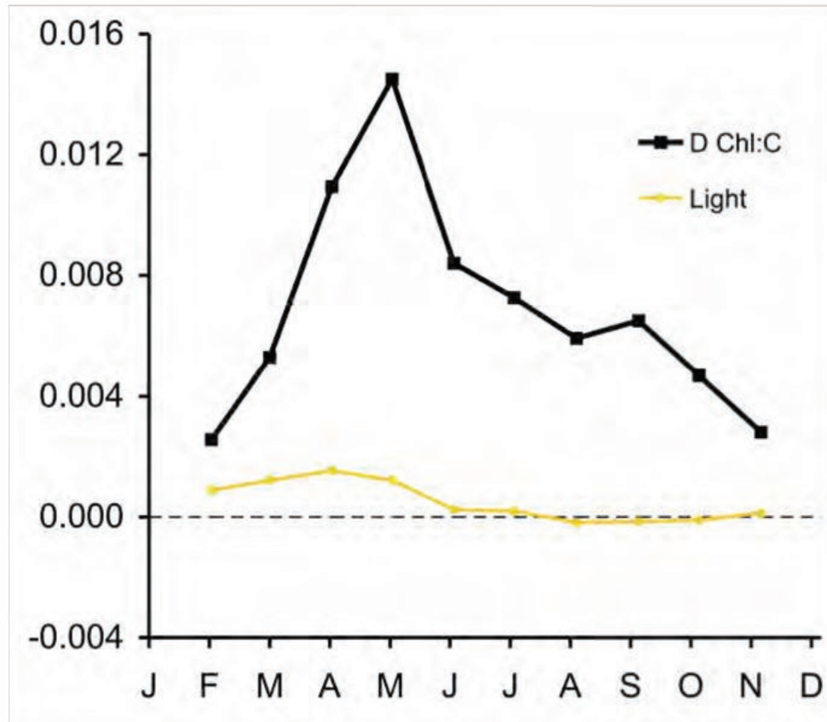

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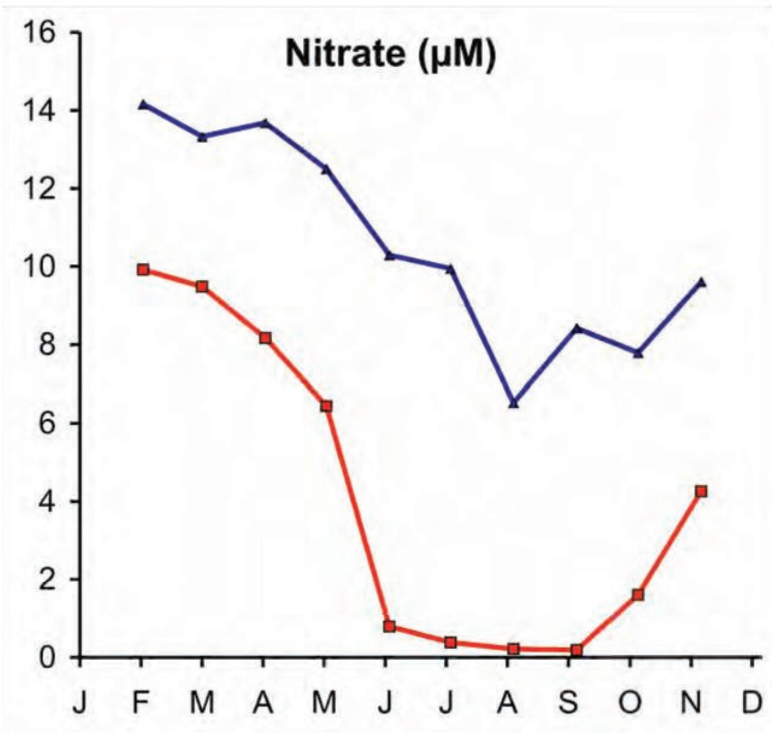

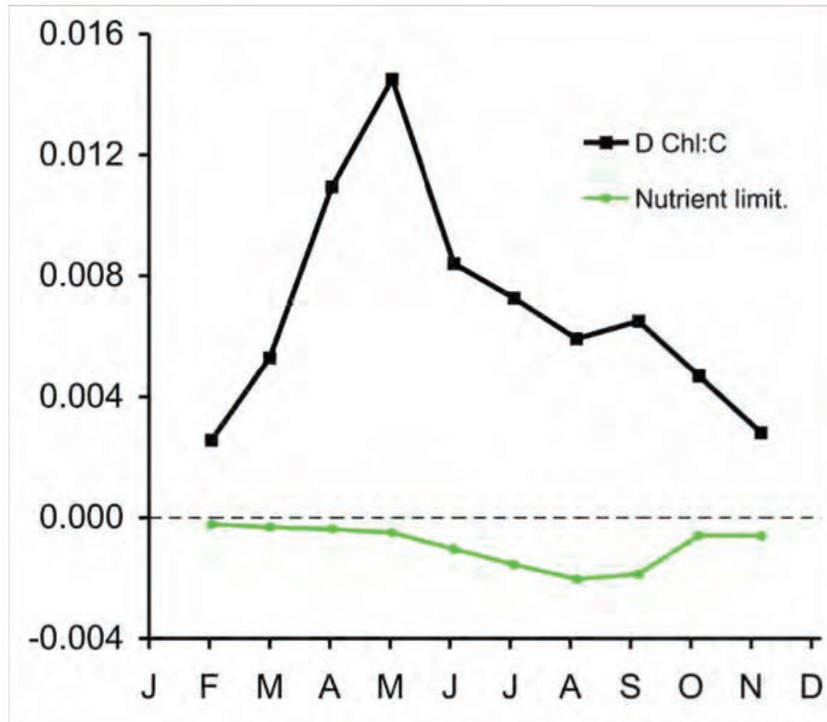

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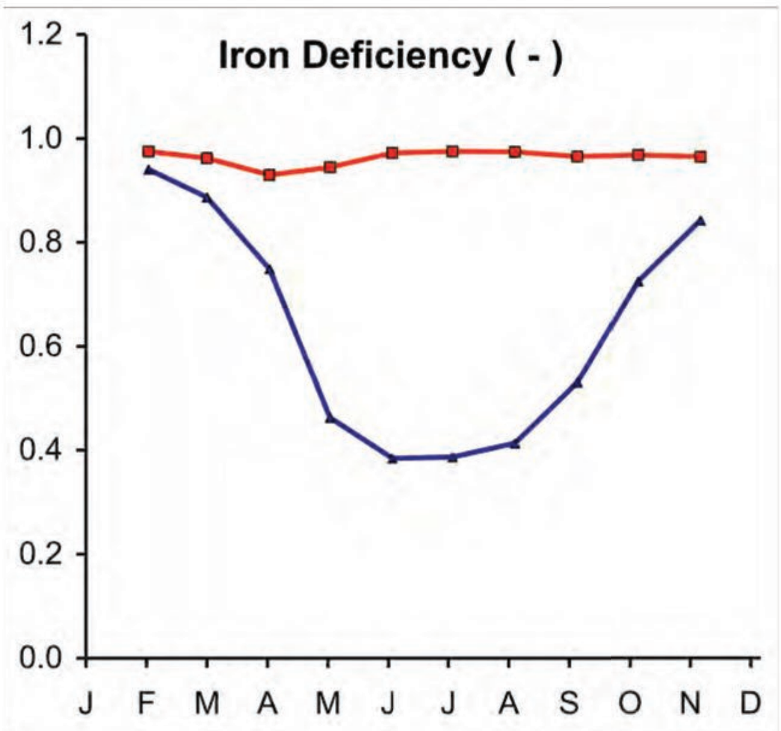
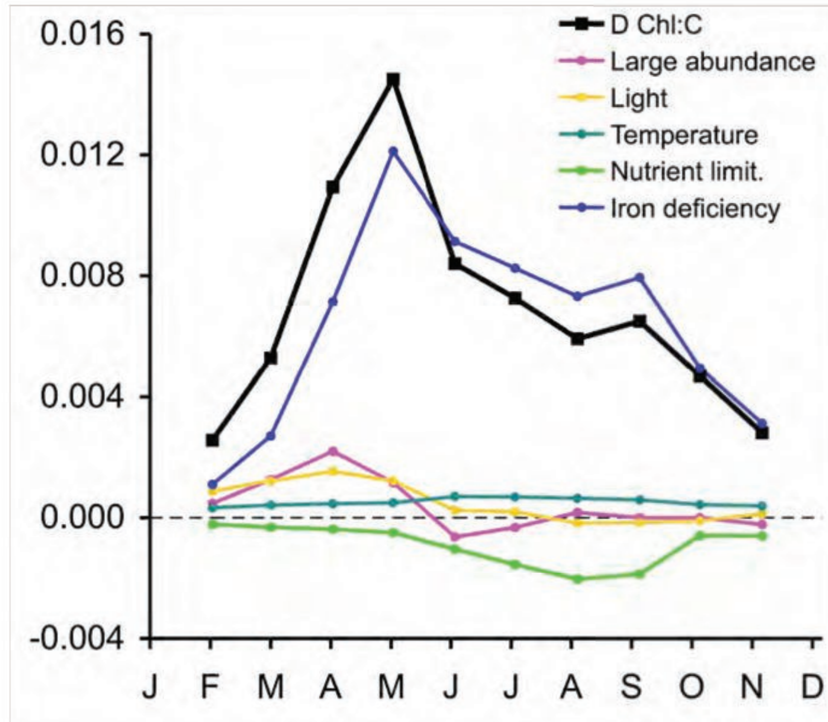




Phytoplankton Physiology

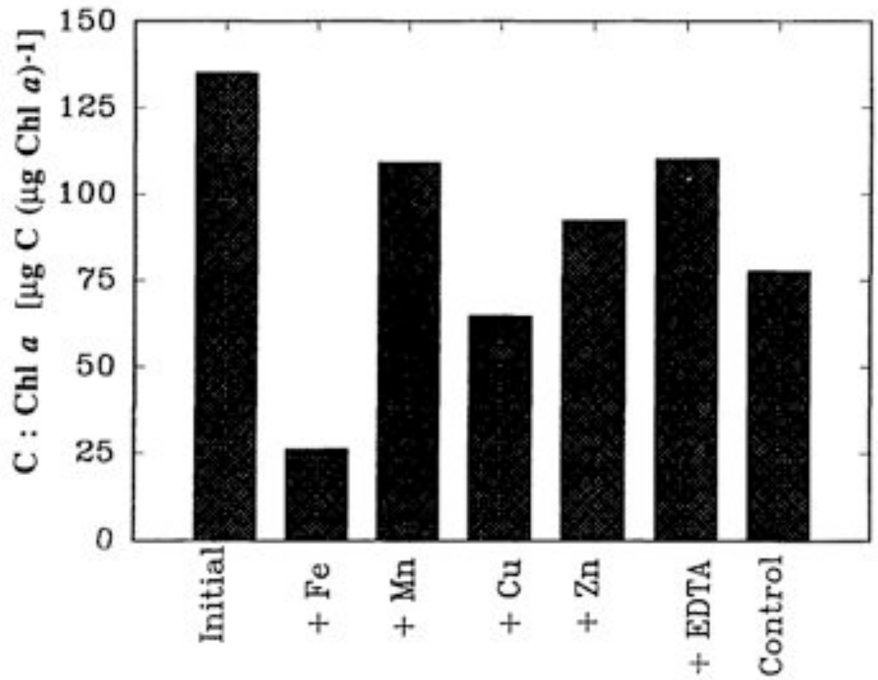
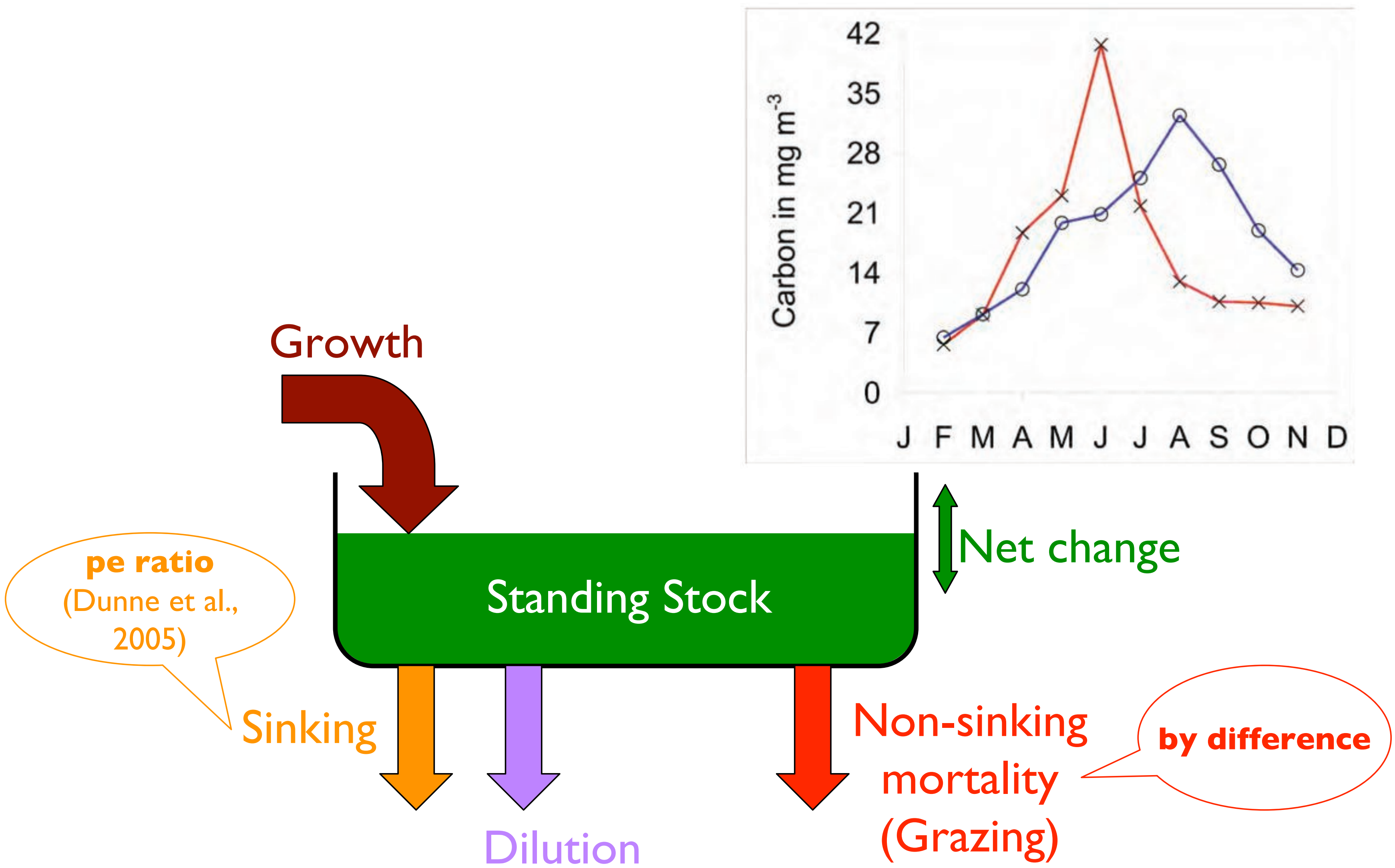


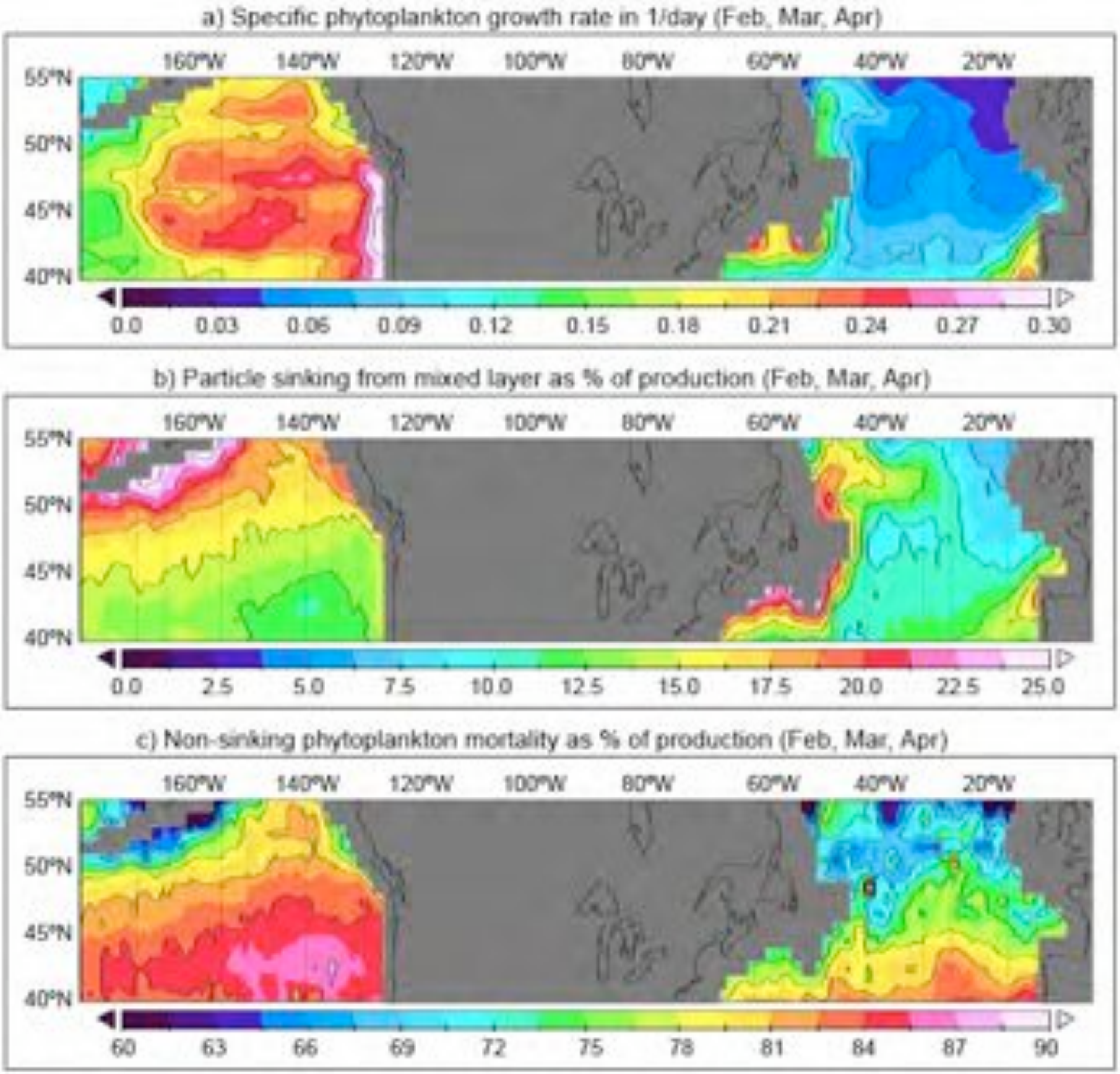
Fig. 6. Initial and final C : Chl *a* ratio for each metal treatment and control. Photosynthetic C was calculated to be the sum of the autofluorescent and diatom C as described in the text.

K. Coale (1991)

"Effects of Iron, Manganese, Copper, and Zinc Enrichments on Productivity and Biomass in the Sub-Arctic Pacific"

The Balance between Growth and Loss





Growth rate

Particle export (Dunne, 2005)

Non-sinking mortality (grazing)

Conclusions (refined)

- North Atlantic
  - Peak biomass and max. Chl:C coincide, leading to the quintessential chlorophyll bloom
  - Despite low growth rates, biomass accumulates rapidly in spring as the result of low sinking and grazing losses.

- North Pacific
  - Biomass increases are accompanied by decreases in Chl:C.
  - Low chlorophyll concentrations reflect suppressed Chl:C, not low biomass.
  - Iron deficiency is the main factor for reducing Chl:C.
  - Despite higher growth rates, biomass accumulates less rapidly in the Pacific as the result of higher sinking losses and grazing pressure.