Phytoplankton Physiology Seminar

Week 3, Session 2

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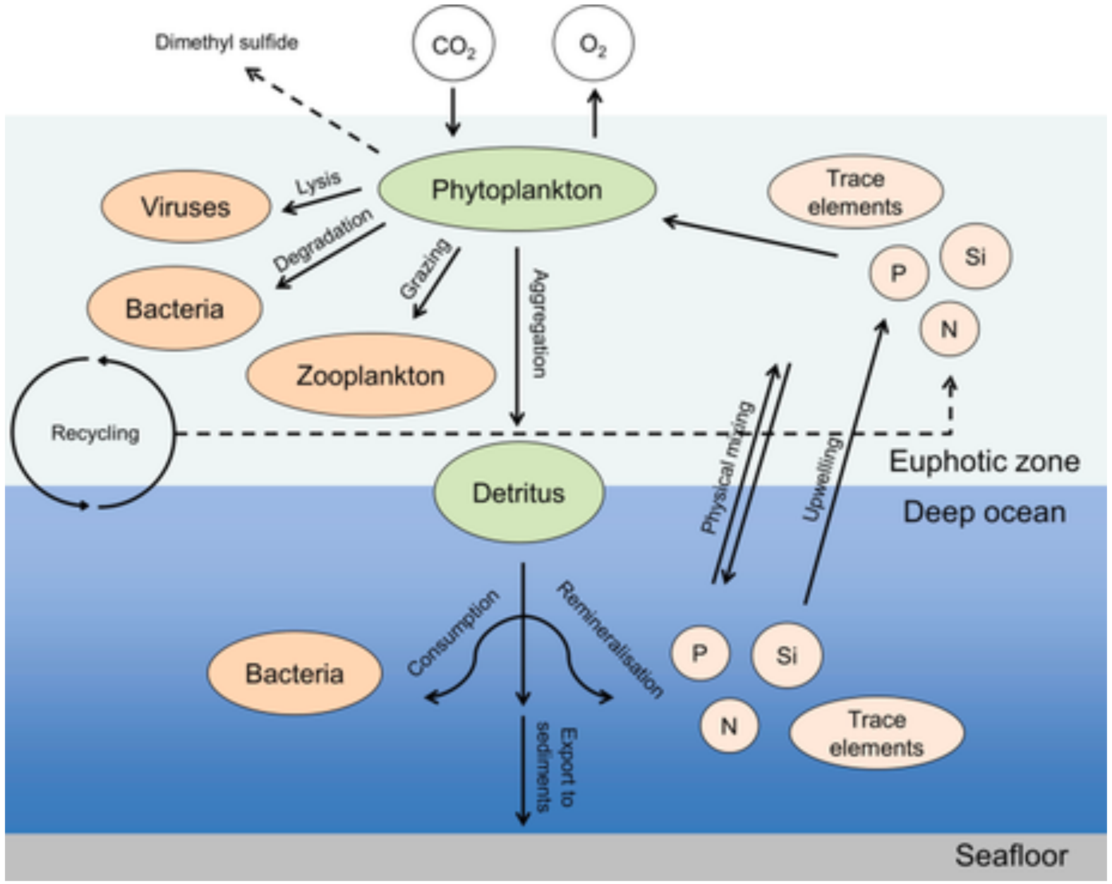
Some logistics!

- Sign up for papers!

Getting the ball rolling

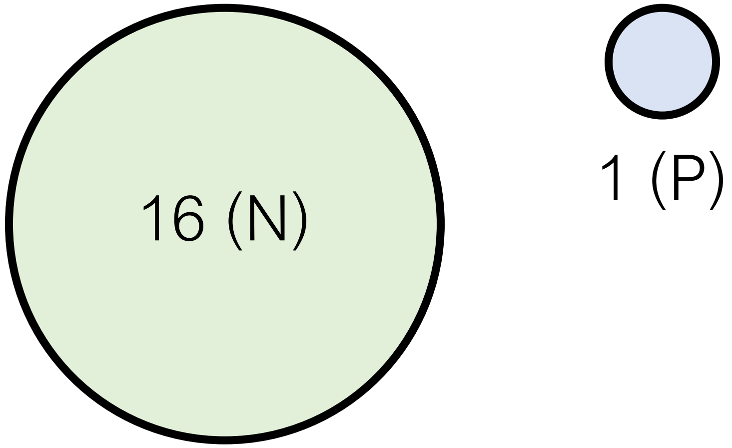
- Was anything surprising from today's papers? Was the "macromolecular breakdown" of the cell what you expected?
- What were your prior notions about the Redfield Ratio? Is it something you could envision using in your own research?

Nutrients play an important, but secondary role in phytoplankton ecology



- The majority of the cellular machinery will be devoted to light harvesting

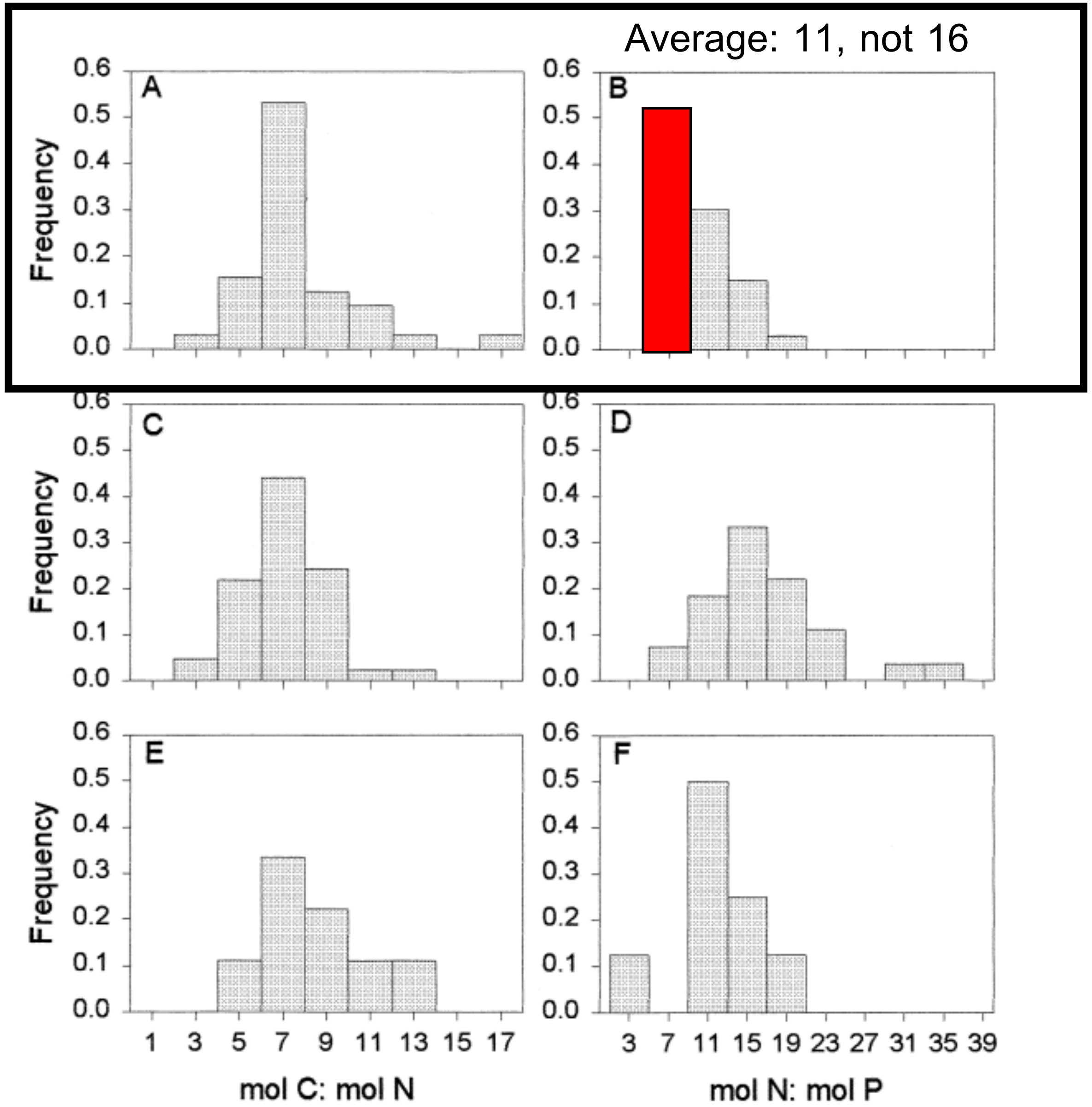
The Redfield Ratio



Three paradigms on Redfield:

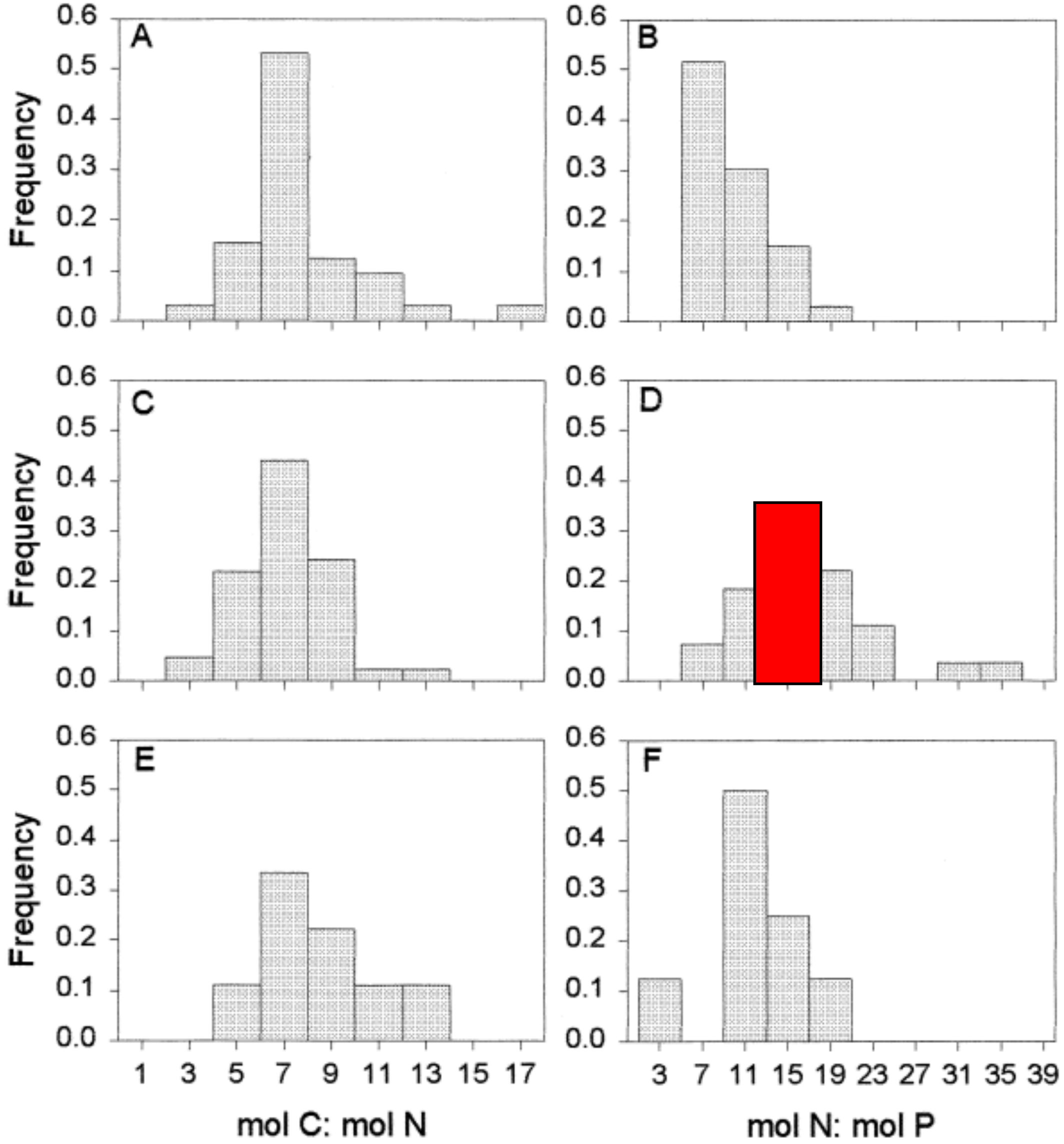
1) The ratio is the cellular N:P of living things
2) The ratio is the average N:P in inorganic material in the deep ocean
3) The ratio is just the fraction of the inorganic components of inorganic C

Cellular N:P does not seem to agree, even under nutrient-replete conditions

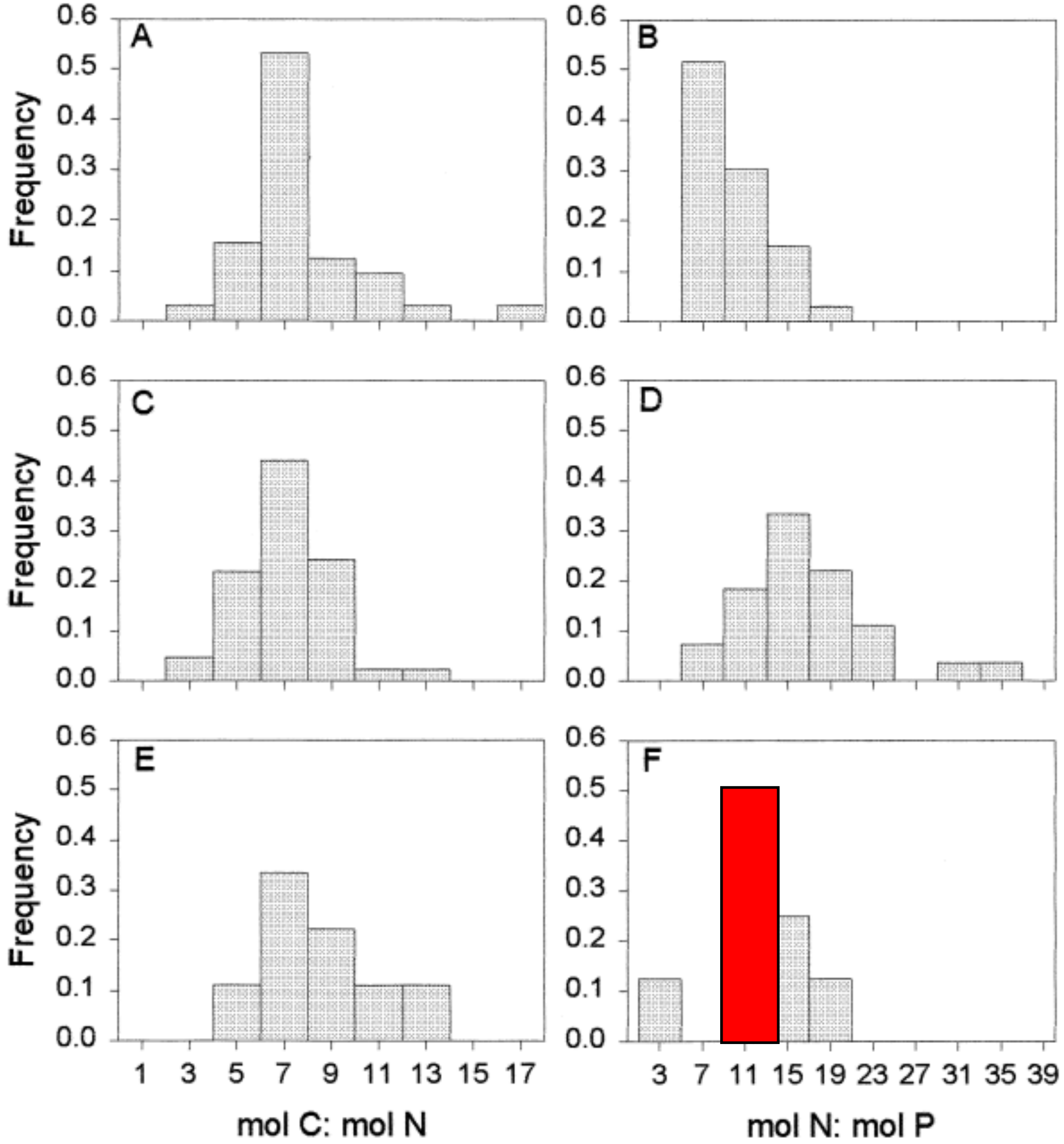


Cellular N:P does not seem to agree, even under nutrient-replete conditions

The ratio agrees better with the 15 average from marine particulate matter



Cellular N:P does not seem to agree, even under nutrient-replete conditions



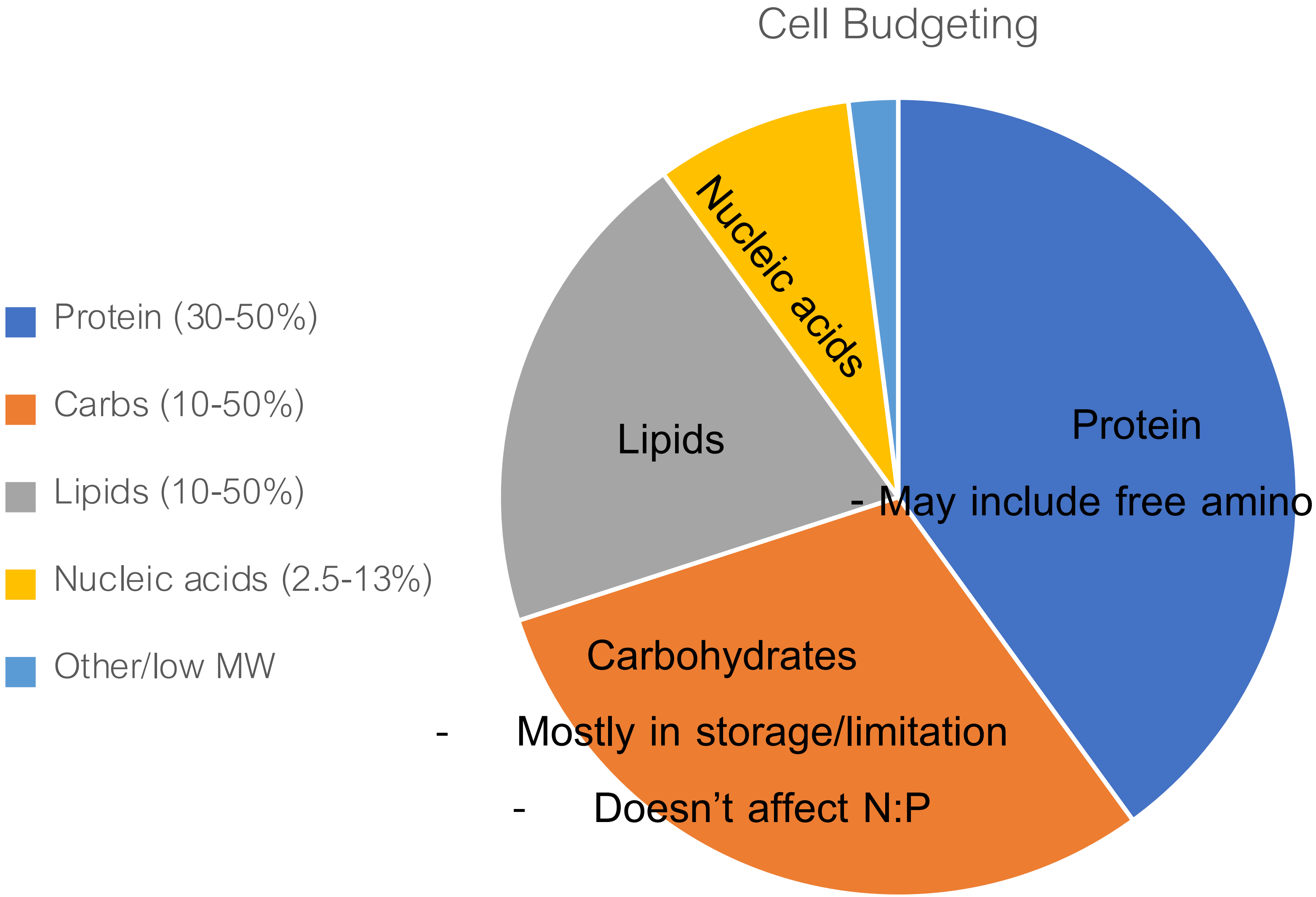
But nutrient drawdown during blooms appears to parallel cellular nutrient-replete conditions

So what contributes to cellular N:P being different from life-agnostic measurements?

Five essential observations from culture experiments

1. <5 to >100 is the range of N:P ratios observed in living organisms. So potentially a lot different than 16. But this is when either N-limited (<5) or P-limited (>100).
2. Phytoplankton are less willing to tolerate variability with respect to their **preferred** N:P ratio as growth rate increases.
3. When **NOT** limited, the range is 5-19 but usually **under** 16.
4. The critical N:P ratio (that we're about to discuss) is more like 20-50
5. C:N ratio is what tends to follow Redfield sans nutrient stress.

Macromolecular distribution in the cell



Protein
- May include free amino acids

Carbohydrates
- Mostly in storage/limitation
    - Doesn’t affect N:P

The critical N:P ratio

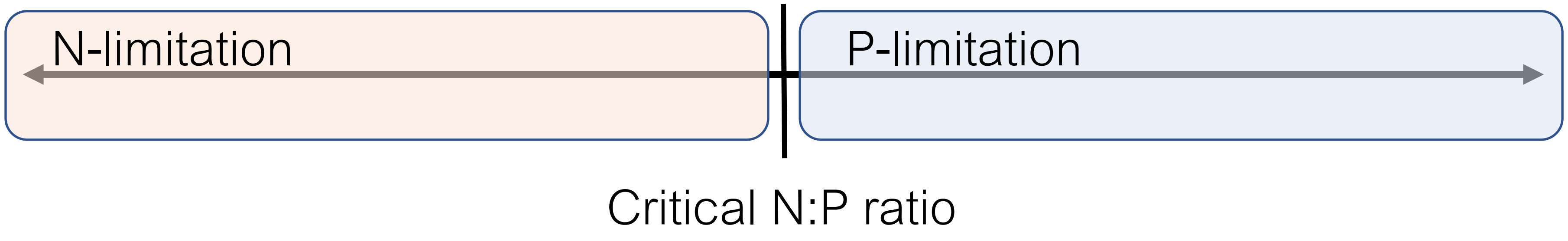
- The first modeling piece of the paper!
- We want to know: **how do organisms cope with the rapidly changing context of nitrogen and phosphorus in their environment**?
- In the cell, this will manifest as N- or P-limitation

The critical N:P ratio is complicated because the quota of one nutrient depends on the availability of the other.

- Under sharp N limitation, the quota of P will be higher
- This is because of (according to Geider)
  - The **physiological plasticity** of phytoplankton
  - The phenomenon of **luxury uptake**

The critical N:P ratio defines where N and P **purely co-limit** growth of phytoplankton

- At the critical N:P ratio, **both** nitrogen **and** phosphorus need to be increased in order for growth rate to increase.



The critical N:P is determined by the Droop model for the nutrient, to some extent

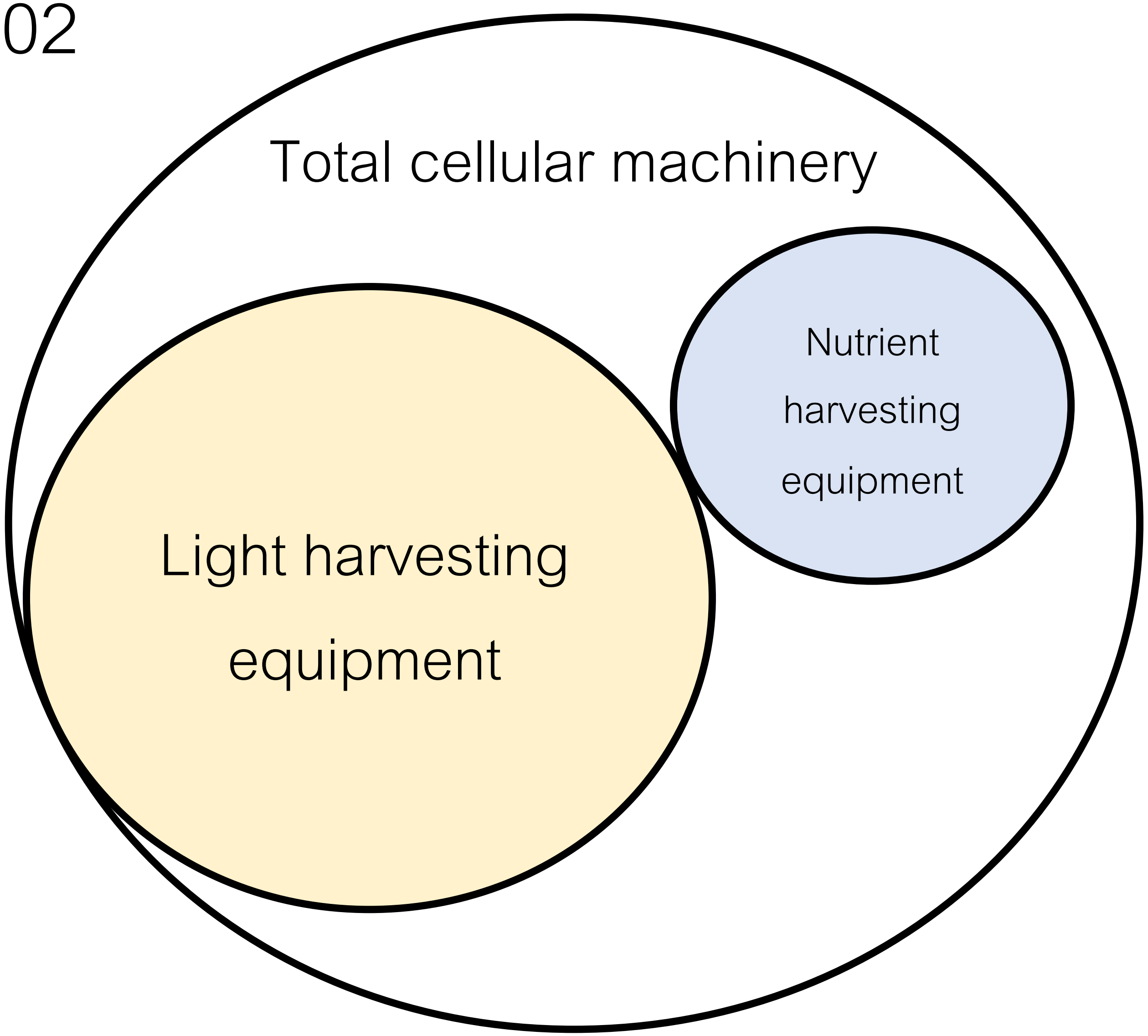
$$\mu = \frac{\mu'(Q_L - Q_{\min L})}{Q_L}$$

- The growth rate is equal to the maximum growth rate times the percentage difference between the current cellular quota of the limiting nutrient, and the minimum allowable quota of that nutrient.

We saw before that critical N:P for nutrient-replete cultures is typically roughly 20-50. What does this mean?

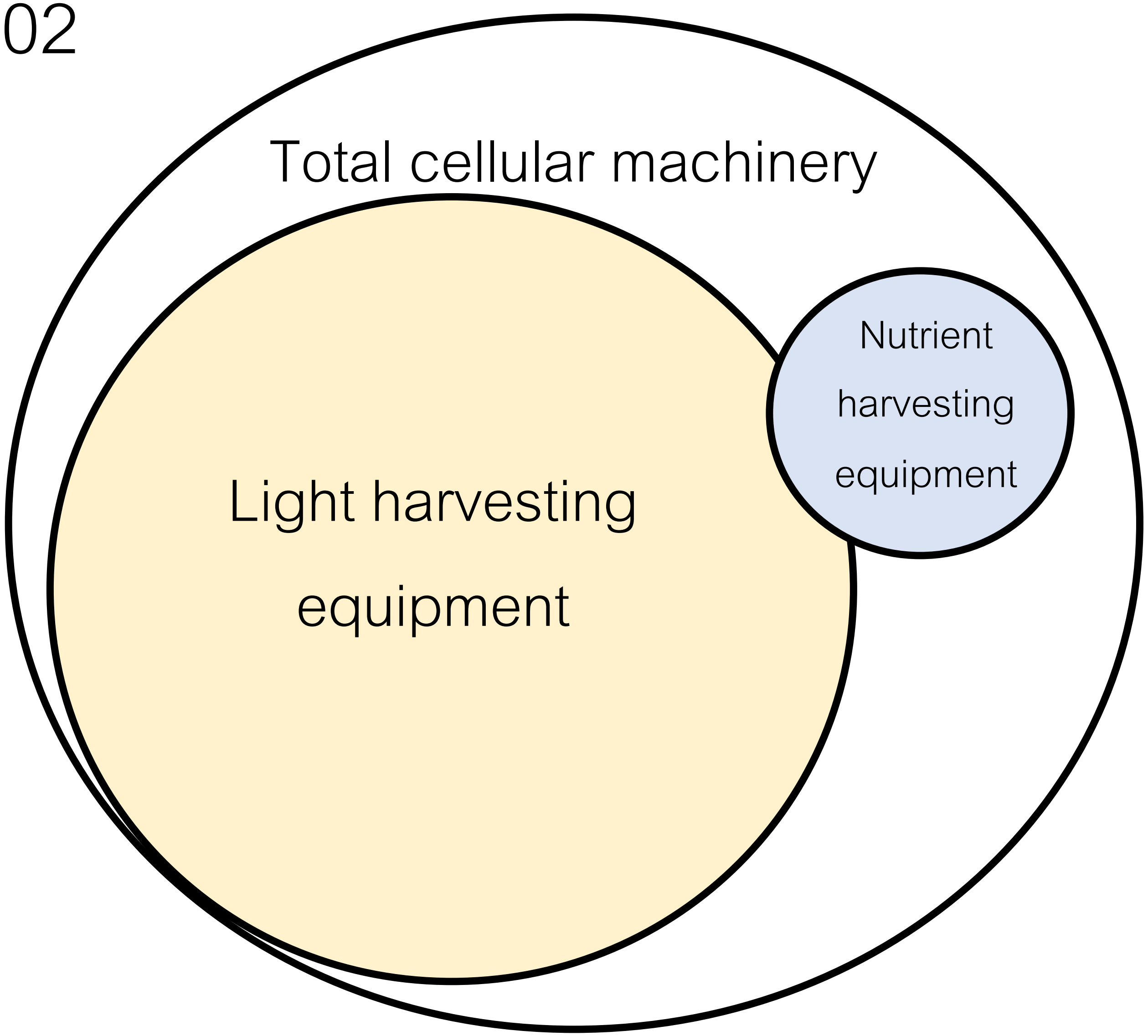
- Balance of N-limitation and P-limitation tends to occur when N is up to 2.5 times what it should be relative to P per Redfield.
- This means that P-limitation tends to be stricter and harder to come by. N limitation appears to be the norm, even when nutrients are replete (we less N relative to P, and P-limitation balances N-limitation at a higher value of N:P than what we expect).

Geider et al. 2002

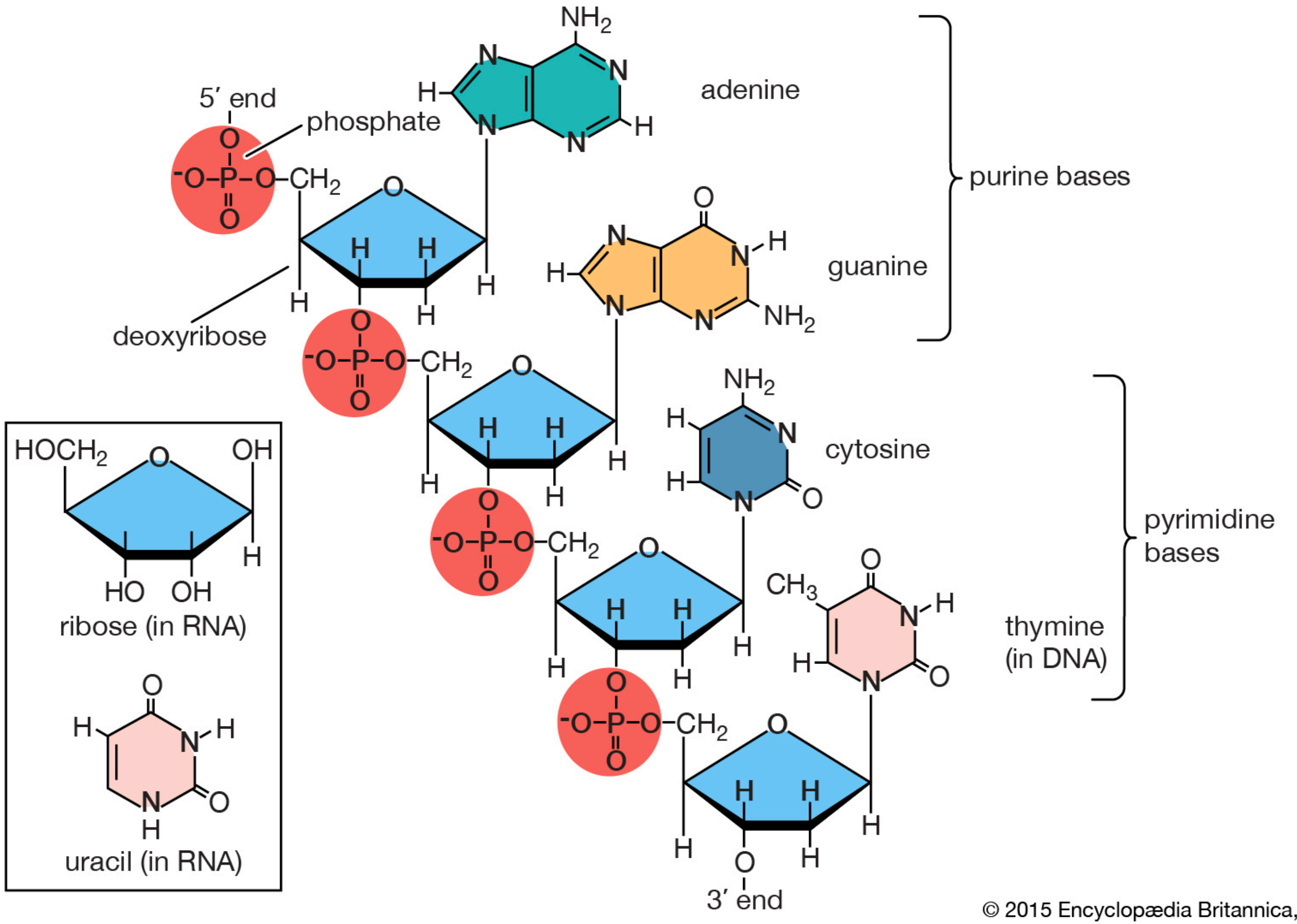


Geider et al. 2002

If more light equipment is needed, nutrient harvesting will **go by the wayside**



The molecular building blocks

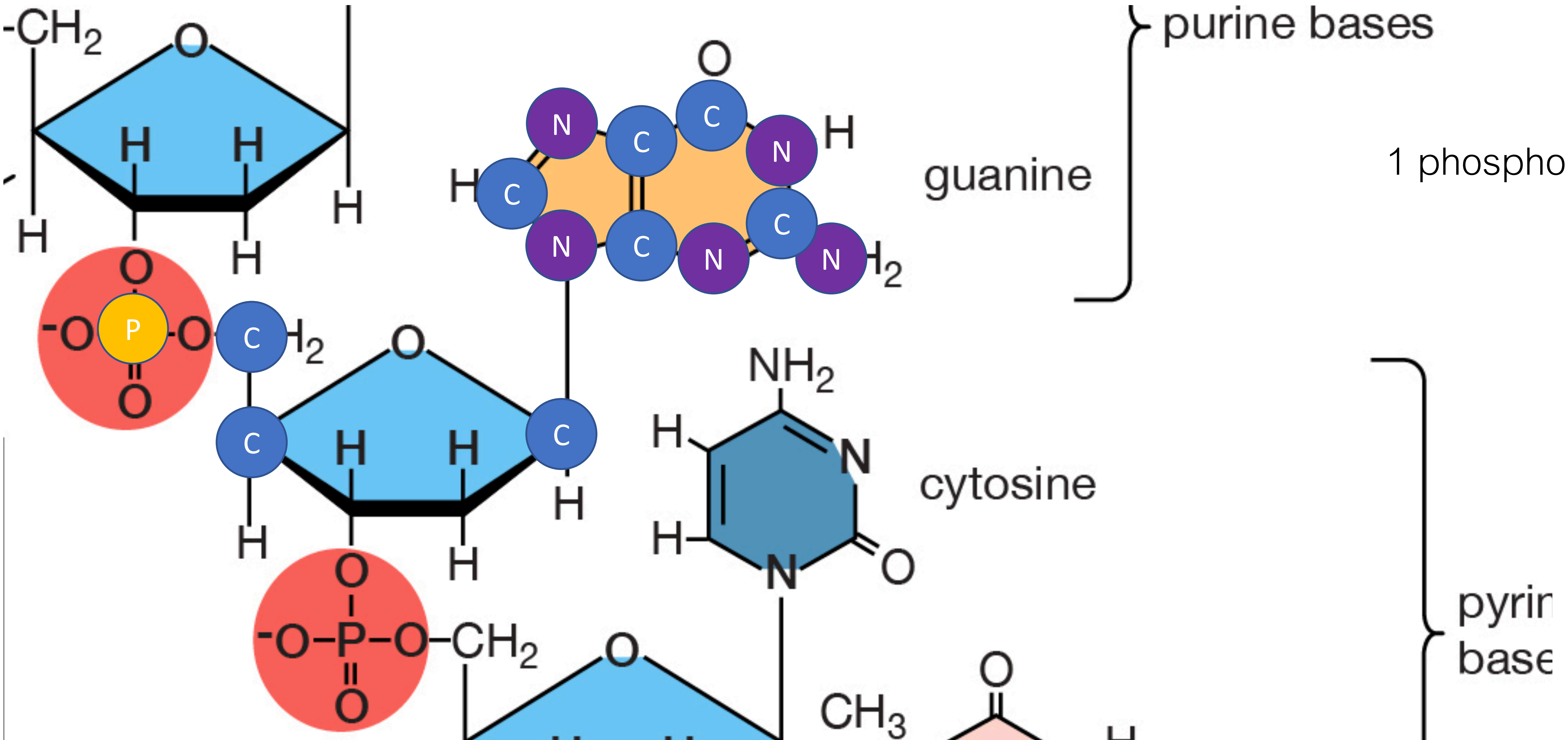


The molecular building blocks

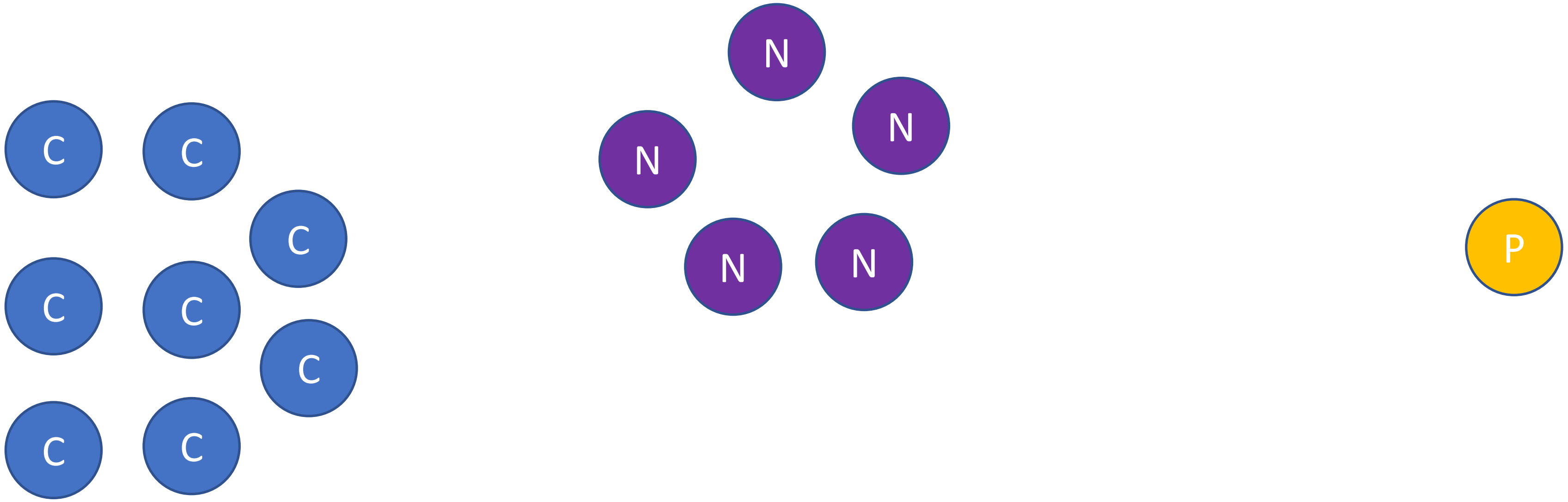
8 carbons

5 nitrogens

1 phosphorus



We could do a similar thing for all of the macromolecules in a cell

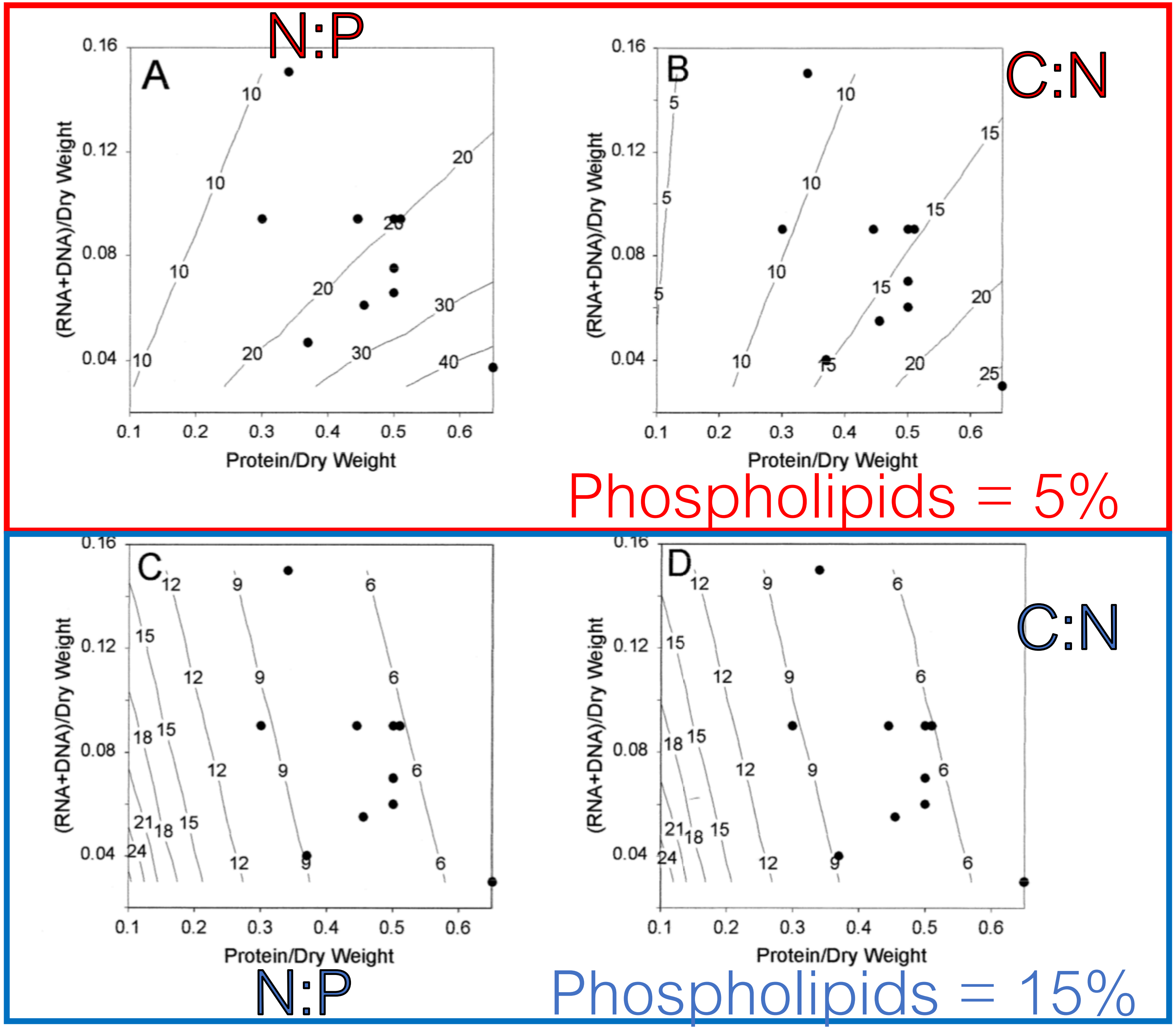


8:5:1 -> 25.6:16:3.2

C:N ratios might be closer to Redfield than N:P because of luxury uptake & plastic processes.

- Under P-limitation, for example, 100% of cell P offerings might be shuttled to RNA building (Laws et al. 1983b).
  - The cell needs to keep directing amino acids to be produced!
- Meanwhile, carbon reserves are being built up as a final source of available energy.
- So the C:N ratio may remain more stable because simultaneously
  - N in the cell is increasing relative to the P available
  - C in the cell is increasing due to storage
  - Under N limitation, C might not be possible to build up

Predicted N:P ratio variability is much greater than 16…but not as wide as what's observed in the field



Conclusions

- C:N roughly follows Redfield (6.6)…except with N-fixers
- But N:P is low when nutrients are replete and high when oligotrophic
- Assuming we know the content of the cellular building blocks, cells are probably just hoarding N and P under some form of limitation

Review > Geobiology. 2008 Jun;6(3):318-24. doi: 10.1111/j.1472-4669.2008.00144.x.

The co-evolution of phytoplankton and trace element cycles in the oceans

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Affiliations – collapse

Affiliation

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Fig 1

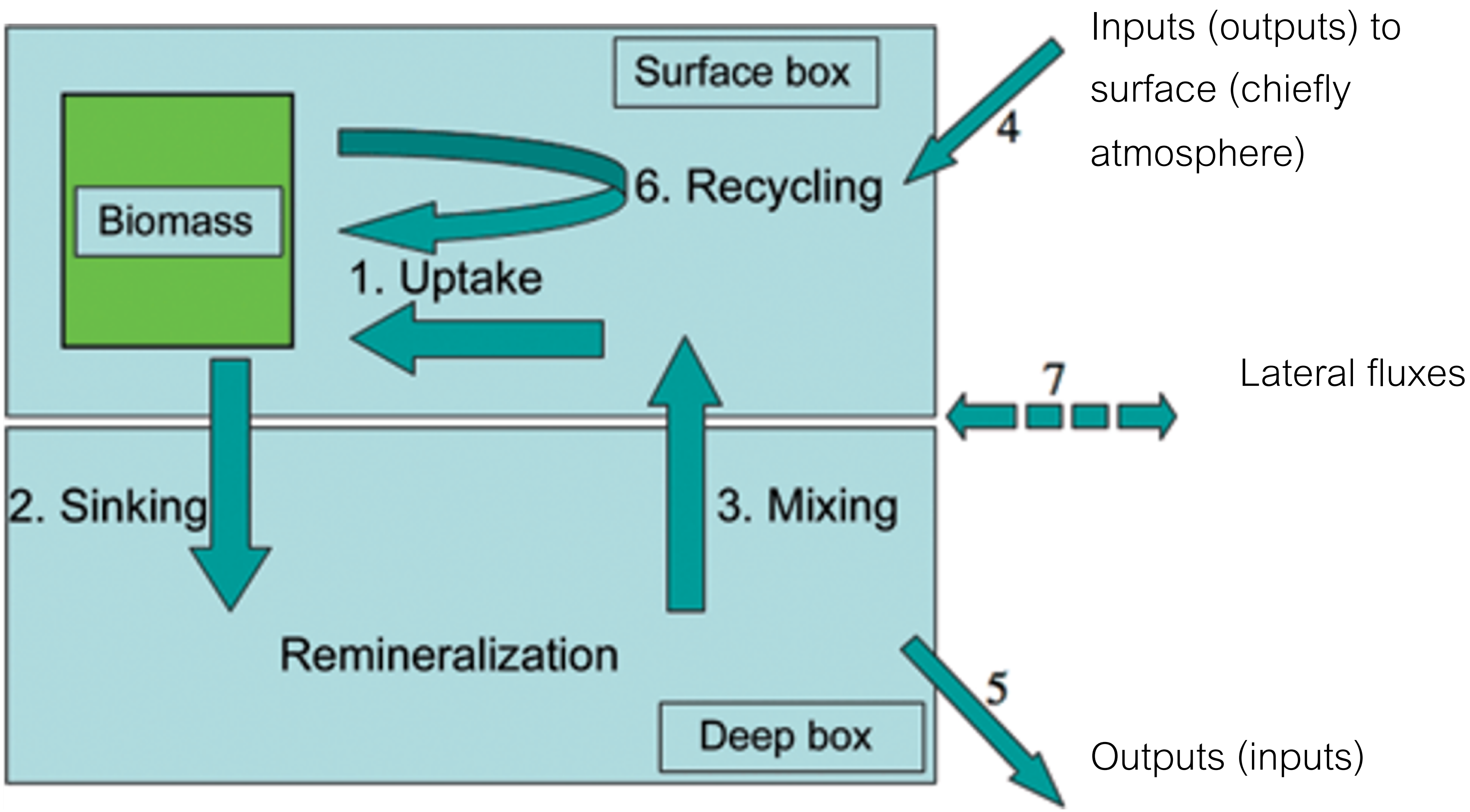


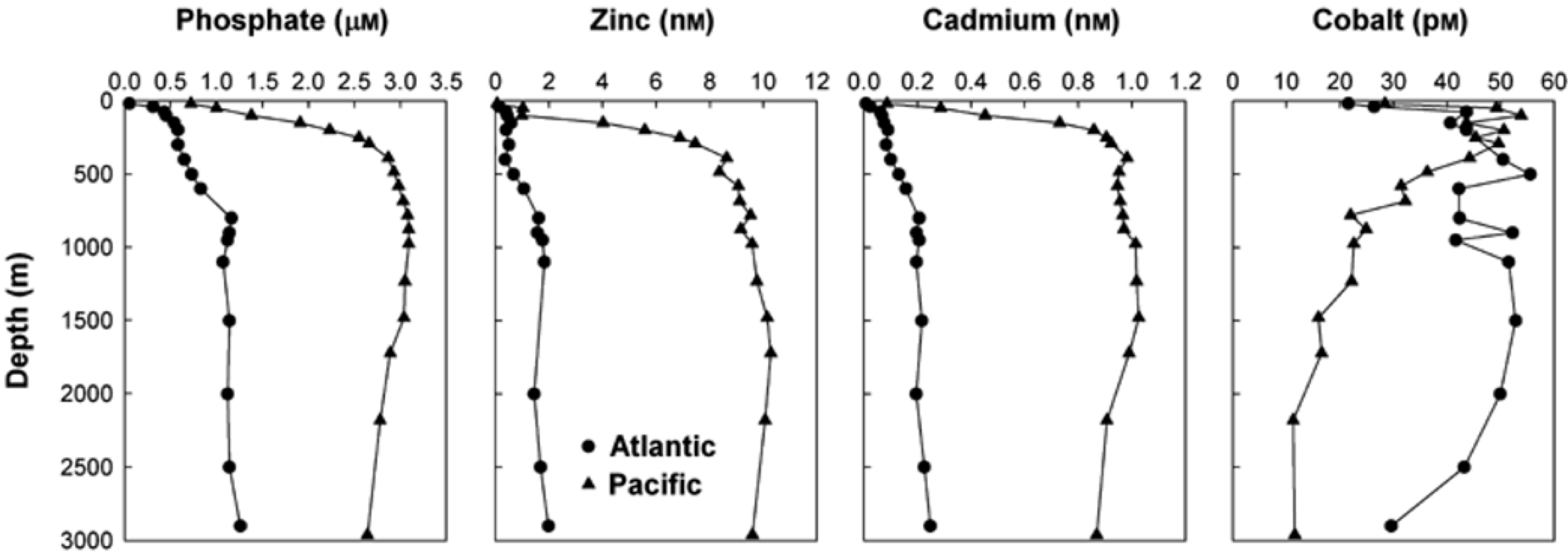
Diagram of a two-box model of the open ocean showing the principal fluxes of nutrients.

Stoichiometry of Seawater and Phytoplankton

$$\text{Deep Pacific ocean: } P_{1000}\,Fe_{0.22}\,Zn_{3.1}\,Mn_{0.10}\,Cu_{0.75}\,Co_{0.007}\,Cd_{0.33}\,Ni_{2.9} \tag{1}$$

$$\text{Pacific plankton: } P_{1000}\,Fe_{4.1}\,Zn_{2.4}\,Mn_{0.35}\,Cu_{0.45}\,(Co_{0.2})\,Cd_{0.54}\,Ni_{0.60} \tag{2}$$

Fig 2



Concentrations profiles of P, Zn, Cd and Co in the Pacific and Atlantic oceans. Pacific data are from station T7 (50.0ºN, 145.0ºW) (Martin et al., 1989); Atlantic data are from a station at 47ºN, 20ºW (Martin et al., 1993).

Defining metal uptake by phytoplankton

$$\text{uptake rate of M} = \rho^M = k_f^M \cdot M' \cdot L^M$$

Steady state in euphotic zone = uptake matches supply:

$$\text{total flux of M} = \sum \rho^M = k_f^M \cdot M' \cdot \sum L^M$$

Rearranged:

$$k_f^M \cdot M' = (\text{total flux of M}) / \sum L^M$$

M = essential trace metal

pM = rate of phytoplankton cell uptake of M

k_f^M = second order rate constant for reaction

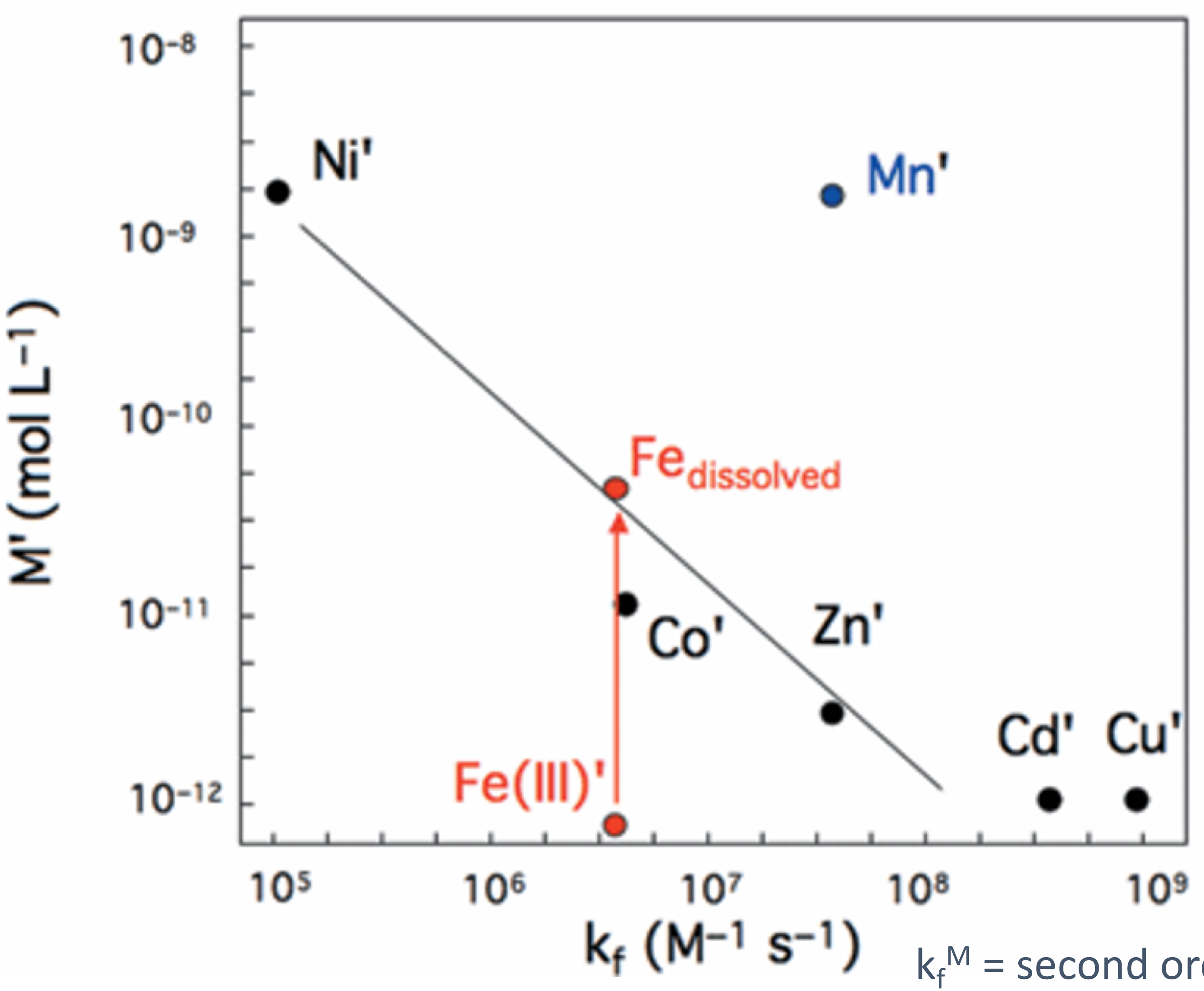
M' = unchelated* concentration of M in external medium

*chelation = bonding of ions and molecules to metal ions

L^M = concentration of uptake ligands for M on cell surface

Fig 3

M' = unchelated concentration of M in external medium



k_f^M = second order rate constant for reaction

Inverse proportionality between the unchelated concentrations of essential trace metals in surface seawater and the second order rate coefficient for complexation.

Comparison of Elemental Composition

- Pacific plankton: $Fe_{4.1}$ $Zn_{2.4}$ $Mn_{0.35}$ $Cu_{0.45}$ ($Co_{0.2}$) $Cd_{0.54}$ $Ni_{0.60}$ (2)
- *Chlamydomonas*: Fe_4 $Zn_{0.5}$ $Mn_{0.7}$ $Cu_{0.2}$ $Co_{0.002}$ $Cd_?$ $Ni_?$ (3)
- *Homo sapiens*: Fe_4 Zn_2 $Mn_{0.01}$ $Cu_{0.06}$ $Co_{0.003}$ $Cd_{0.02}$ $Ni_{0.01}$ (4)

Fig 4

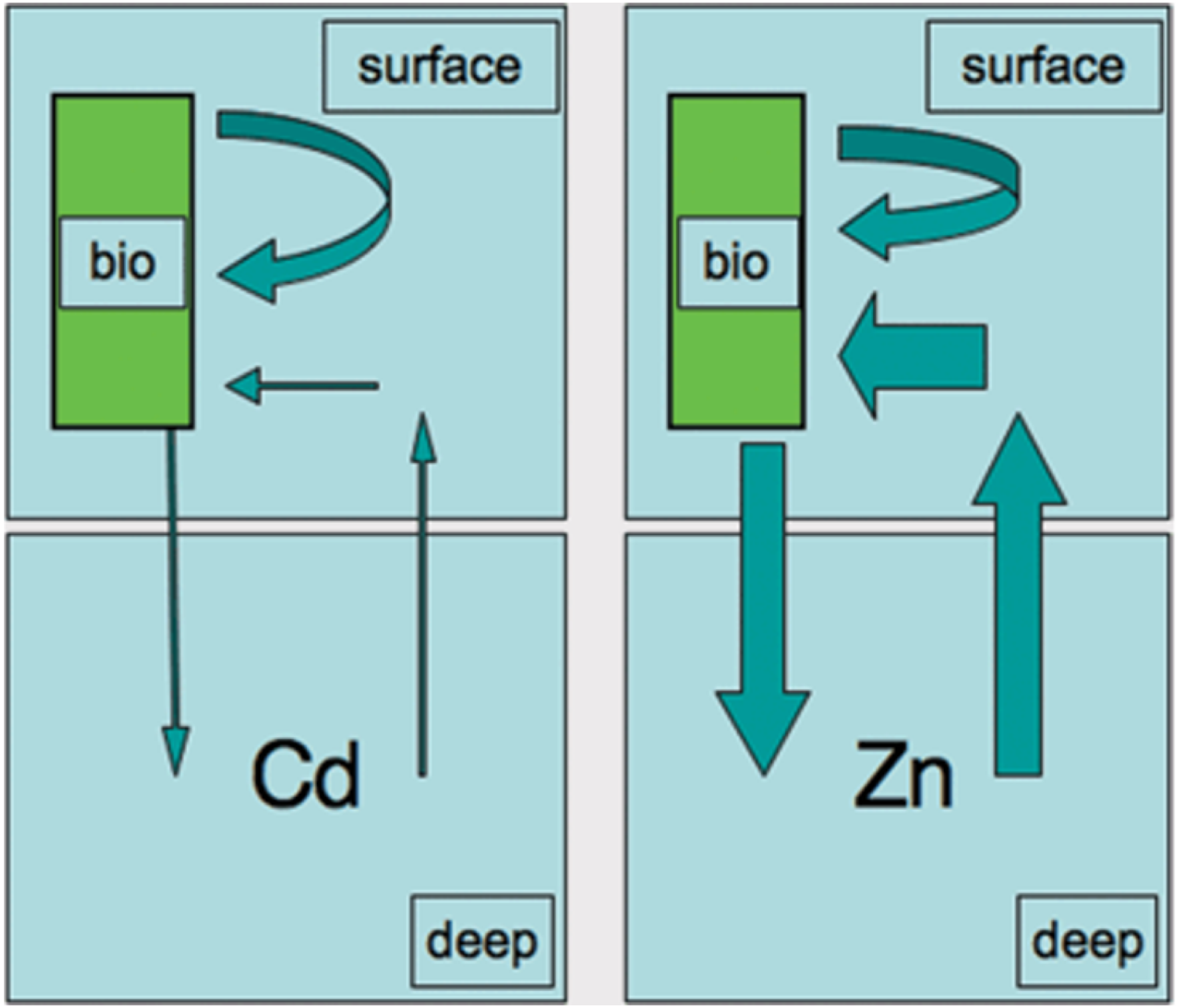


Illustration of the contrast between the oceanic cycles of Zn and Cd: the proportion of Cd taken up by the plankton that comes from recycling in surface water is much larger than that of Zn. This is necessitated by a larger Cd:Zn ratio in plankton than in deep seawater.