Phytoplankton Physiology Seminar

Week 1, Session 0

Mick Follows, Instructor

Arianna Krinos, Teaching Assistant

Some logistics!

- Meet 1 time/week for 1.5 hours (Fridays 1-2:30pm)
- Other than participation in weekly discussions, students are required to lead the discussion approximately twice over the course of the semester
- 1-2 papers will be discussed per week, and each will have a discussion leader

Landscape of this brief introduction

I. The ocean context

II. The microbial loop + biological carbon pump

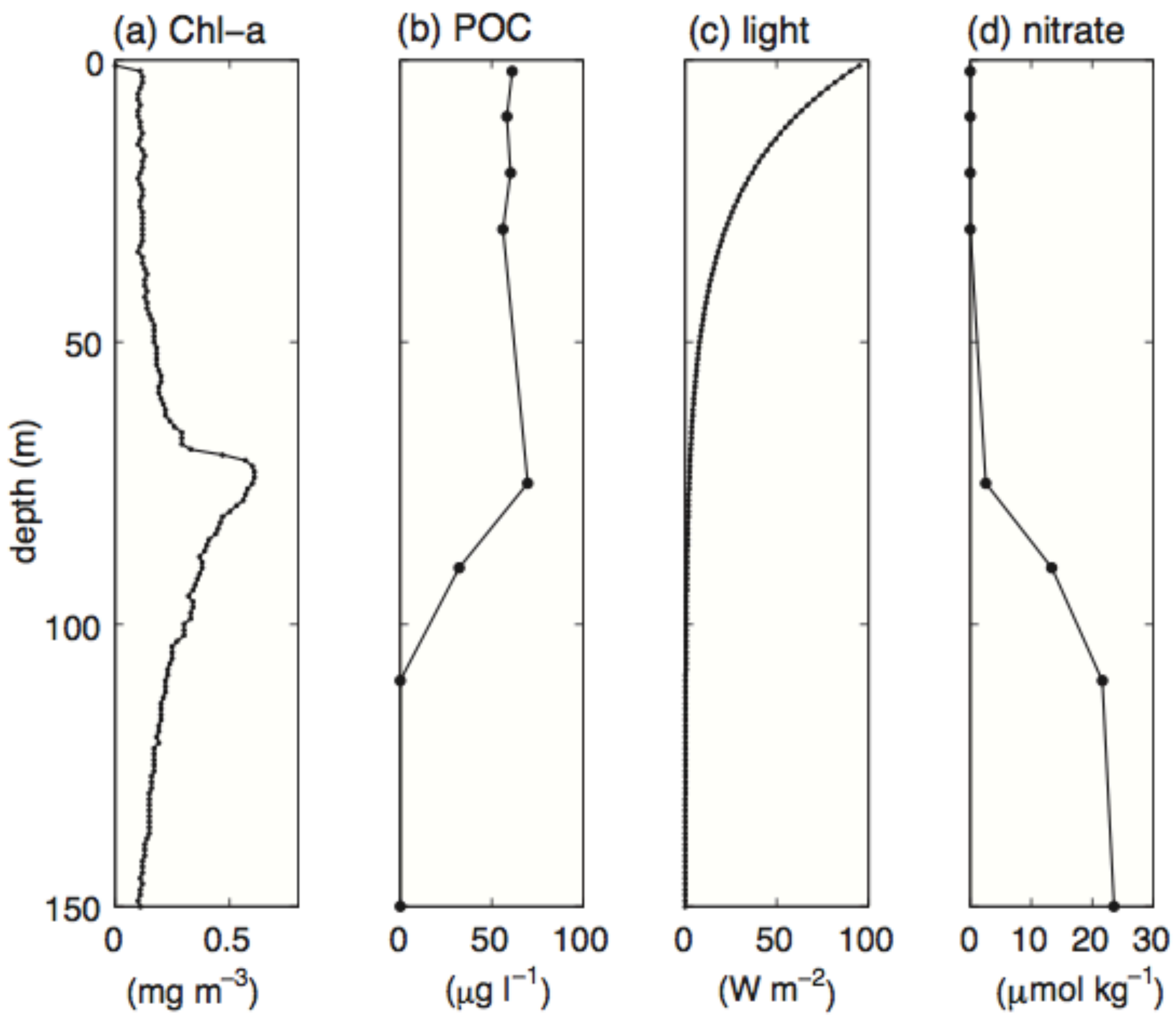
   I. Why phytoplankton, though small, are mighty in global ocean ecology + even physics and chemistry

III. A primer on phytoplankton sizes, functions, and physiological features

IV. An introduction to major taxonomic groups

The oceanic context for phytoplankton communities

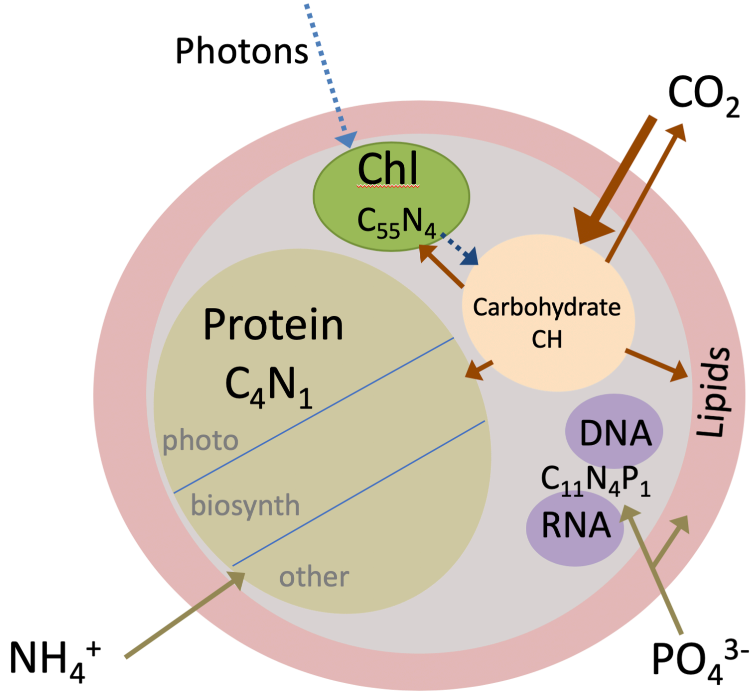
Light and mixing in the upper ocean enables phytoplankton growth



Average molar elemental composition of phytoplankton

The **Redfield Ratio** describes average particle nutrient ratios

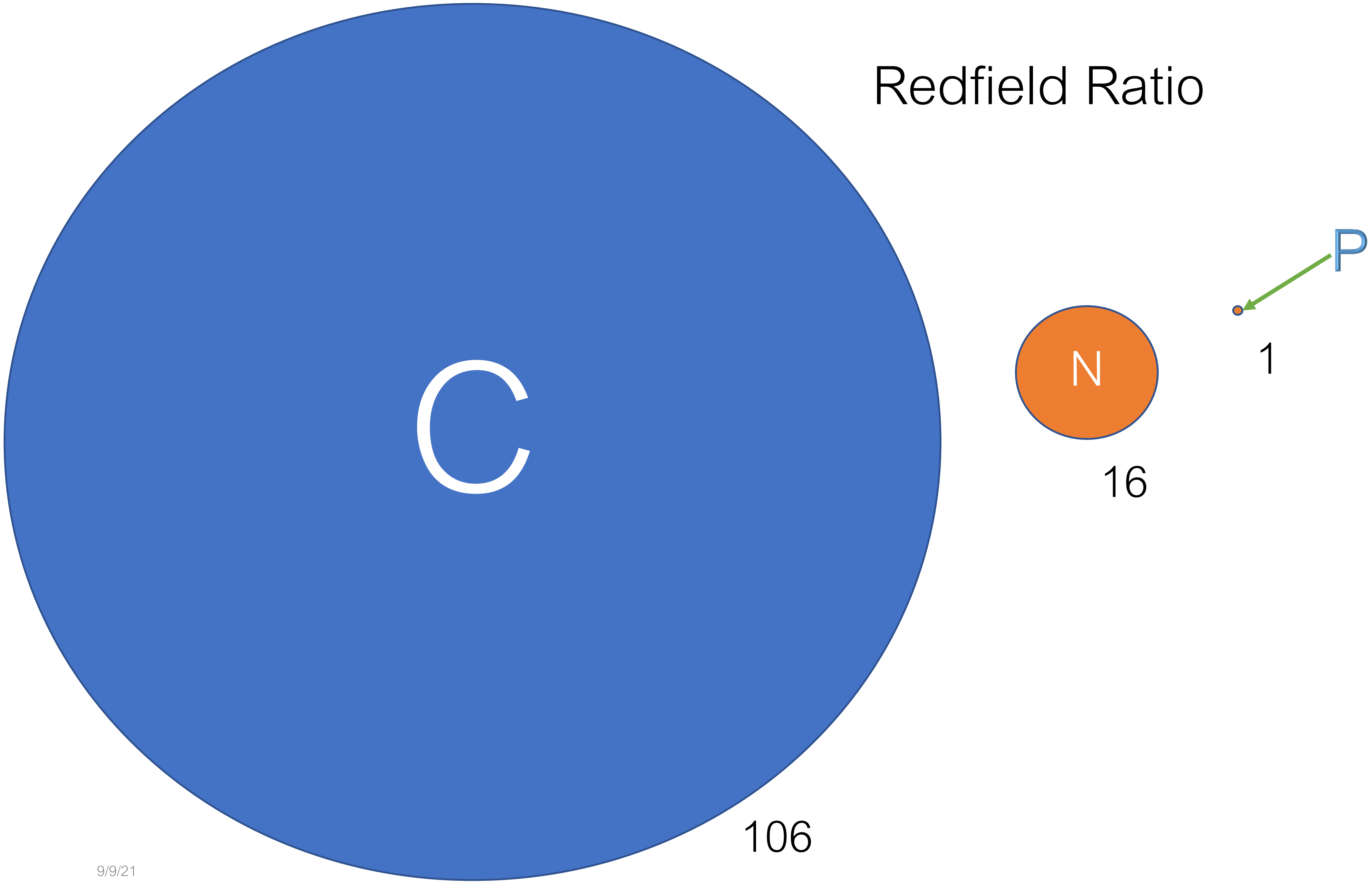
$$C:N:P:O_2 \approx 106:16:1:138$$



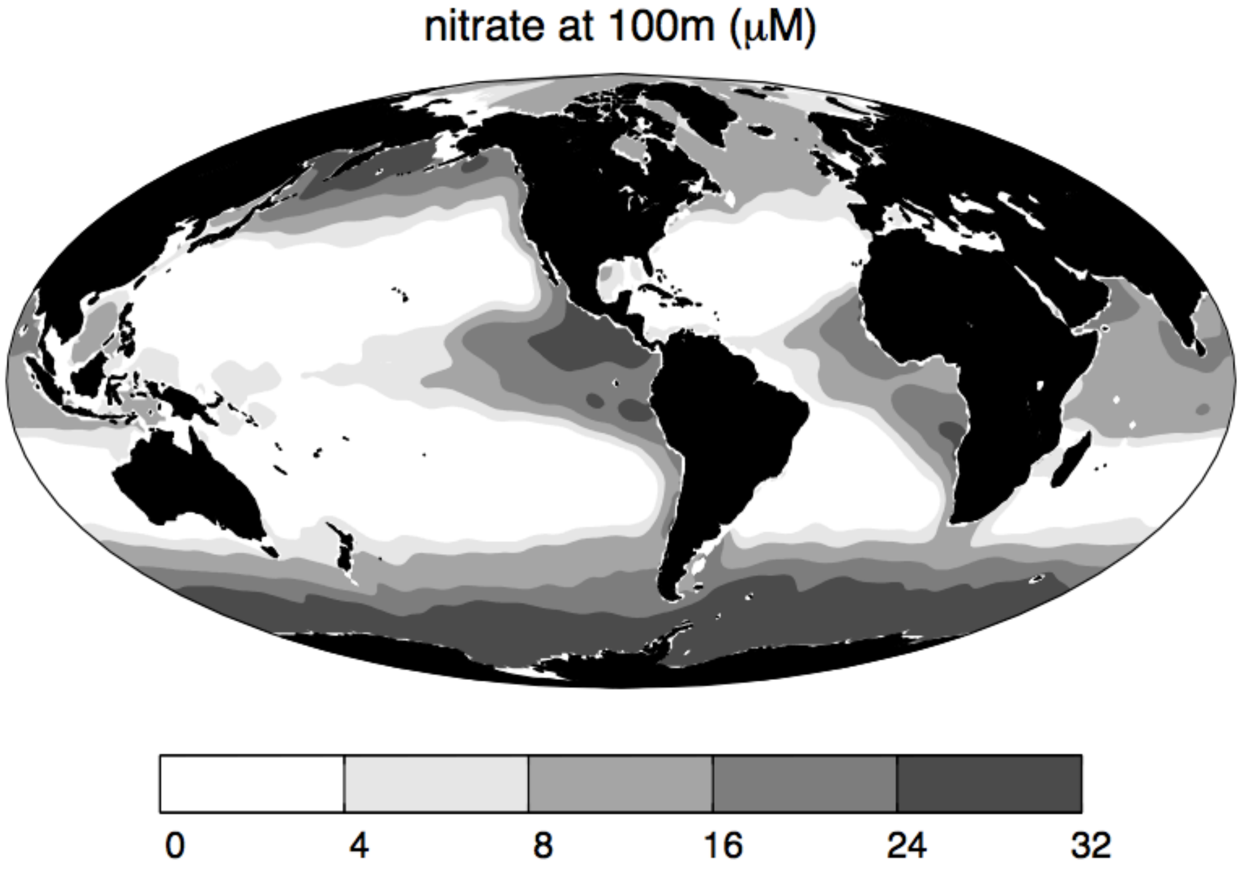
Notes:

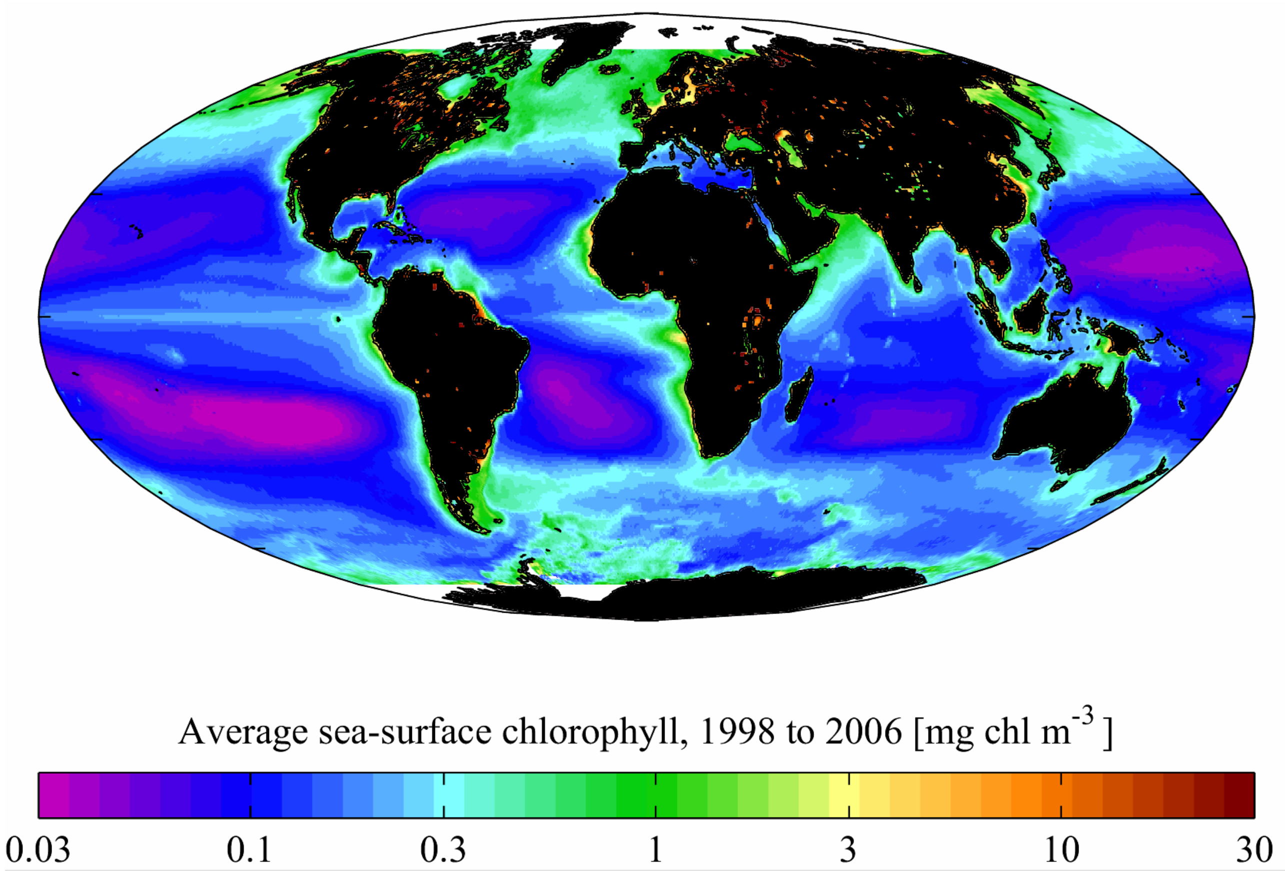
- Highlighted by Alfred Redfield in 1930s
- O_2 estimated by Redfield from Redox/thermodynamic considerations
- Recent authors find the values aren't always constant

Redfield Ratio



Near surface nitrate concentration reflects pattern of upwelling



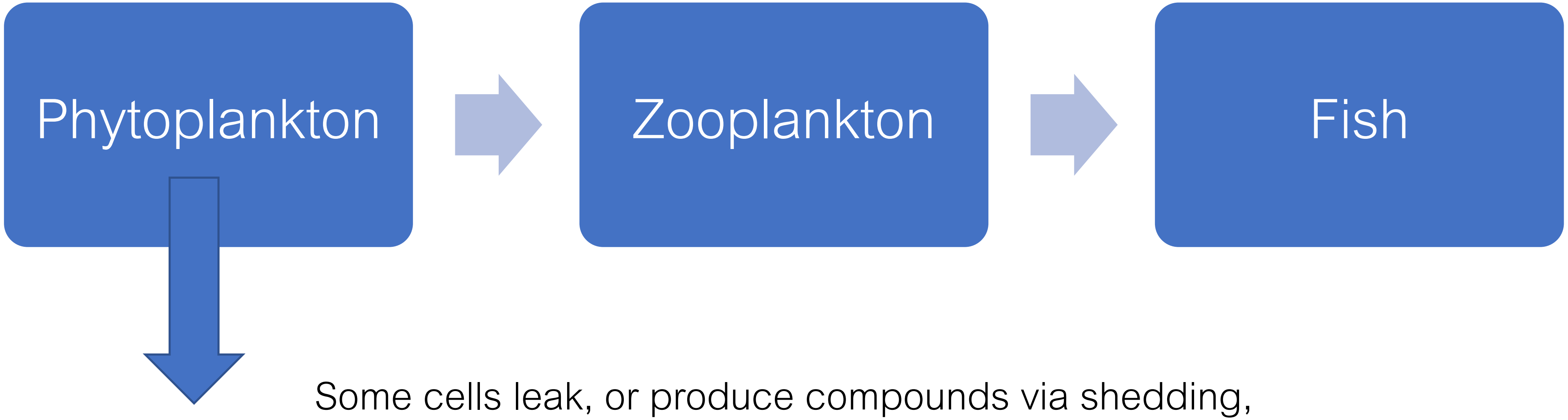


Carbon doesn't typically limit phytoplankton growth – other nutrients do

Why are phytoplankton important?

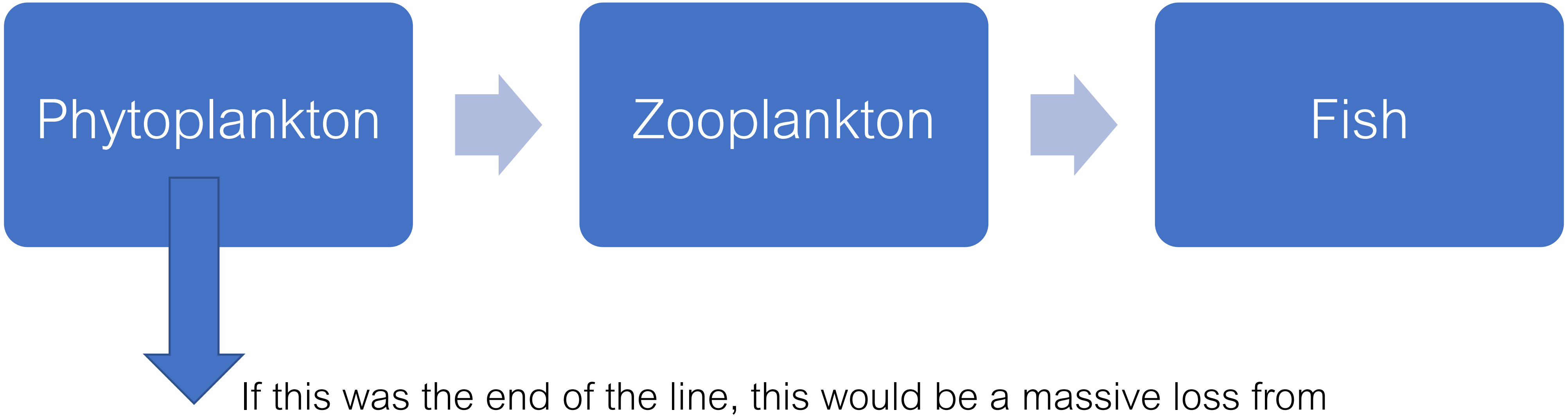
The traditional paradigm of the ocean food web

It turns out that this oversimplifies things…



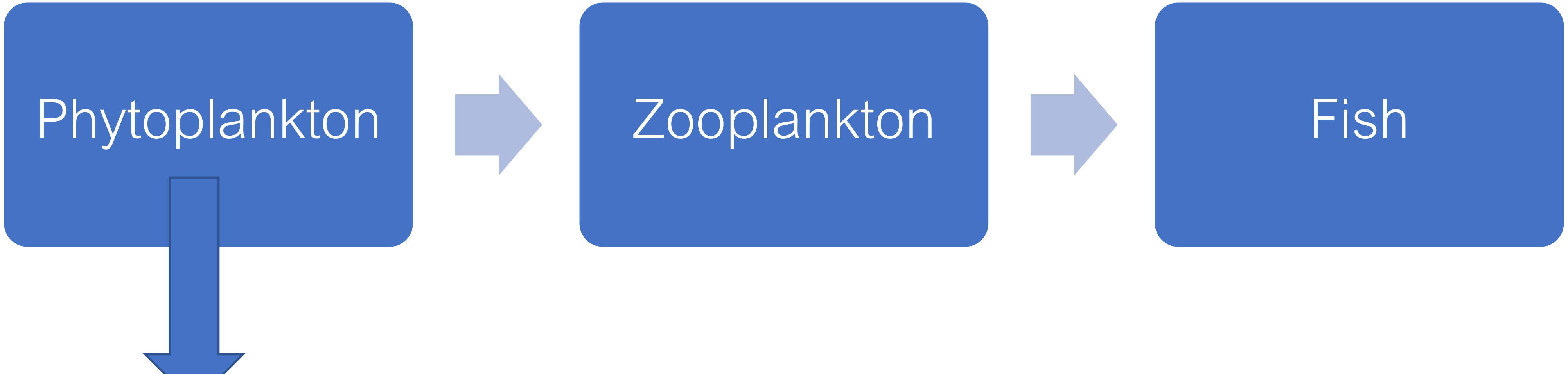
Some cells leak, or produce compounds via shedding, dissolution, etc. The feeding process also tends to be messy.

It turns out that this oversimplifies things…



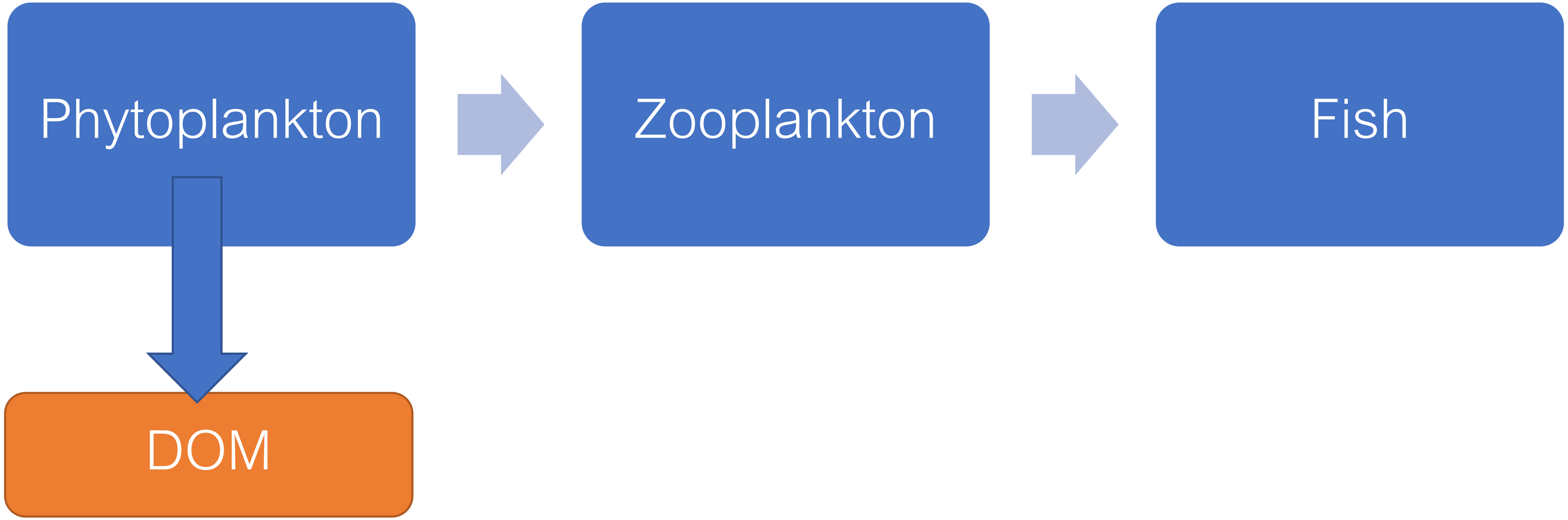
If this was the end of the line, this would be a massive loss from the surface, quickly.

It turns out that this oversimplifies things…



Instead, organic matter + nutrients are kept cycling in the productive surface oceans via the microbial loop.

It turns out that this oversimplifies things…



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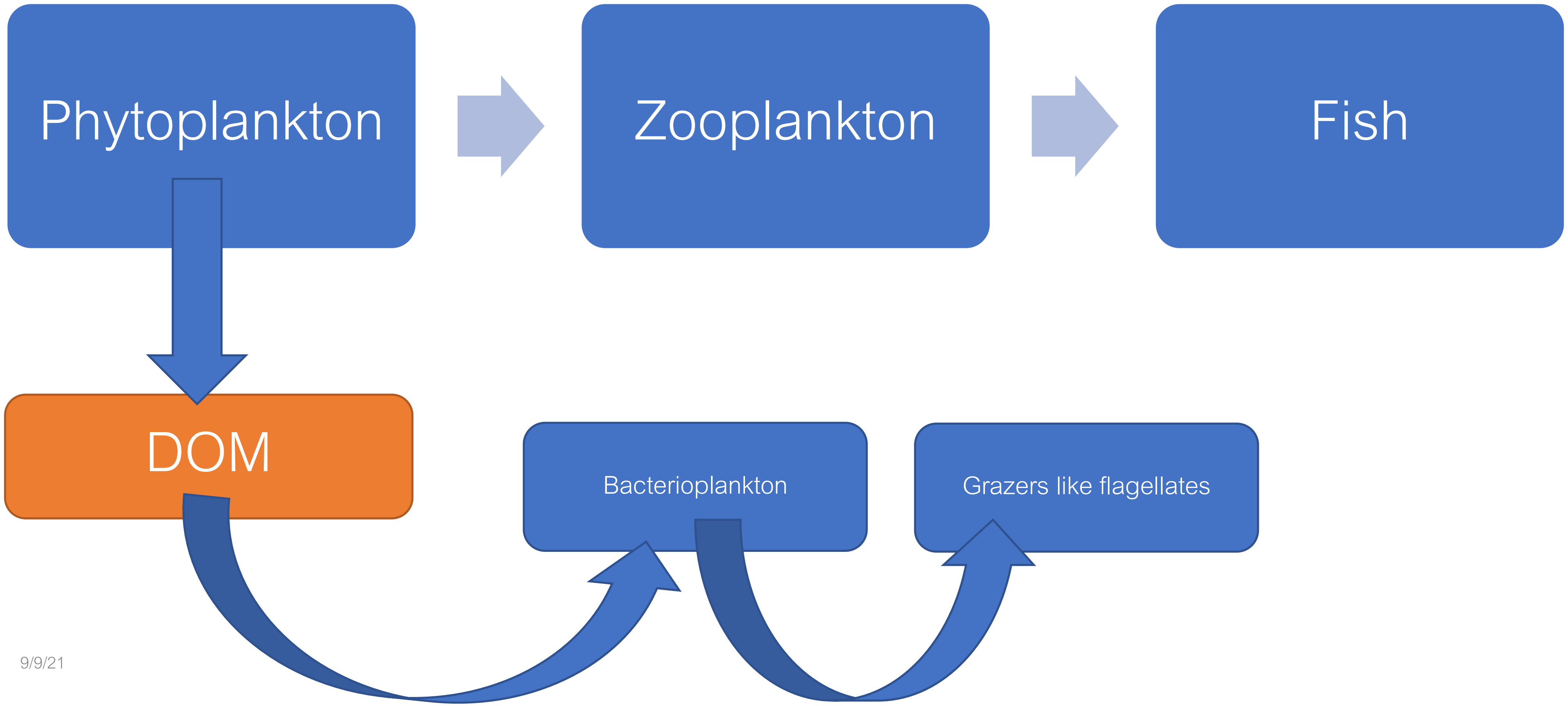

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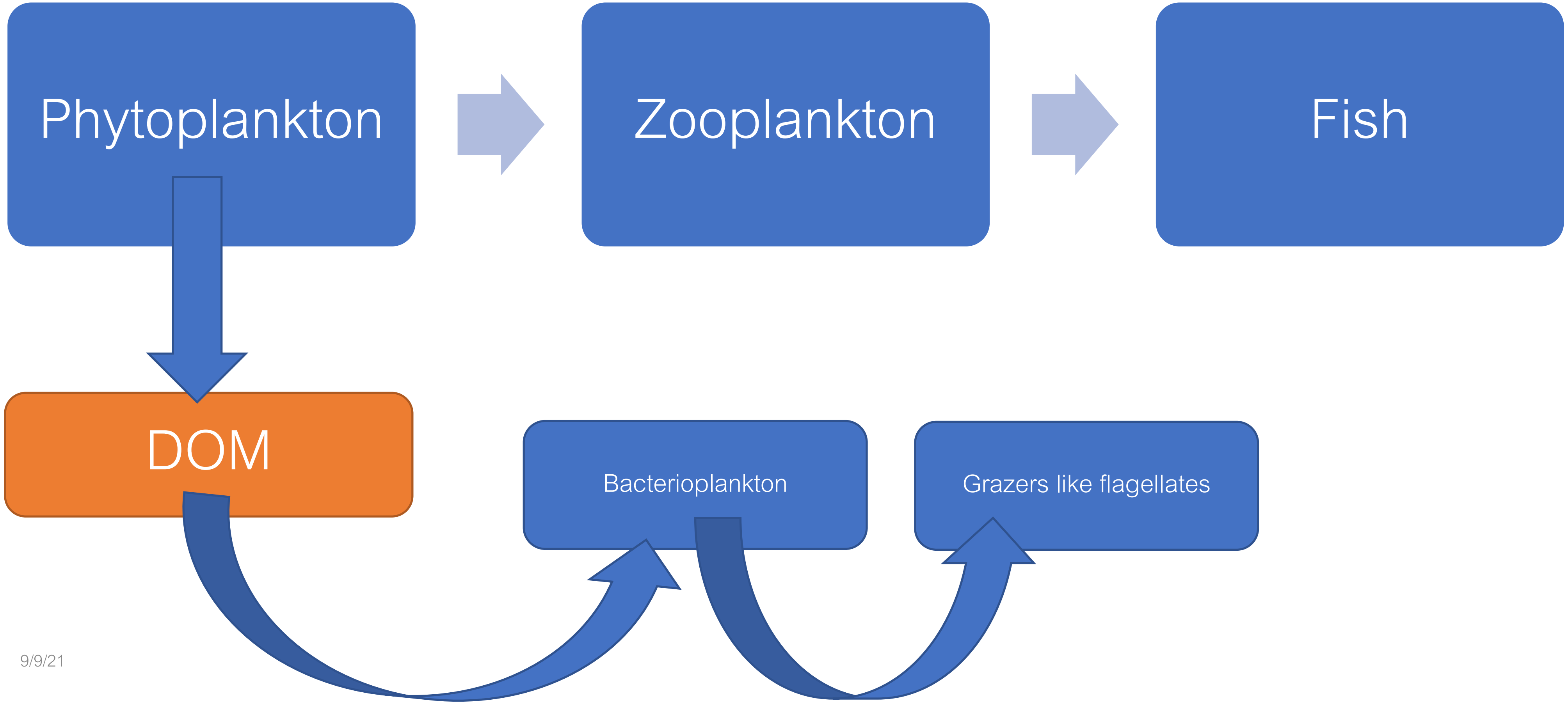

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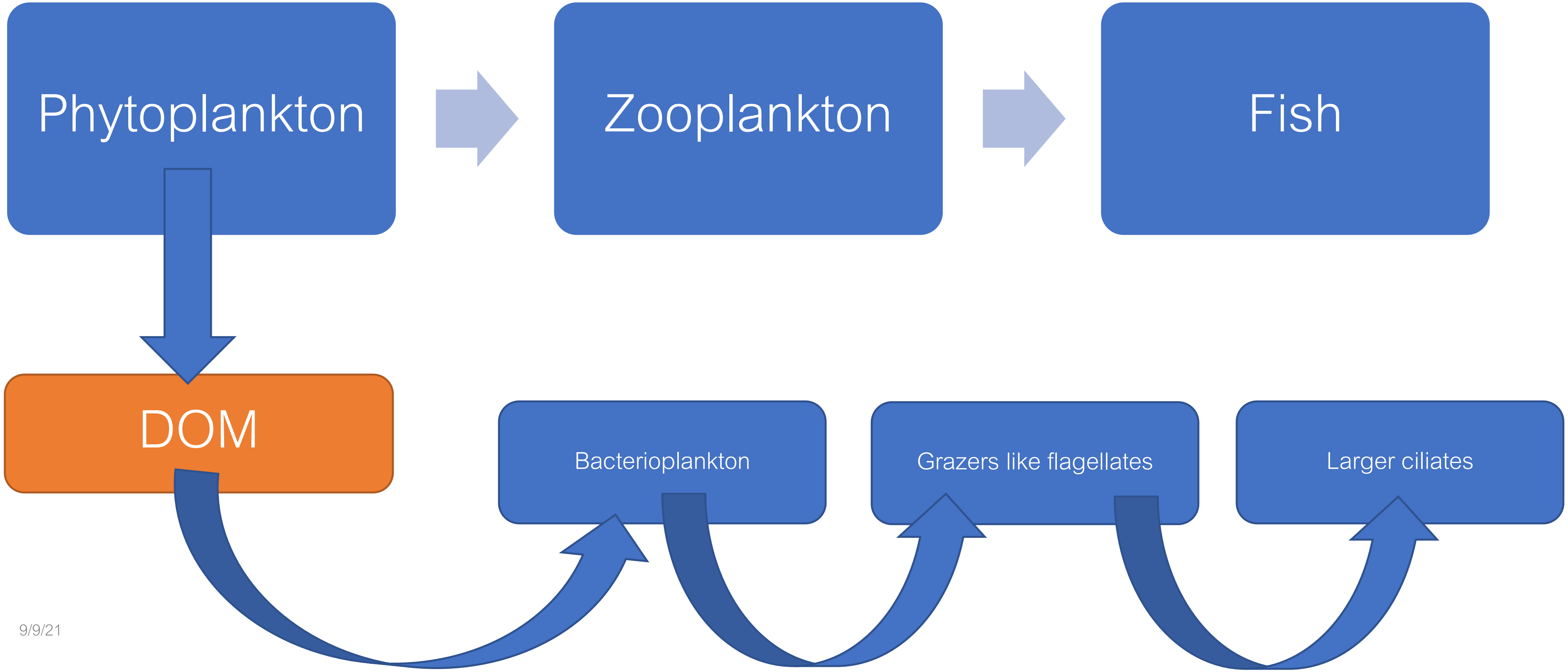

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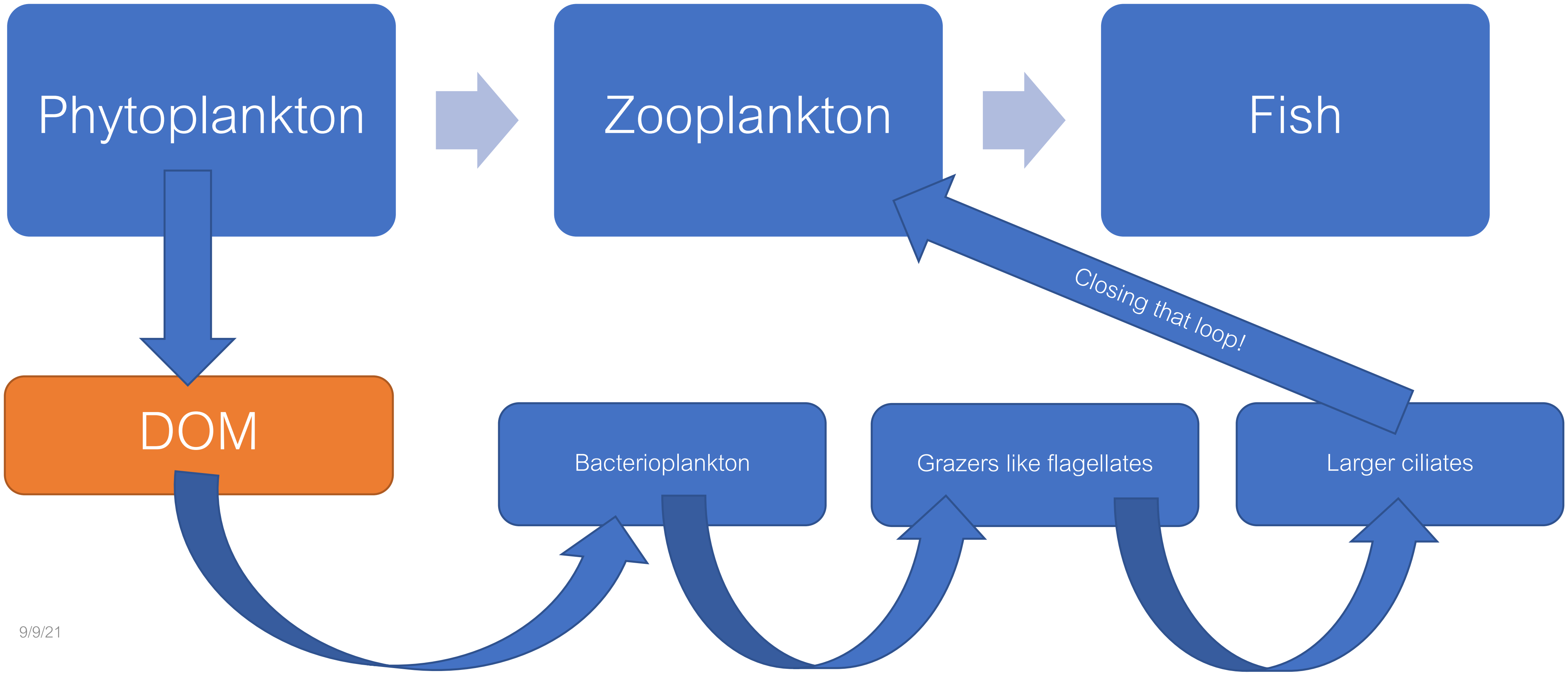
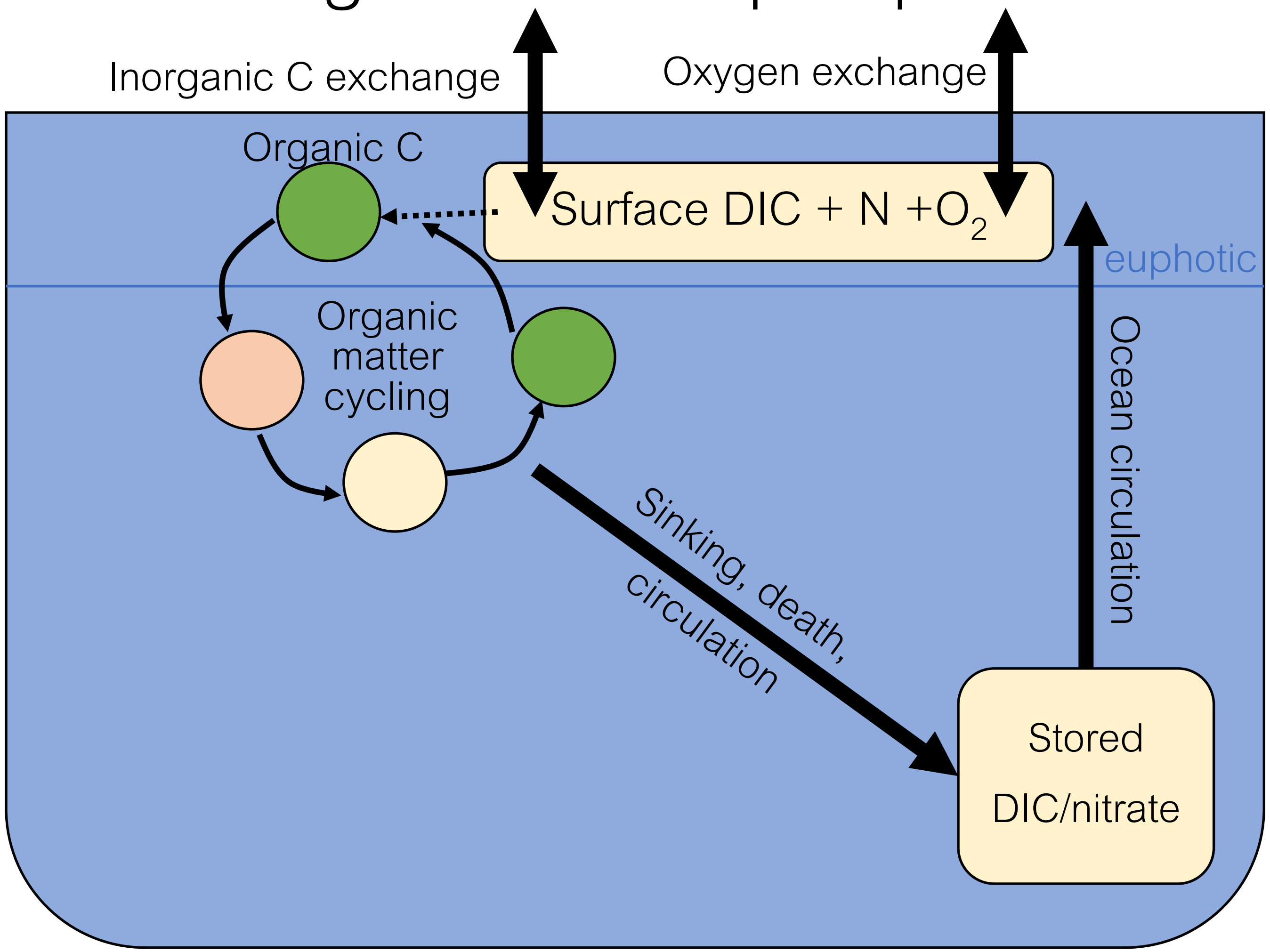
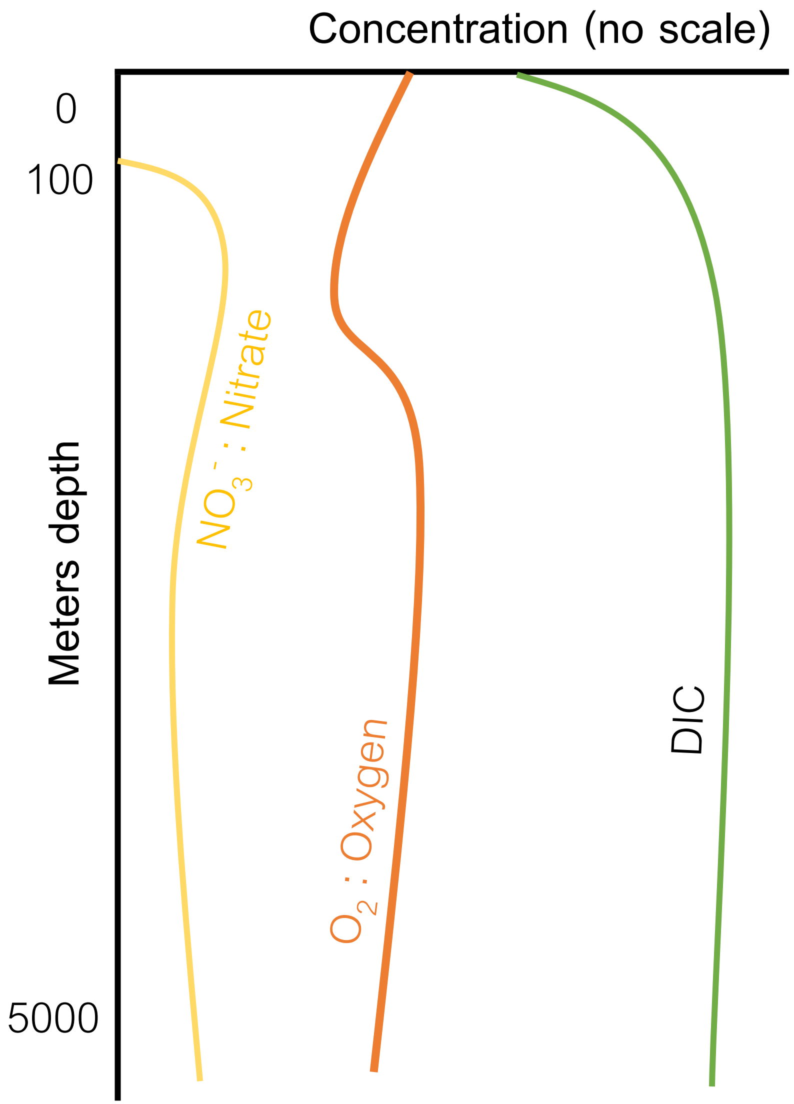


Copepods hunting phytoplankton

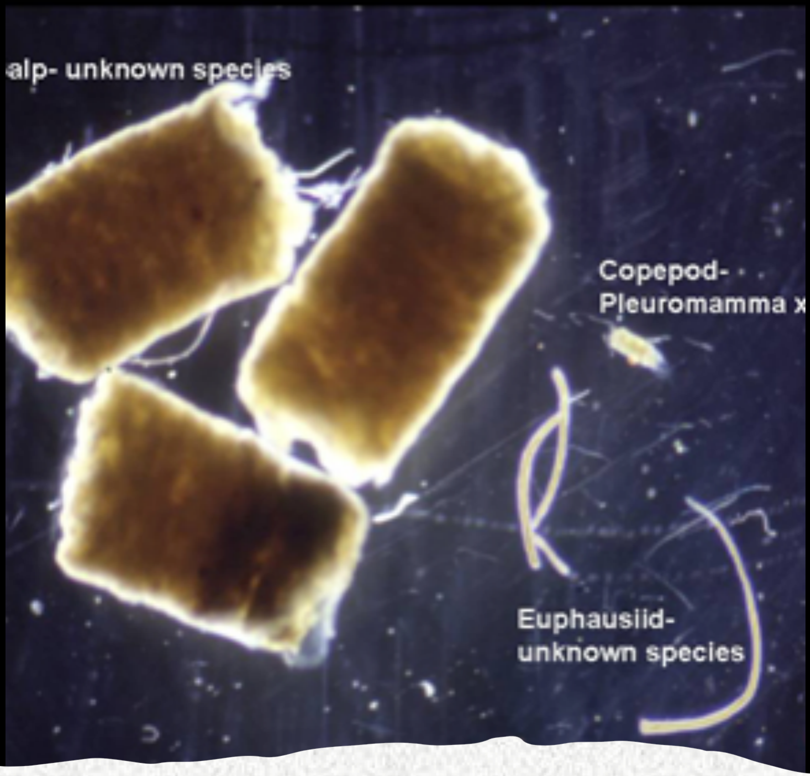
Copepod consumes a diatom

The biological carbon pump

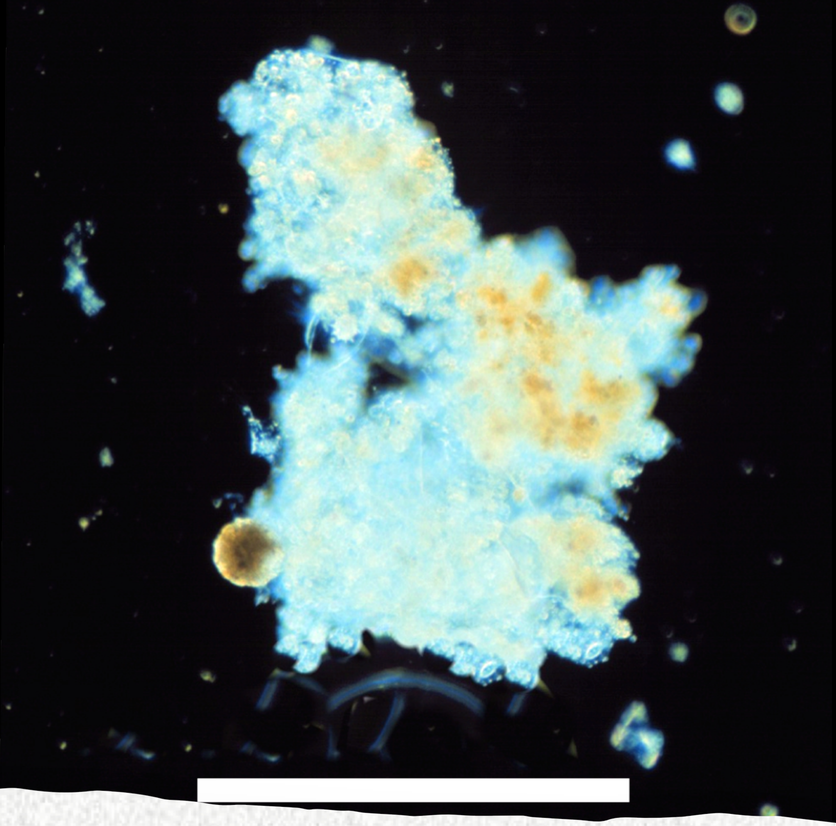




Salp – L. Koren

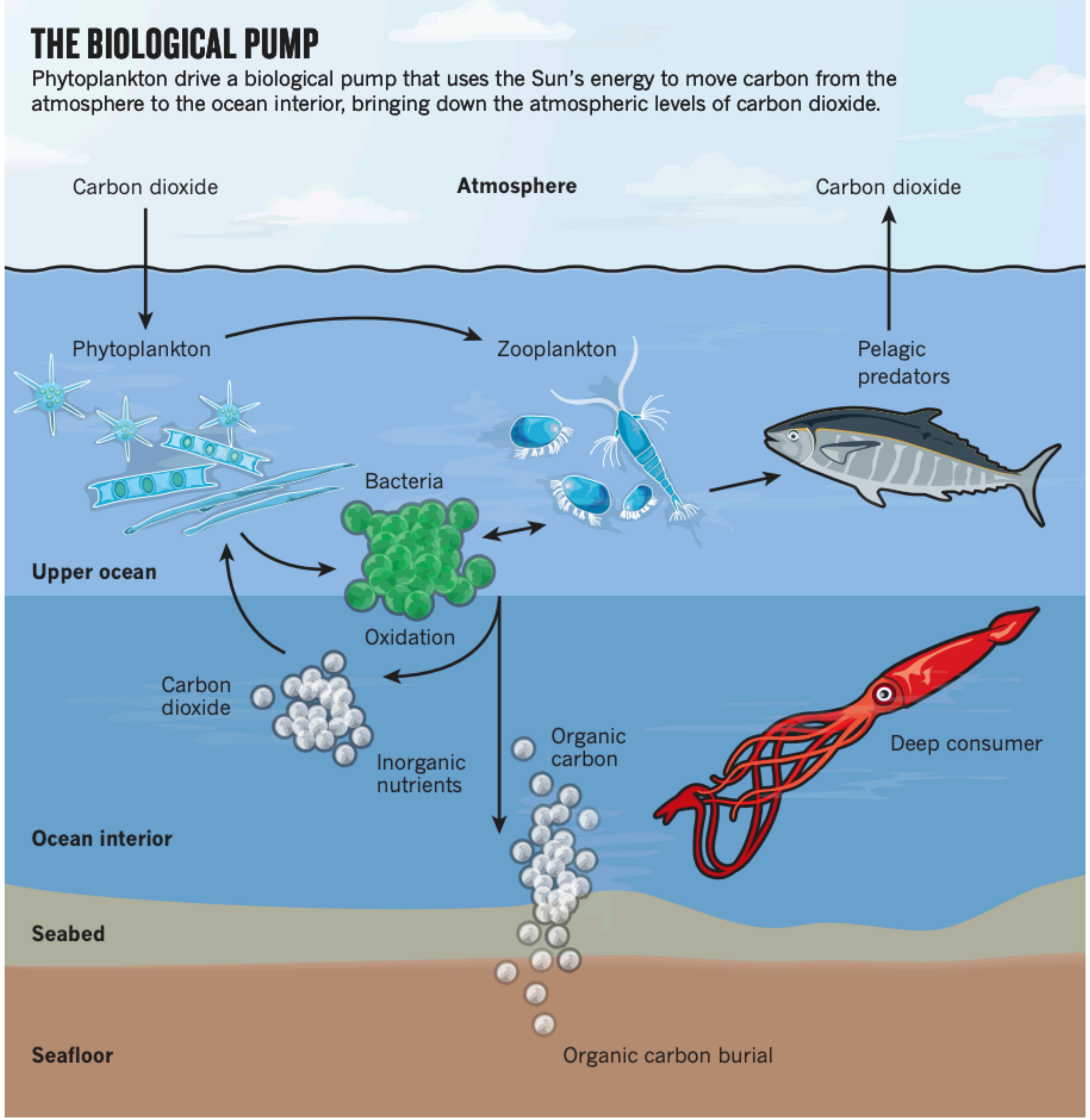


Zooplankton Fecal Pellets – Debbie Steinberg



Marine Snow – Richard Lampitt

When particles sink, they export (and potentially bury) these nutrients



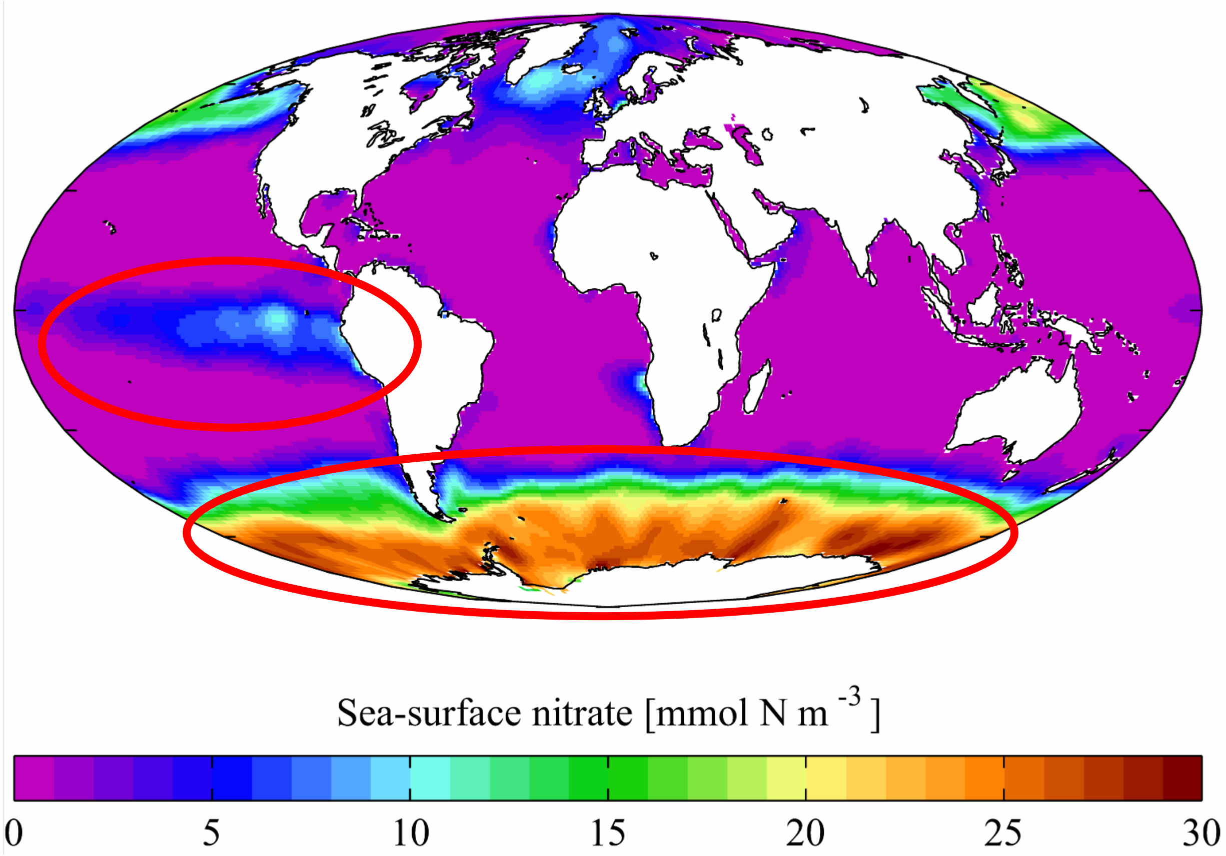
Falkowski et al. 2007

The biological pump is relevant to global biogeochemical cycles

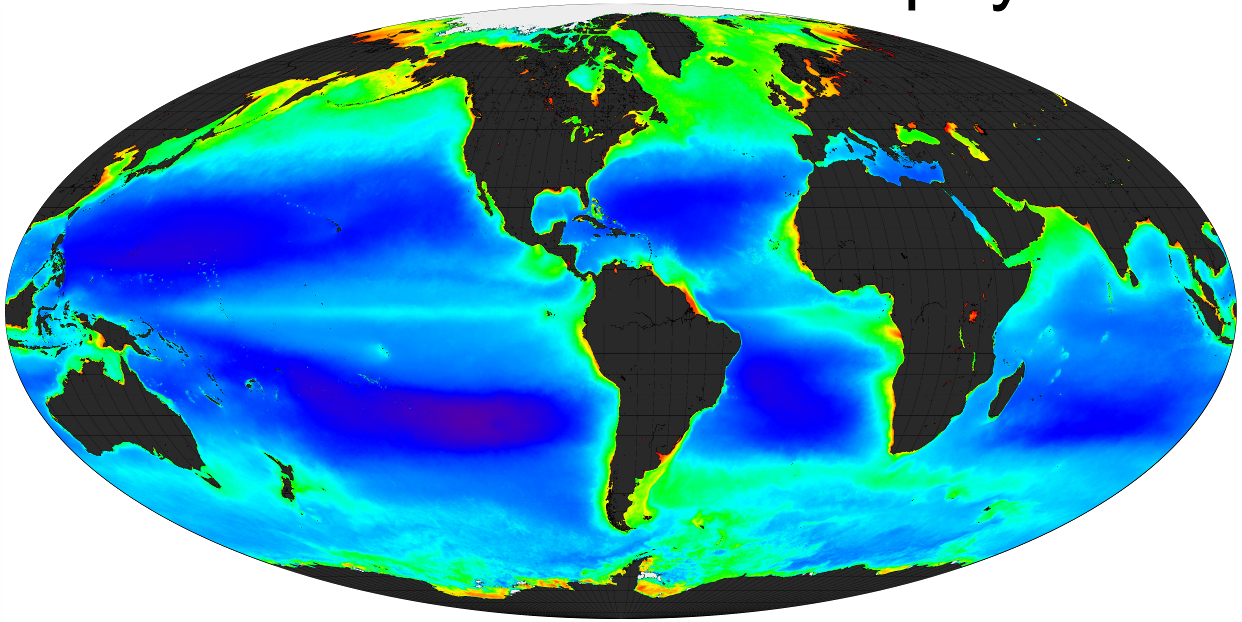
An exploration of nutrient limitation in the ocean

In some areas of the ocean, production stops, but nitrate is still available – "**High Nutrient, Low Chlorophyll**" regions

Surface nitrate concentration

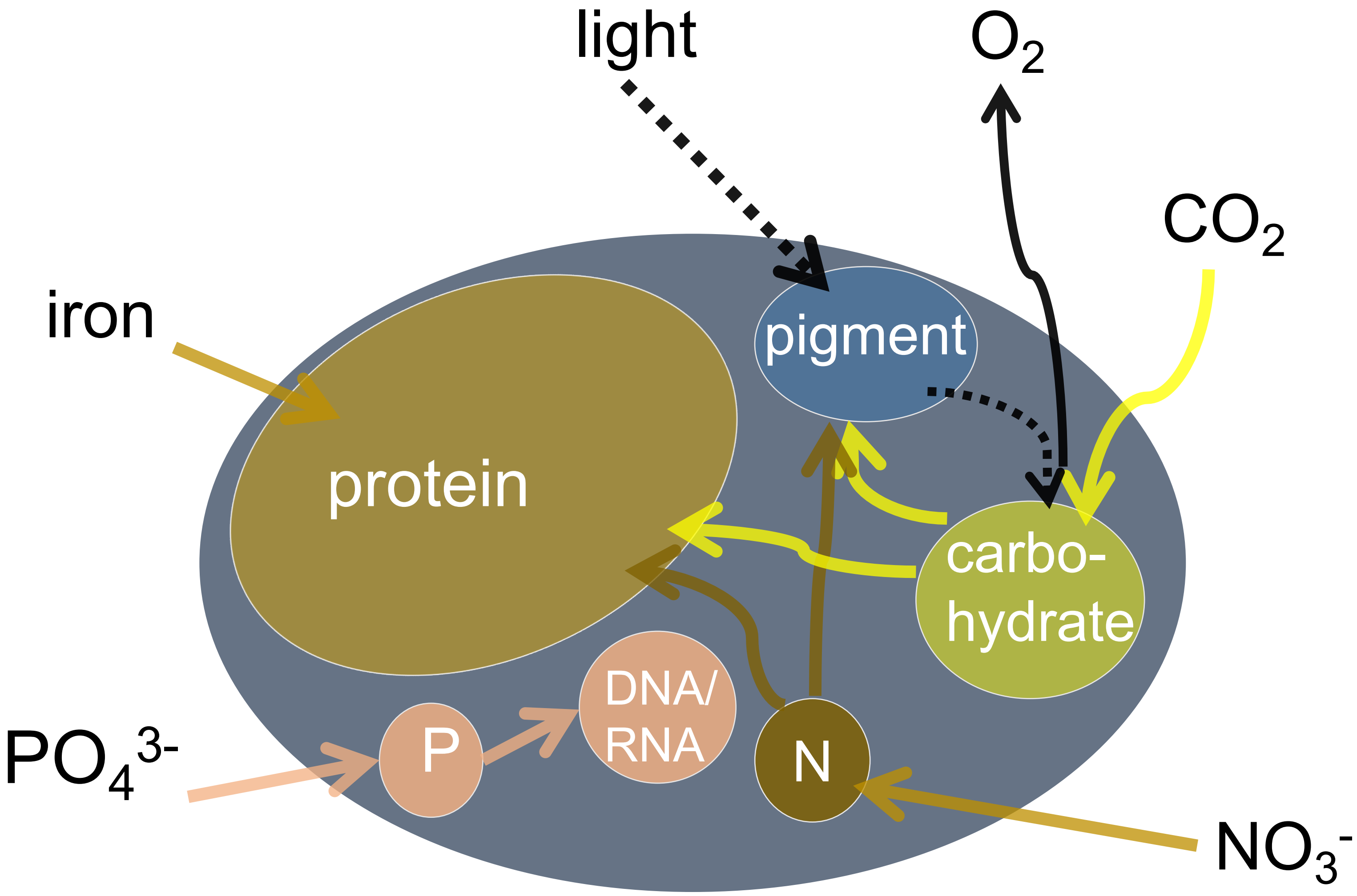


NASA MODIS chlorophyll



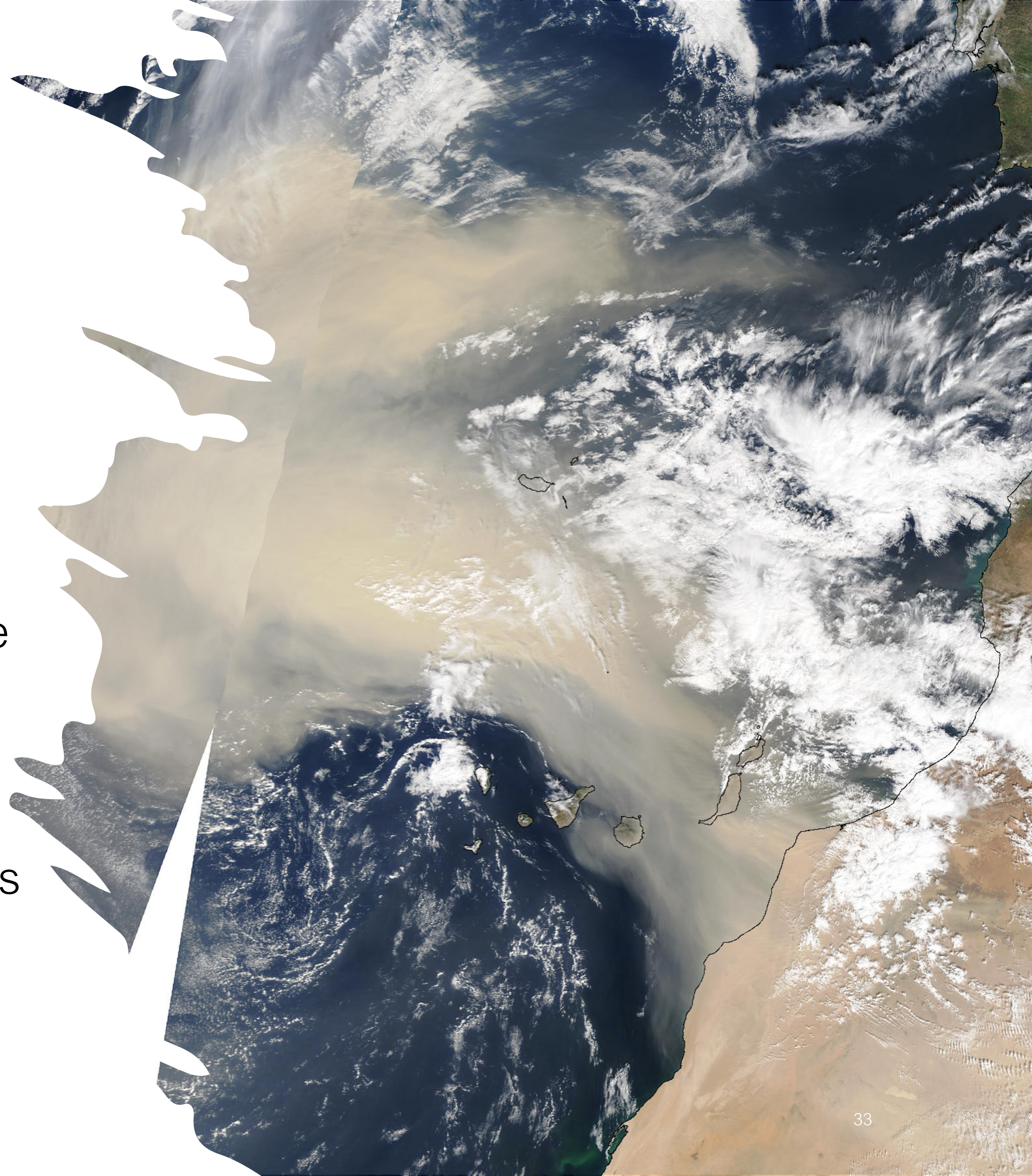
HNLC regions show how the N:P ratio we expect might be off in the oceans

- Some other nutrient must be off from the average Redfield ratio



Trace metals like iron throw a wrench into the plan

- Because iron is a necessary nutrient, but also quite scarce, it is easily scavenged from surface waters
- This means in some upwelling areas, there might not be enough Fe to go around, making nitrate over-abundant
- Dust storms are one of the biggest sources of iron to the ocean, which keeps the Atlantic reasonably well-supplied



The iron requirement necessitates a new look at the Redfield ratio

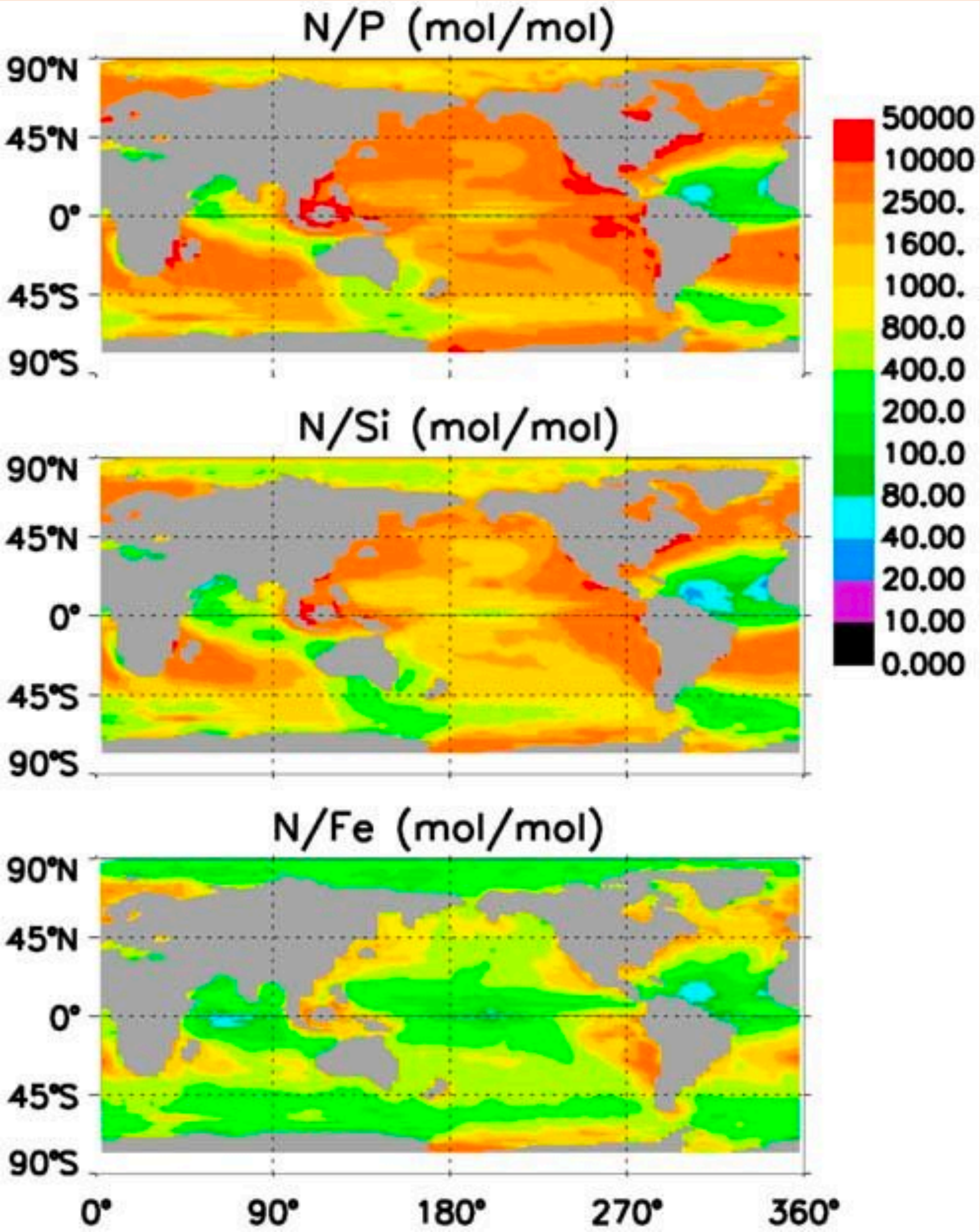
$C:N:P:-O_2:Fe$

106:16:1:170:0.005

For every 16 moles N (one per NO_3^-), 0.005 moles of iron are required. This is a ratio of 3200 N per 1 Fe.

In most of the ocean, N:Fe is much **lower** than 3200, indicating that we have an **excess of Fe** relative to N.

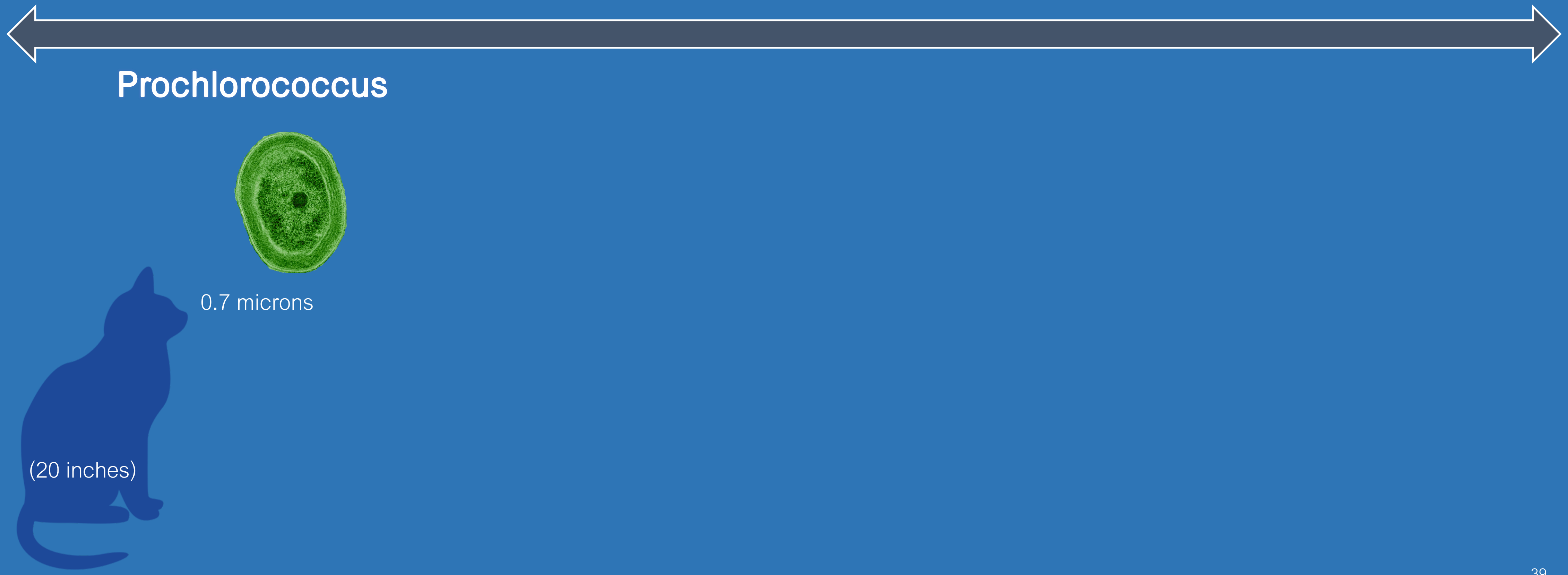
In HNLC regions, the pattern is flipped, and the **iron availability is too low** relative to N.



How can we contextualize phytoplankton sizes and functions?

The mind-boggling scales of (marine) phytoplankton

The mind-boggling scales of (marine) phytoplankton



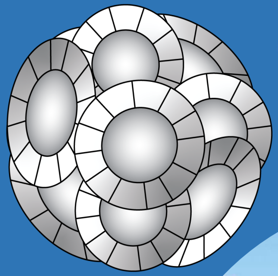
The mind-boggling scales of (marine) phytoplankton

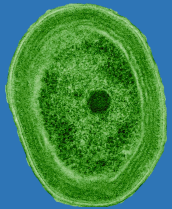
5-20 microns

(10x bigger than 0.5)

Prochlorococcus

Emiliania huxleyi





0.7 microns

The mind-boggling scales of (marine) phytoplankton

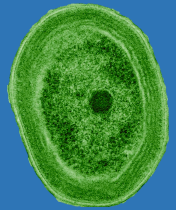
Karenia brevis

Prochlorococcus

5-20 microns

(10x bigger than 0.5)

Emiliania huxleyi



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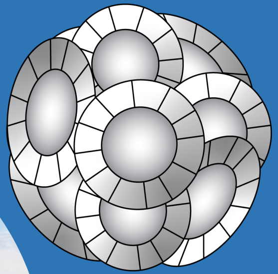

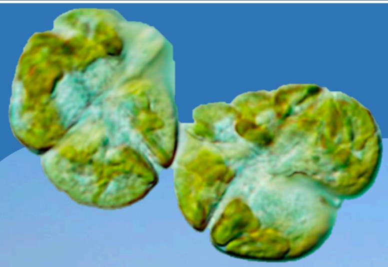

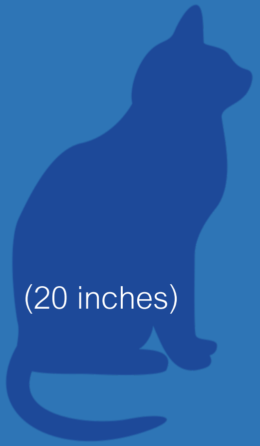

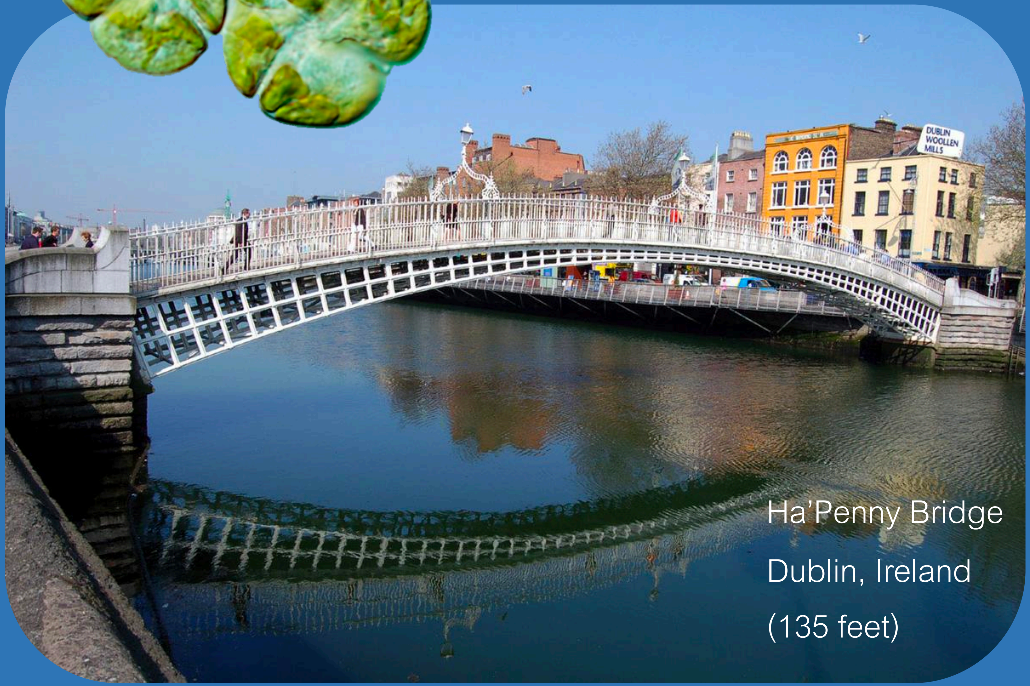

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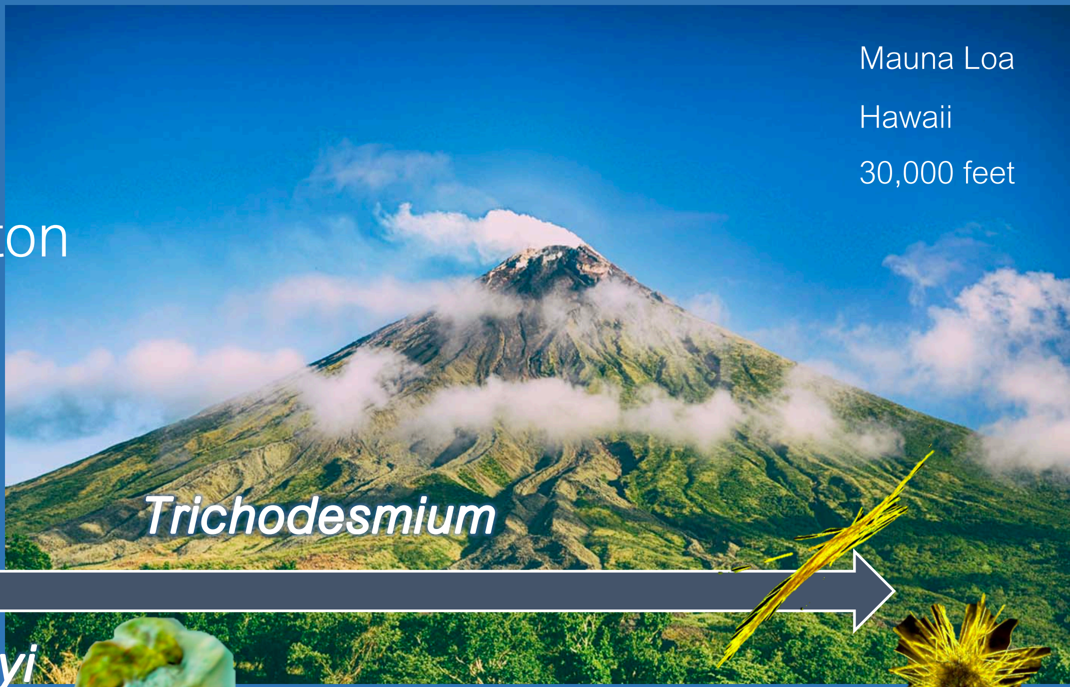
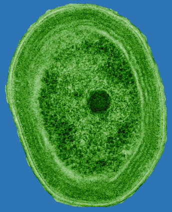


Prochlorococcus



0.7 microns

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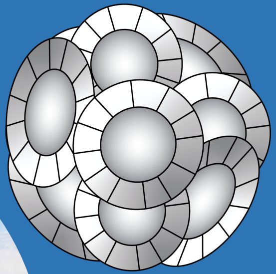
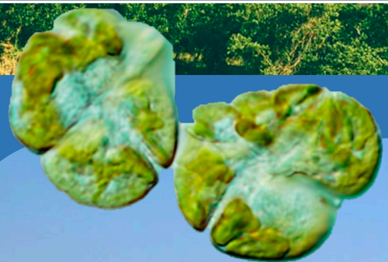
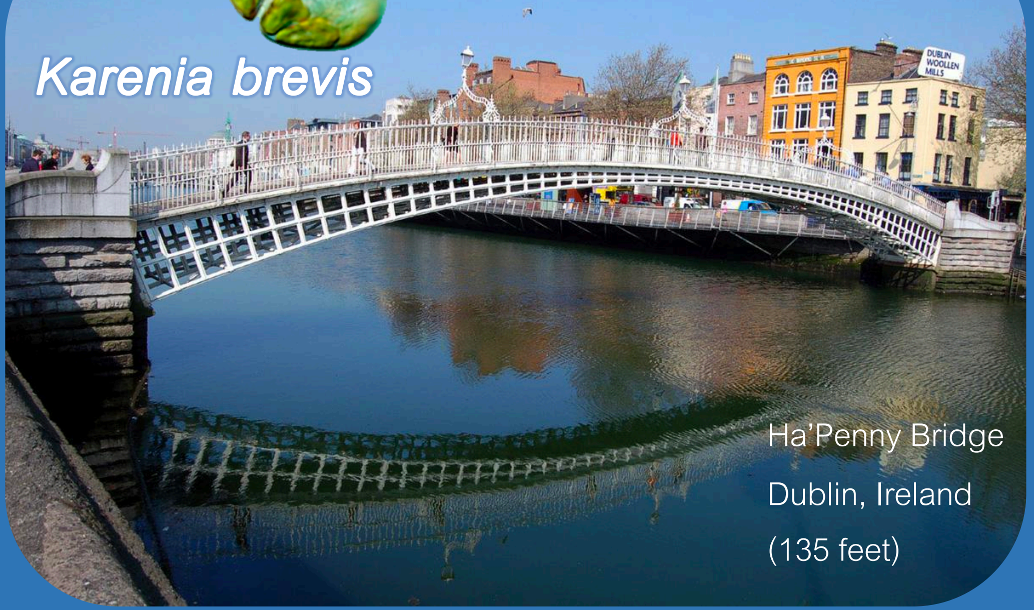
Emiliania huxleyi

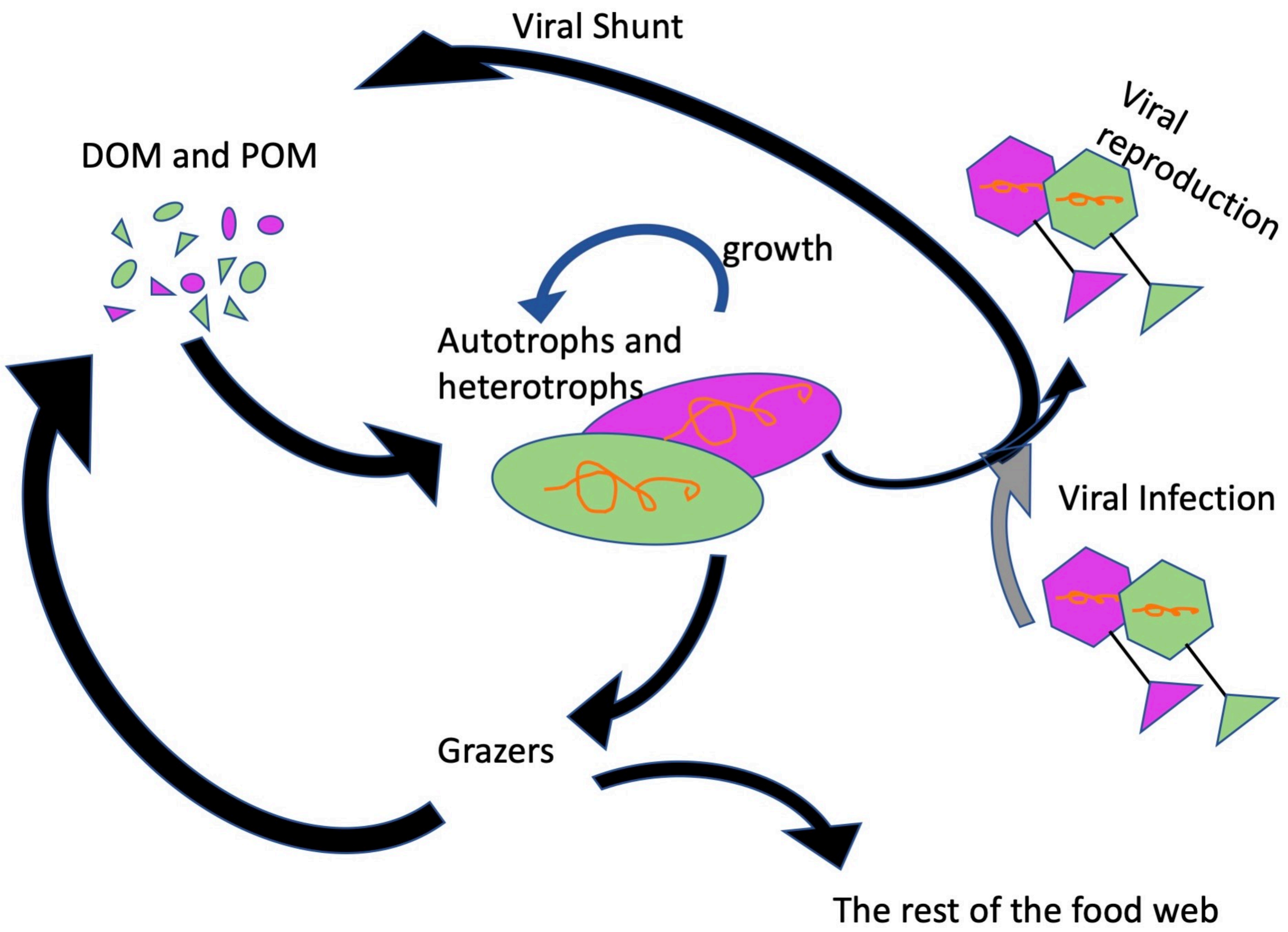




Karenia brevis

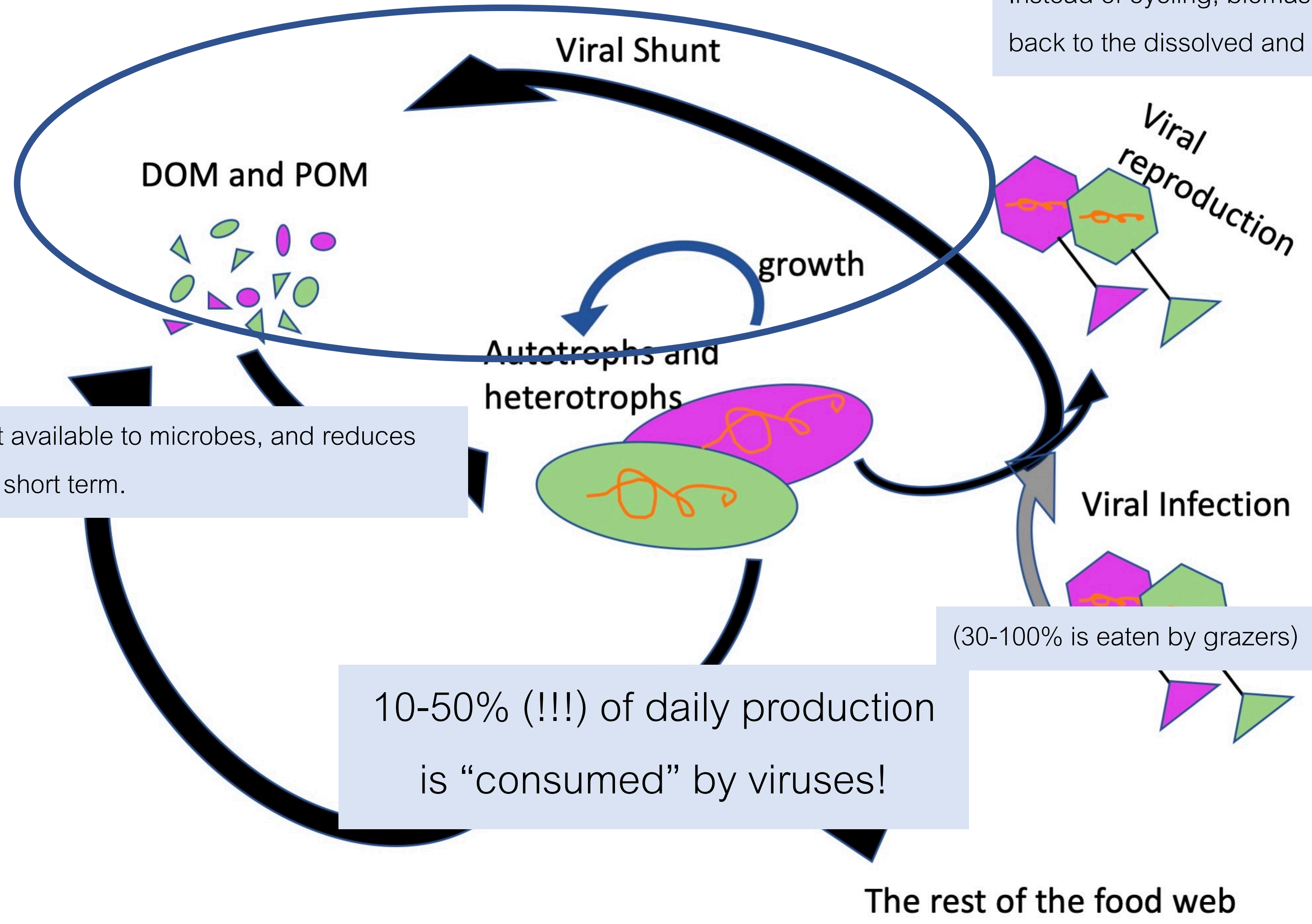


The microbial loop is further complicated by viral activity



Wikimedia Commons

The microbial loop is further complicated by viral activity



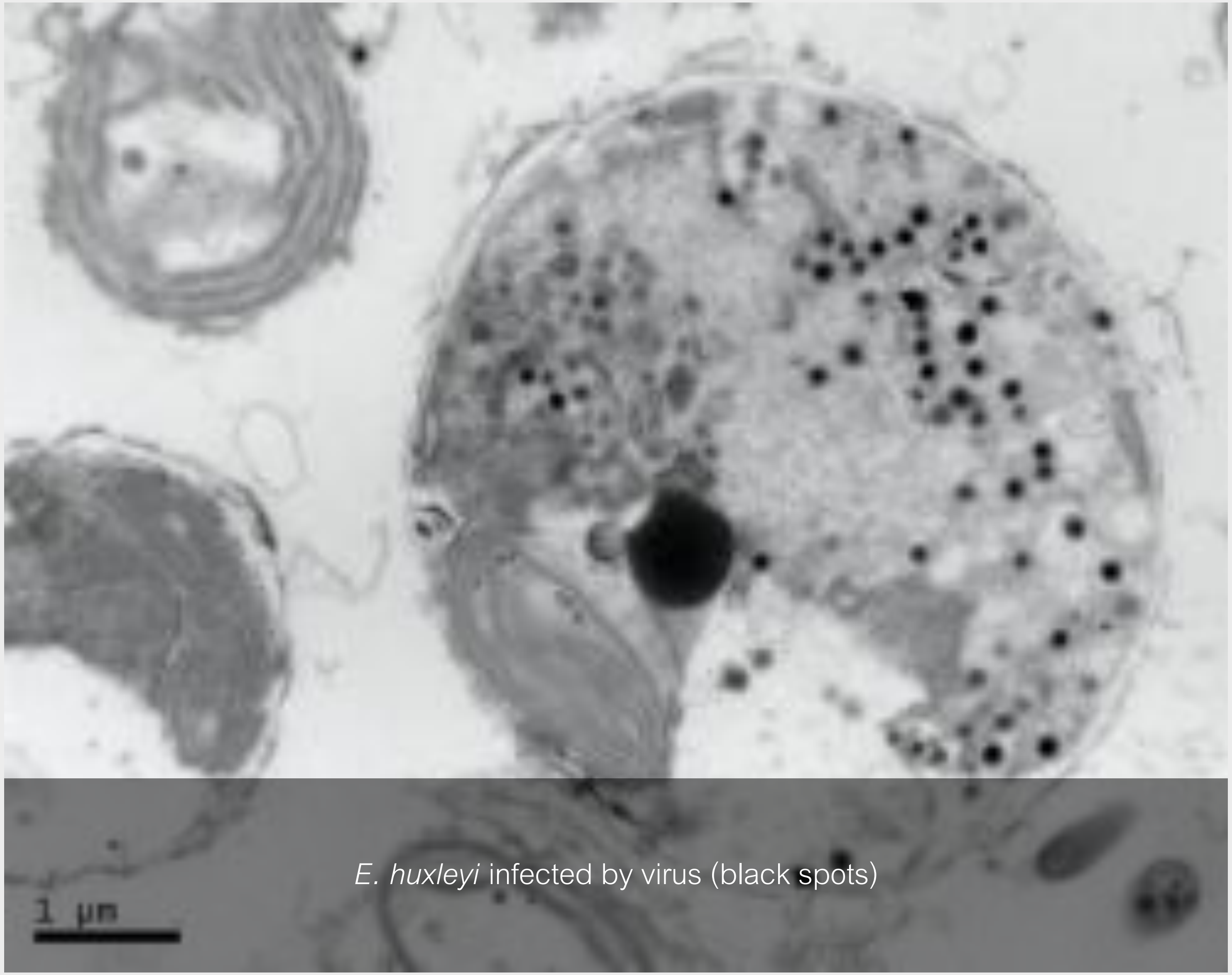
Instead of cycling, biomass gets shunted straight back to the dissolved and particulate pools.

This makes it available to microbes, and reduces export in the short term.

(30-100% is eaten by grazers)

10-50% (!!!) of daily production is "consumed" by viruses!

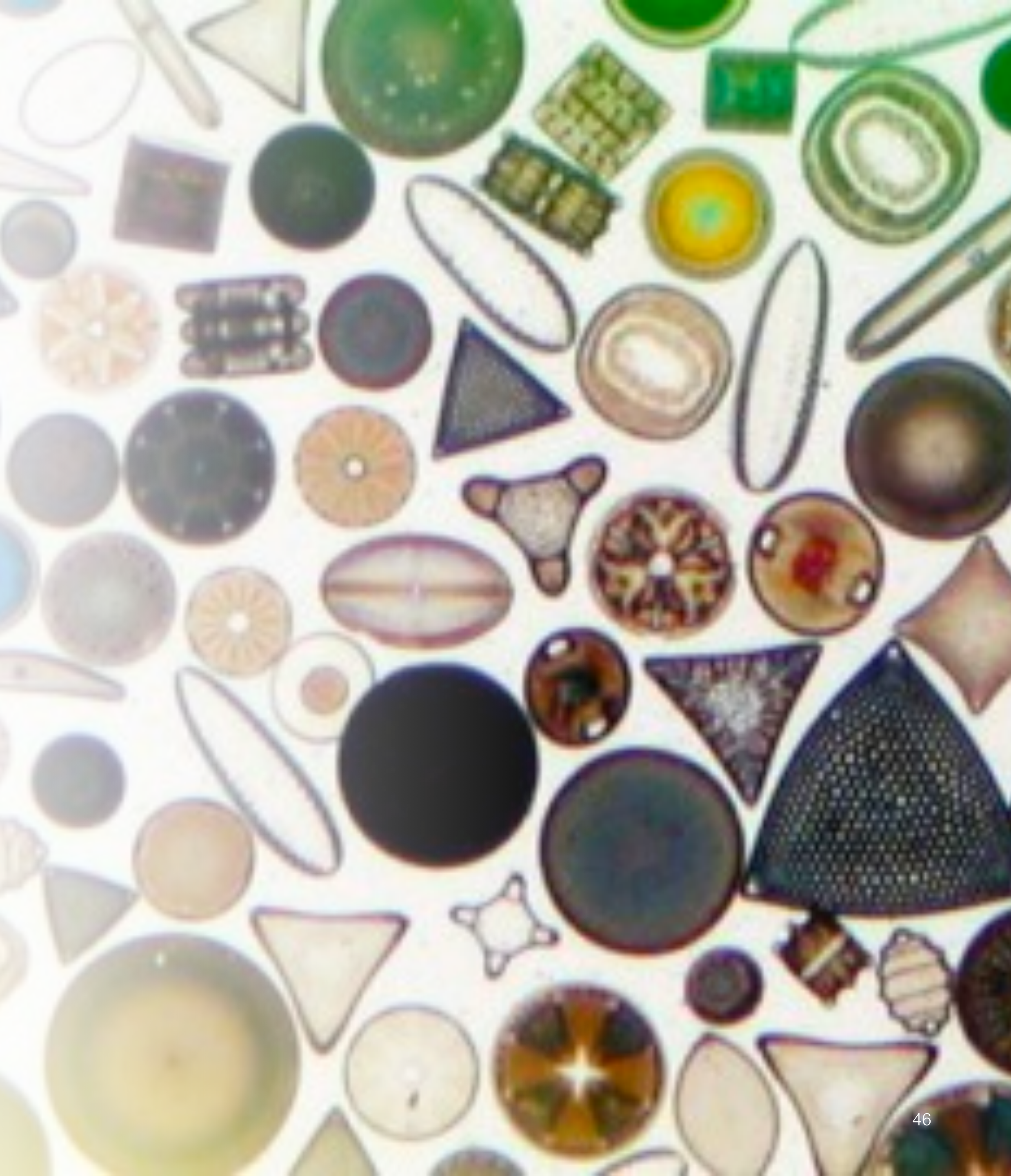
Wikimedia Commons



E. huxleyi infected by virus (black spots)

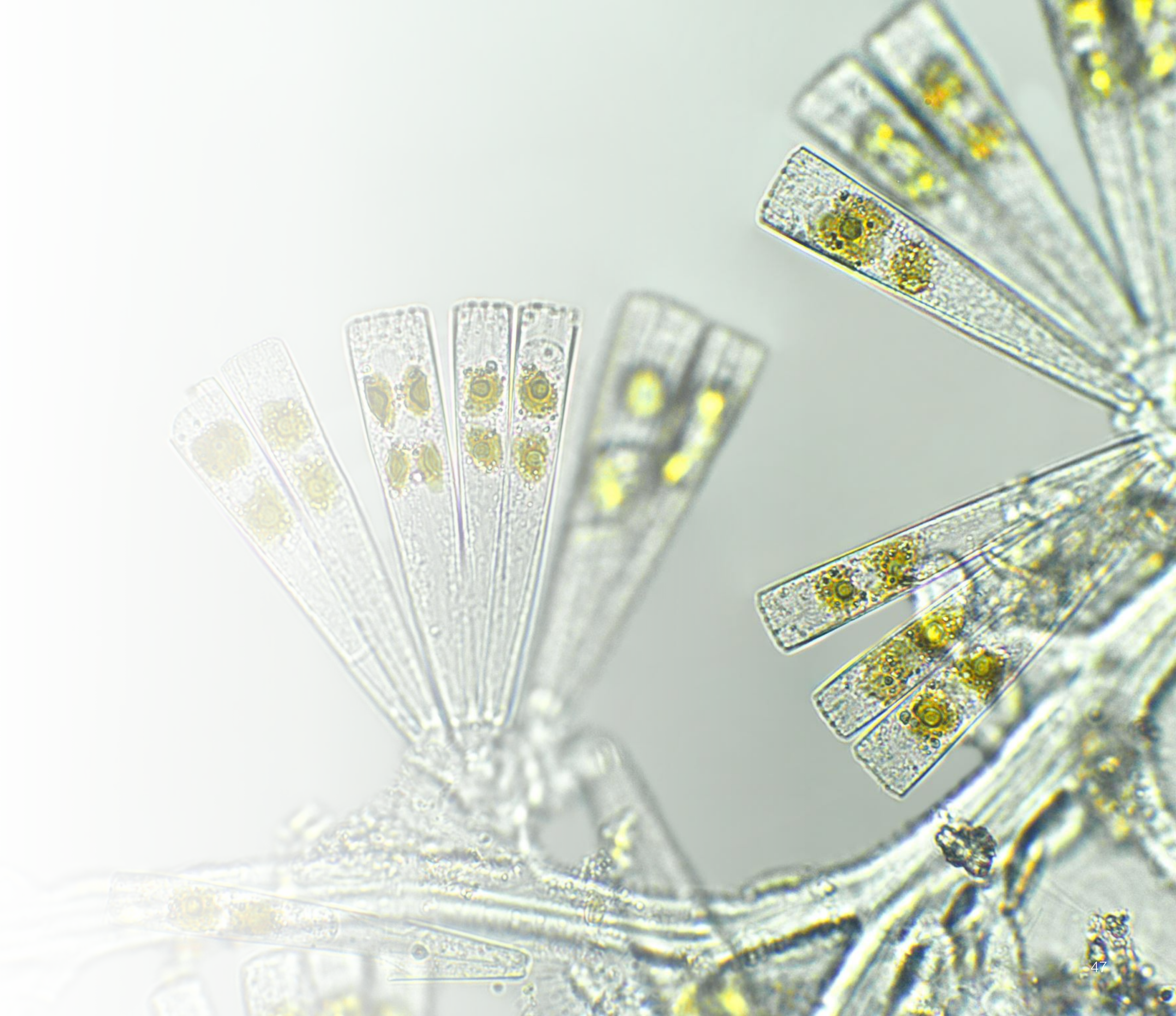
Phytoplankton are too diverse to adequately lump into categories

- Thousands of phytoplankton can be uniquely morphologically identified
- These can be classified into taxonomic groups which typically correspond to biogeochemical function



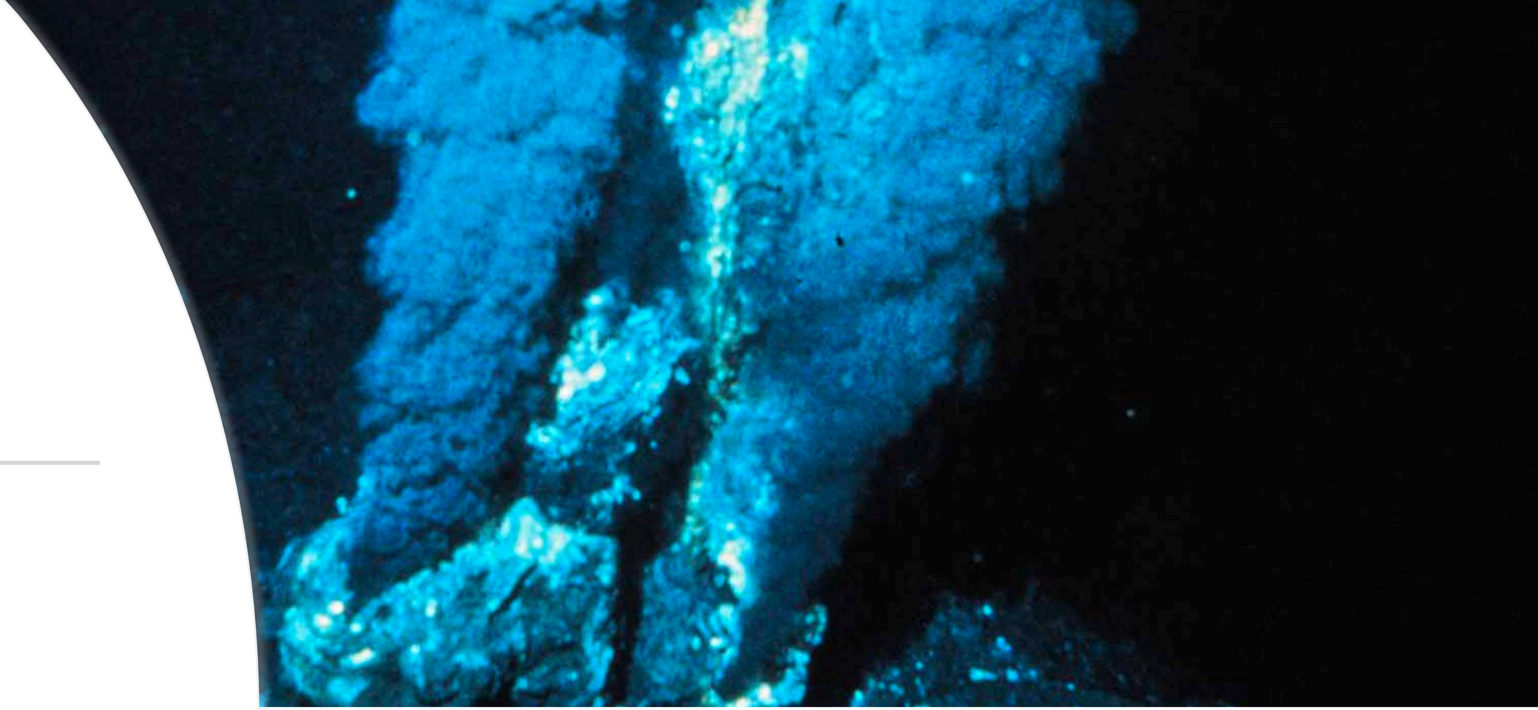
Major functional classes of phytoplankton

- Calcifiers
- Nitrogen fixers
- Silicifiers
- DMS producers



Other ecologically-relevant microbes

- Traditional denitrifying + nitrifying bacteria + archaea
- Anammox-involved bacteria + archaea
  - Also in hydrothermal vents – whole other topic!!



Pico-cyanobacteria

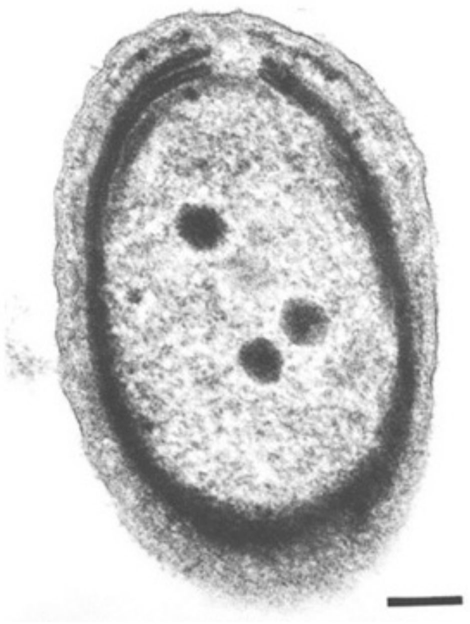
Pico-cyanobacteria

Prokaryotic (not true algae); genome ~1.7-9 Mbp

Smallest photo-autotrophs in existence, in particular

Prochlorococcus (<1 um Effective Spherical Diameter/ESD)

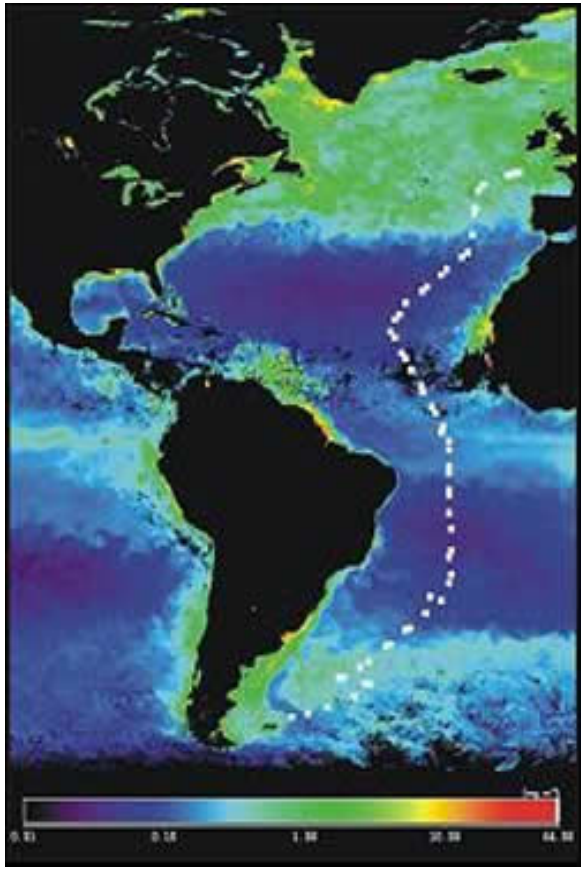
As much as half of the biomass in subtropical water

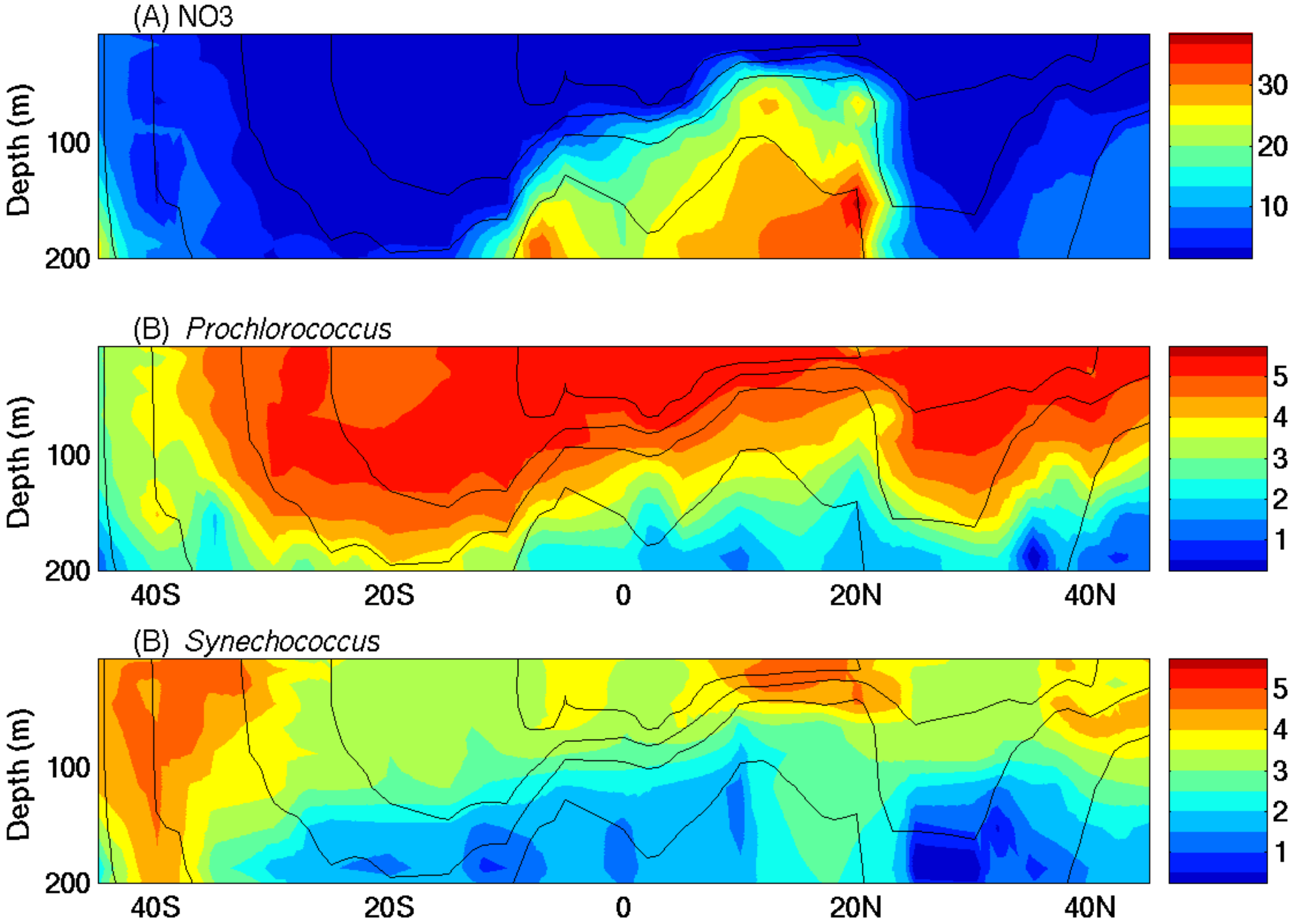


0.1 micron

Prochlorococcus:
image C. Ting

Low-nutrient subtropical gyres are picocyanobacterial stomping grounds





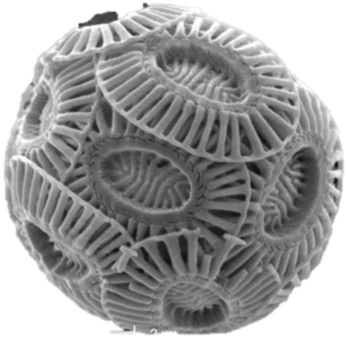
Phytoplankton: log(cells ml^{-1})

Nitrate (micromoles kg^{-1})

Johnson et al, Science (2006)

Coccolithophores

Some example calcifiers



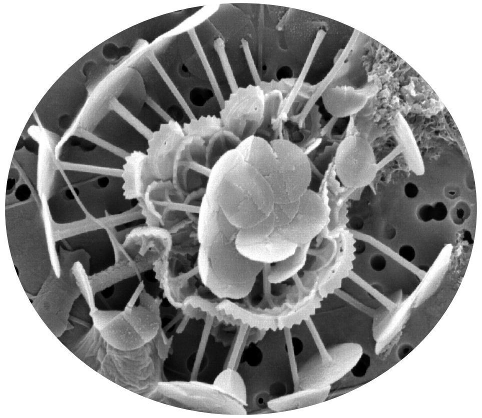
Emiliania huxleyi

Haptophyte

Associated with EhV, large viruses that collapse blooms

Coccolithophore poster child

Calcidiscus leptoporus

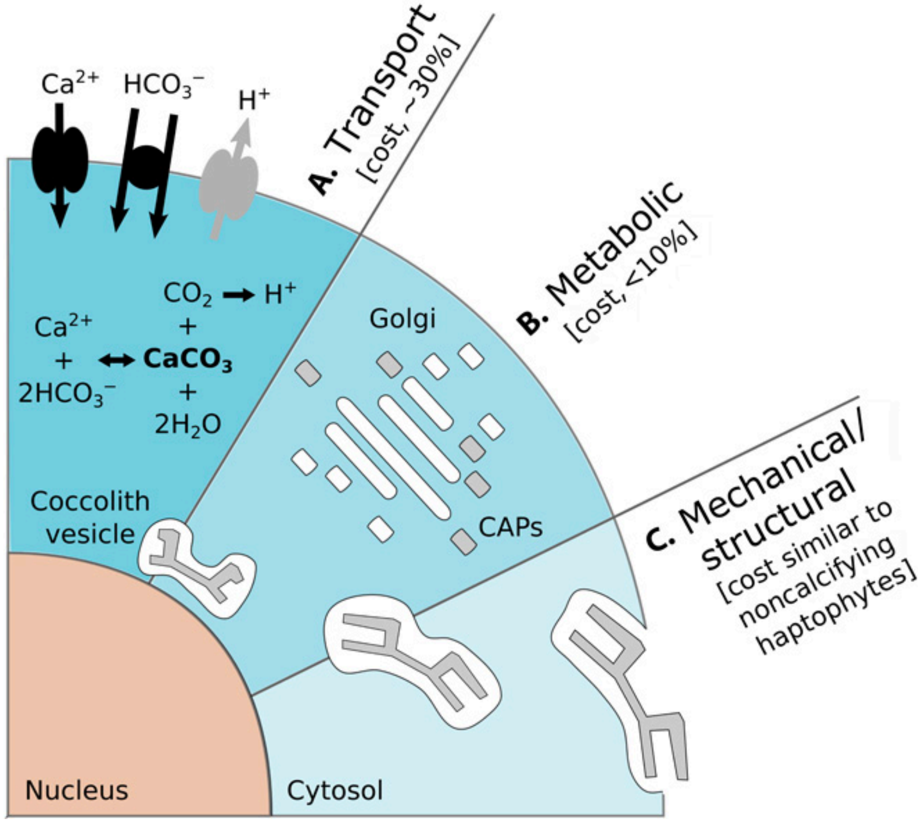


Papposphaera lepida

Coccolith formation in coccolithophores (Allison Taylor, UNC)

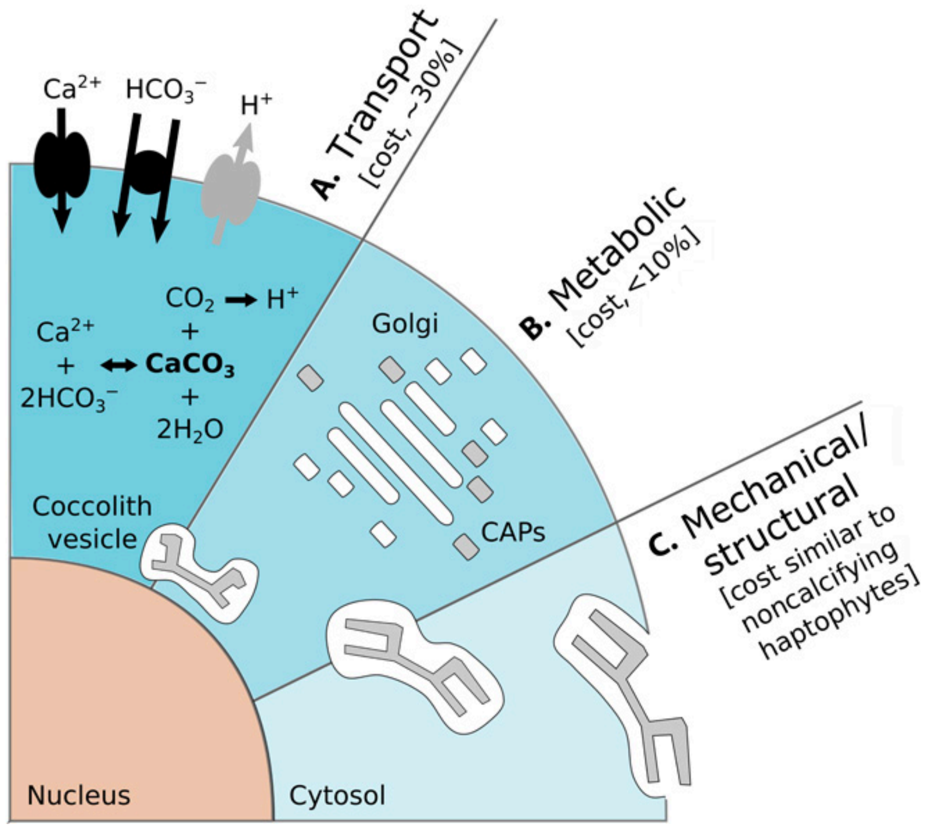
Calcification: an enigmatic process

- Calcifiers are abundant, and the calcification process is complex with respect to global CO_2



Calcification: an enigmatic process

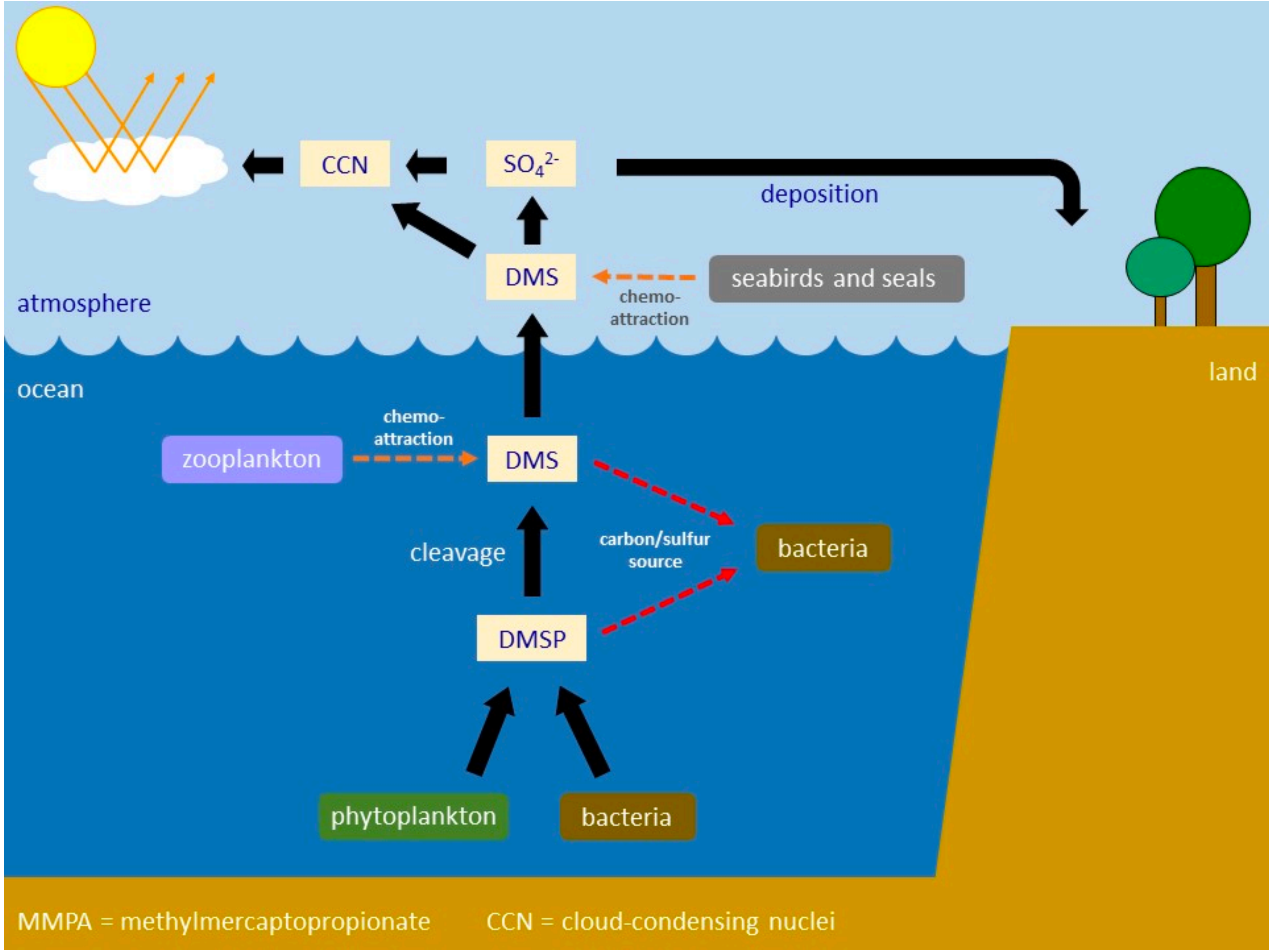
- No one quite knows how calcifiers *afford* the energetic costs of calcification



Calcification can result in large-scale calcite formations after blooms + deposits

$$Ca^{2+} + CO_3^{2-} \Leftrightarrow CaCO_3$$

DMS production in *Emiliania huxleyi*

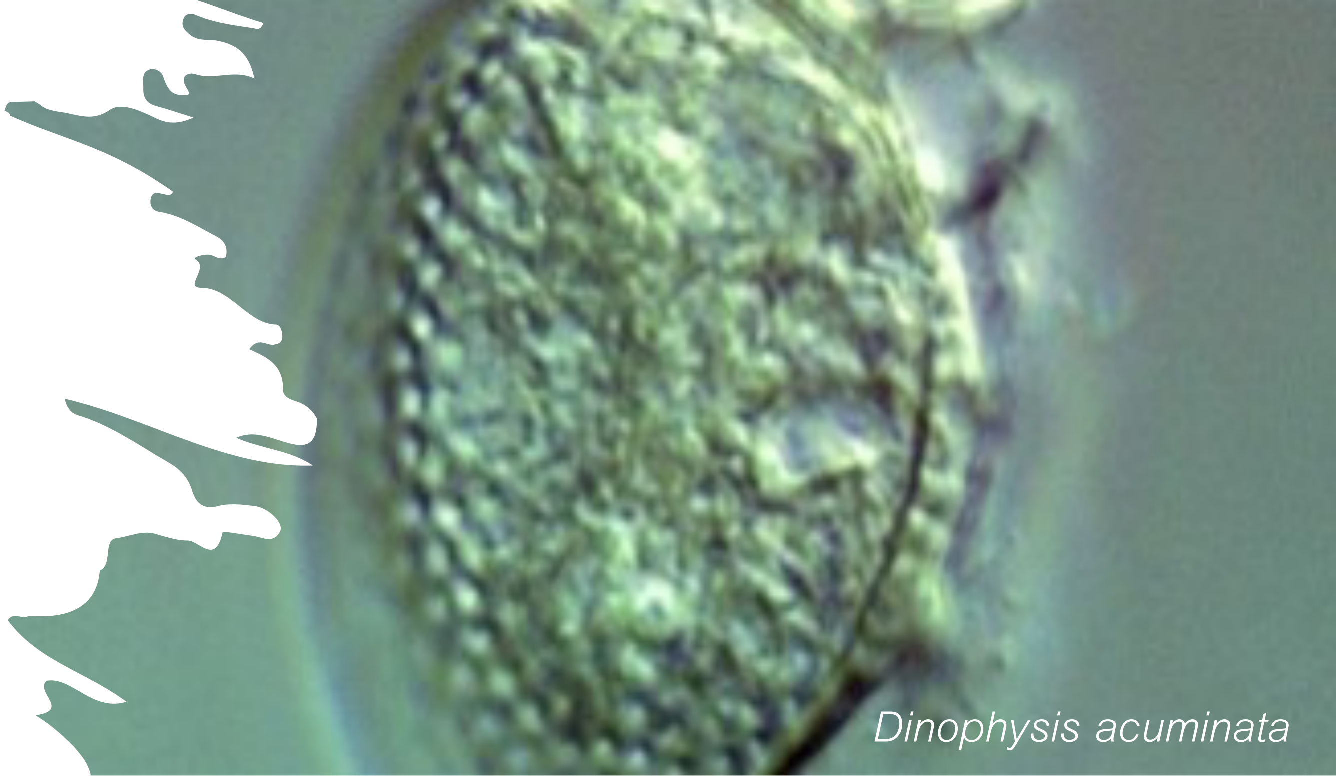


Curson et al. 2018

Dinoflagellates

Dinoflagellate key traits

- 10s to 100s of microns
- Have flagella, but no frustule/mineral
- Grow relatively slowly and often **mixotrophic**

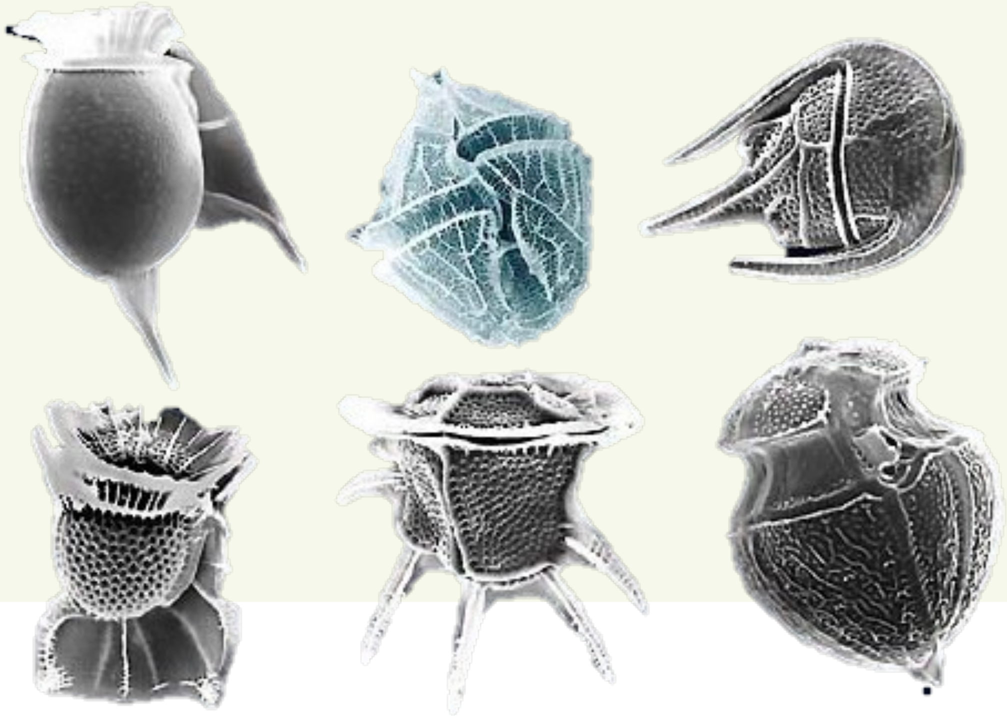


Dinophysis acuminata

Ceratium

Toxic bloom-formers

- This is one of the most diverse groups of phytoplankton around
- Includes red tide species *Karenia brevis*
- Also responsible for a lot of surface **bioluminescence**

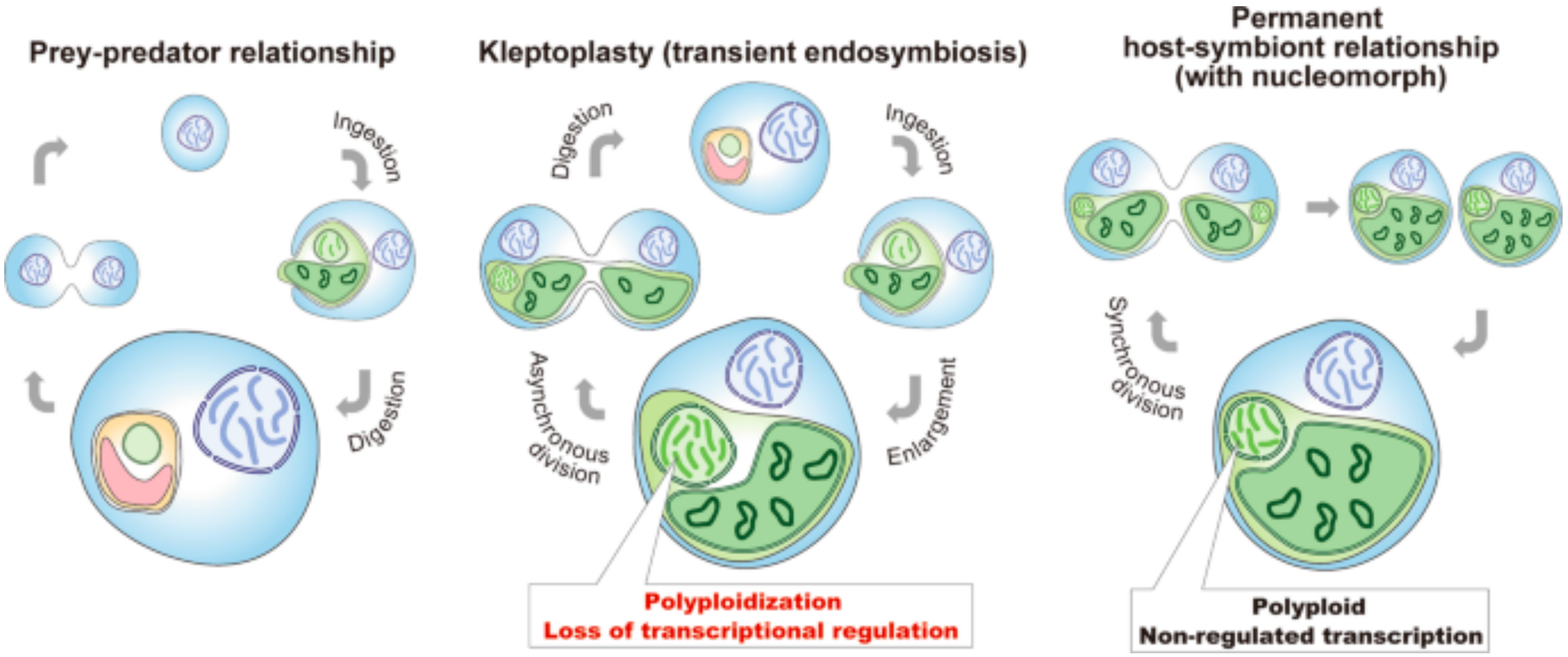


Feeding in dinoflagellates

Dinoflagellates have complex evolutionary histories

- Many phytoplankton gained photosynthetic ability through acquiring **plastids**
- This involves an endosymbiotic event, in which a photosynthetic bacterium is engulfed and eventually it becomes an organelle rather than a separate organism
- In dinoflagellates this has happened *multiple* times independently

Kleptoplasty – piecewise motion towards photosynthetic ability

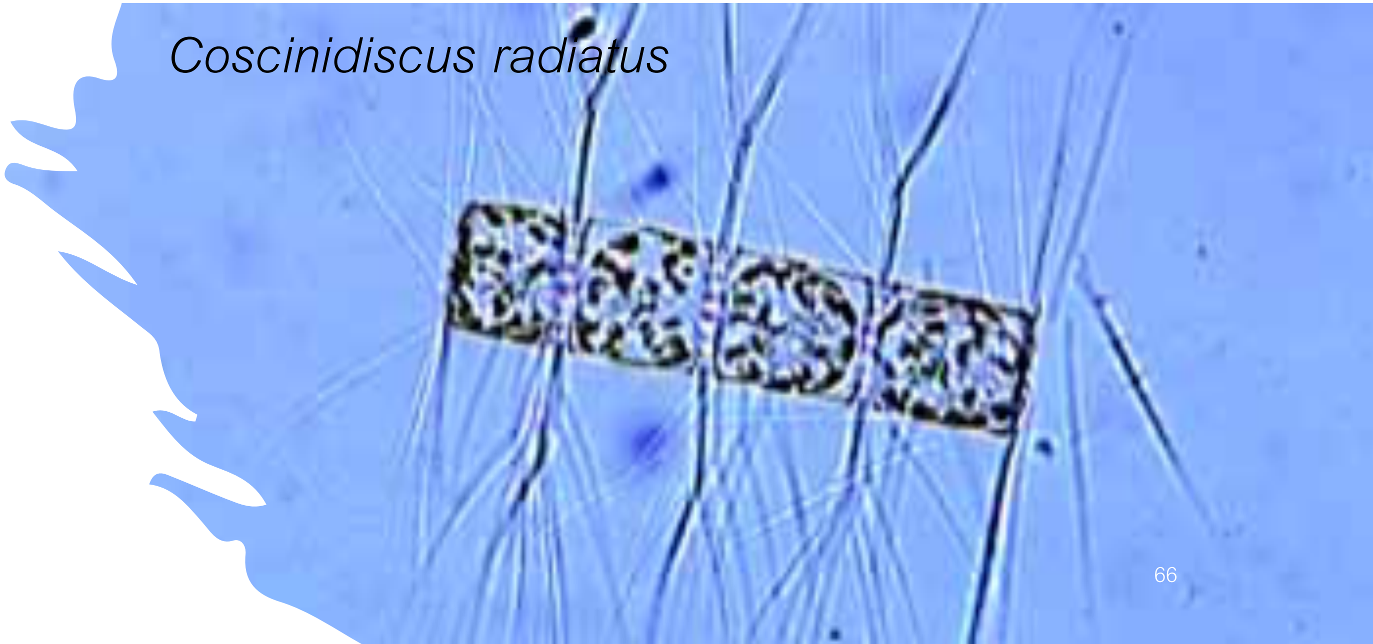


Diatoms

Silica + high-nutrient conditions

Diatom key traits

- A few hundred microns in size
- Have a hard silica frustule that contributes to their high sinking (contribute to high sinking flux)
- Dominate seasonal & local blooms because they grow quickly when opportunity strikes



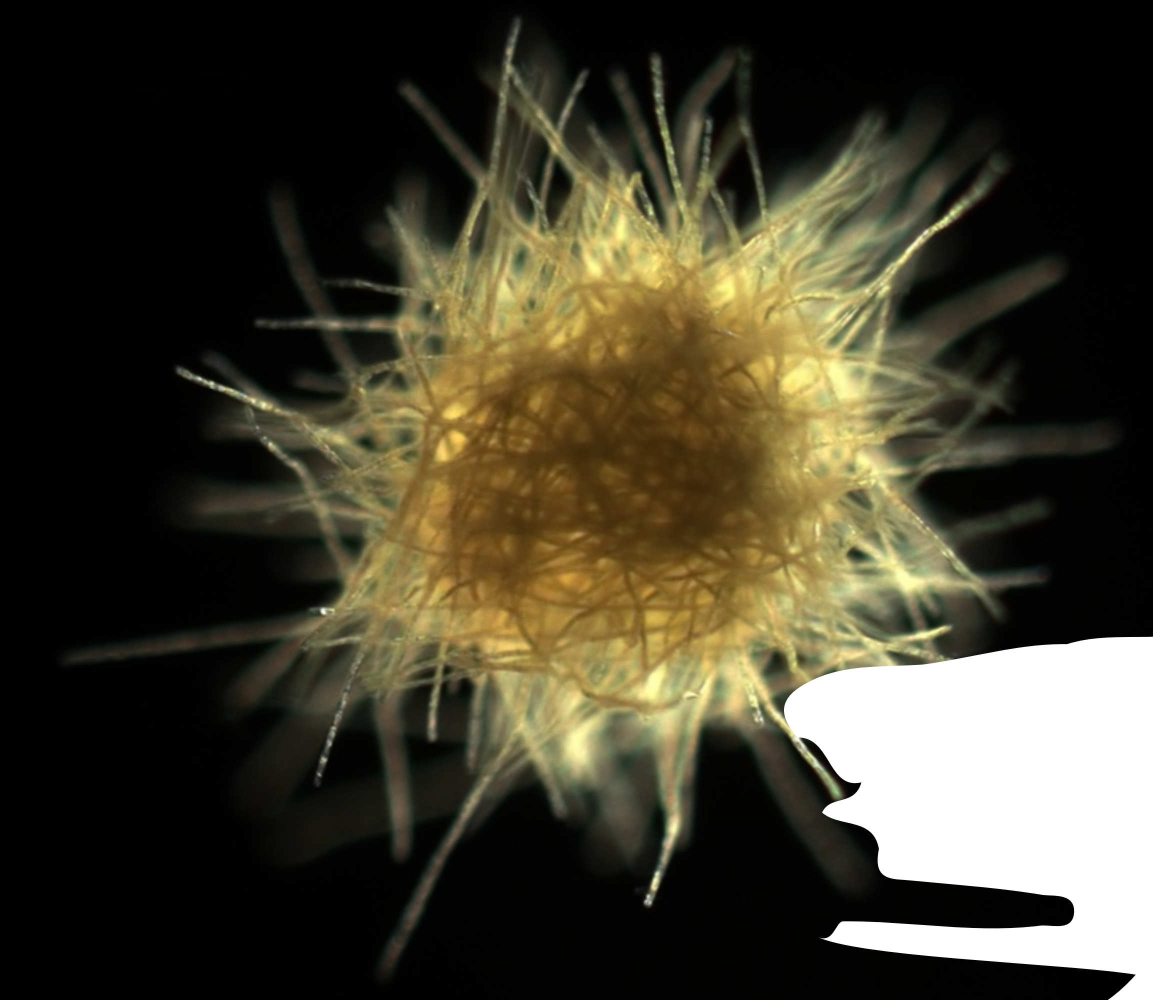
Diatoms can potentially manipulate their position in the water column

- They can move about by controlling how quickly they sink
- Being bulky, they would ordinarily sink quickly, but they may be able to *ballast* to keep themselves afloat
- Bulky glass shells may protect them from predators

The end of diatoms' life

- As diatoms die, they sink and form diatomaceous earth material
- Chalky + lightweight
- Actually used to manufacture explosives
- You may have seen the material in the garden center for pest control when planting

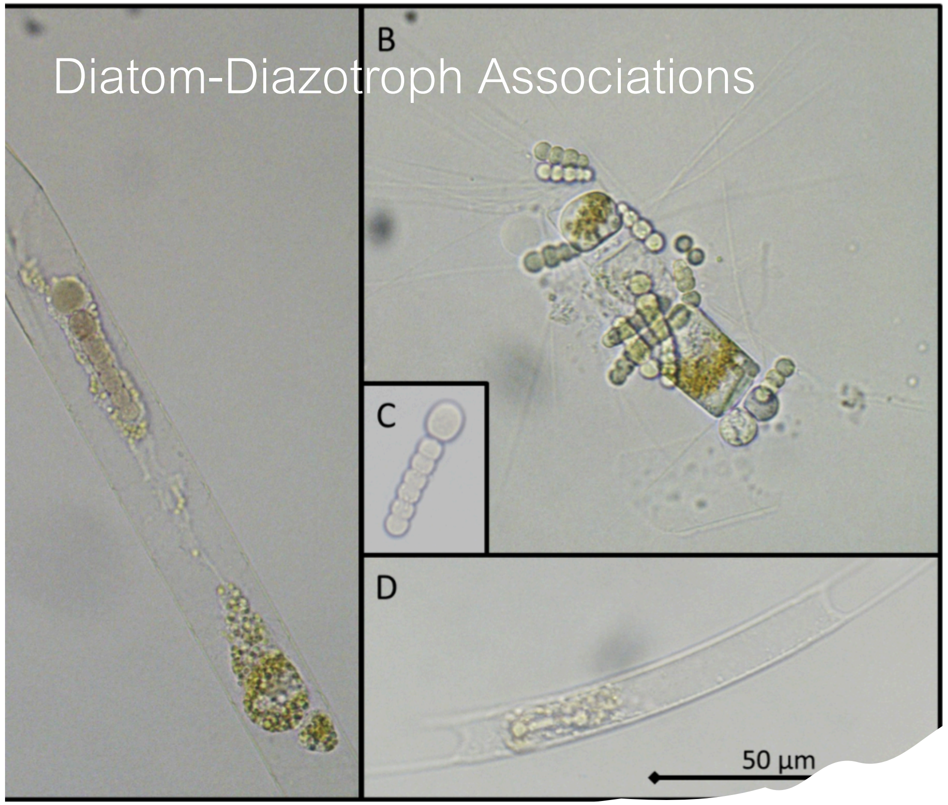
Nitrogen fixers // diazotrophs



Trichodesmium*

Colony ~1mm

Diatom-Diazotroph Associations



Diazotrophs take atmospheric nitrogen and make it usable

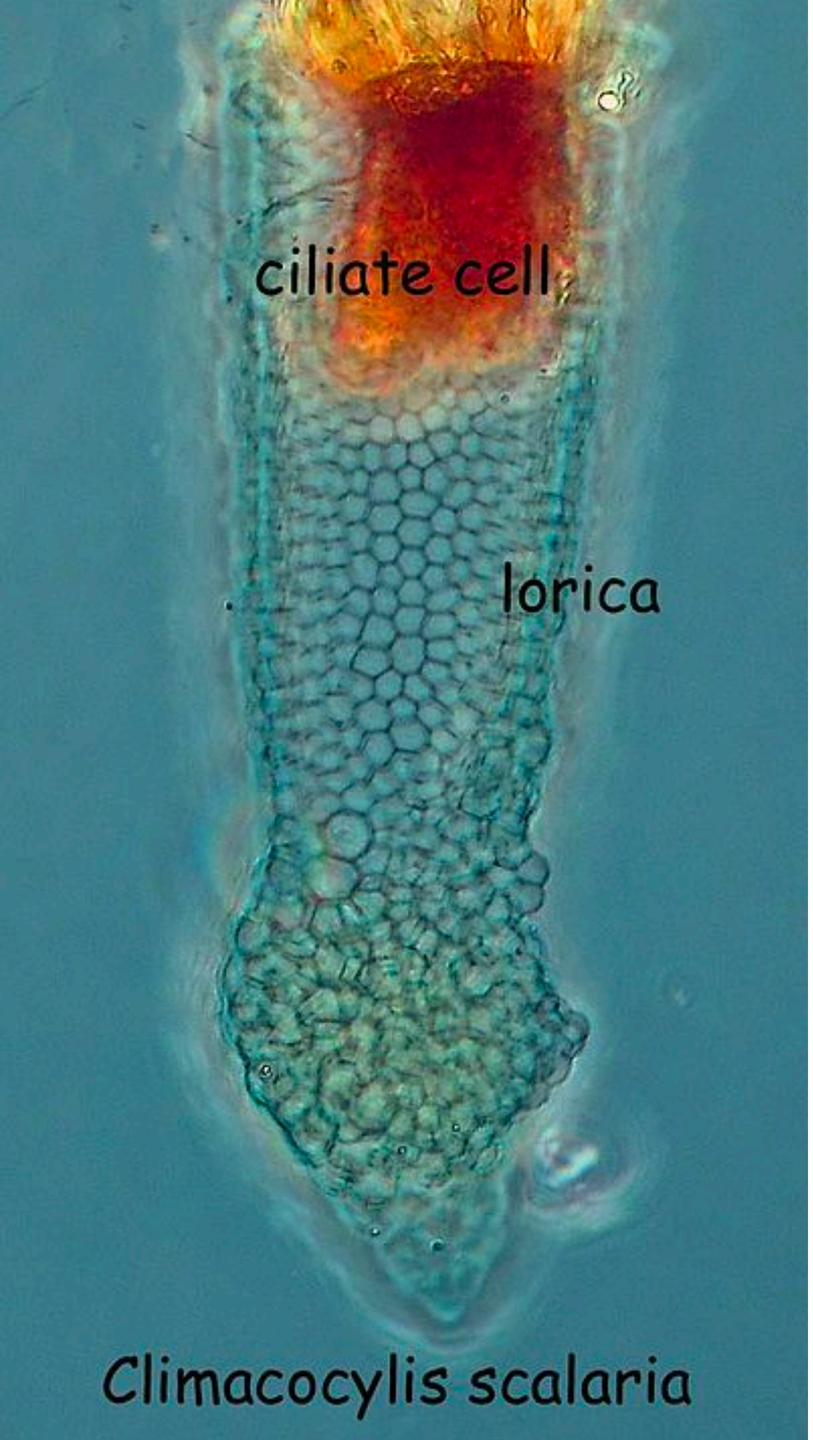
Diatoms & diazotrophs may have **symbiotic** relationships

Ciliates

Ciliates are important **heterotrophic** protists

- Chow down on biomass of bacteria and smaller eukaryotic phytoplankton
- Form a key link in the microbial loop
- Also kleptoplastidic

Oligotrichs



Choreotrichs (including tintinnids)

- Lorica are the shells
- So, they’re preserved like diatoms + coccolithophores
- Generally considered zooplankton/heterotrophs

Readings for next week!

communications
earth & environment

ARTICLE

Check for updates

https://doi.org/10.1038/s43247-021-00201-y

OPEN

Photoacclimation by phytoplankton determines the distribution of global subsurface chlorophyll maxima in the ocean

Yoshio Masuda[1,7]✉, Yasuhiro Yamanaka[1,8], Sherwood Lan Smith[2,7], Takafumi Hirata[3,8], Hideyuki Nakano[4], Akira Oka[5] & Hiroshi Sumata[6]

- Reading 1: Masuda 2021 – more general paper

Readings for next week!

New Phytologist

WILEY

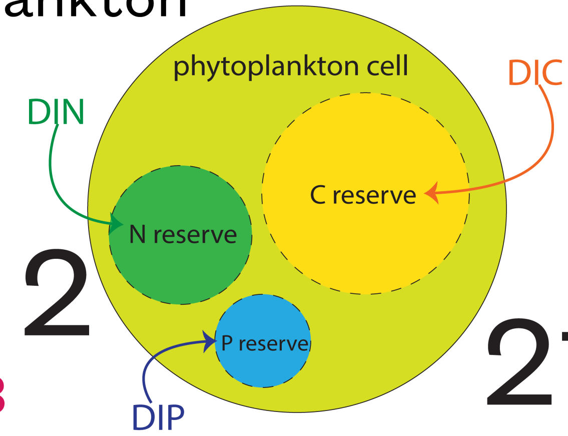
Light and Temperature Dependence of the Carbon to Chlorophyll a Ratio in Microalgae and Cyanobacteria: Implications for Physiology and Growth of Phytoplankton

Author(s): Richard J. Geider

Source: *The New Phytologist*, May, 1987, Vol. 106, No. 1 (May, 1987), pp. 1-34

- Reading 2: Geider 1987 – more model-specific

Phytoplankton 2021 Physiology Seminar



2 21

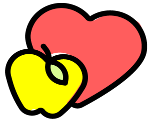
fridays
1-2:30 pm
54-824

12.S593

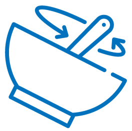
Physiology Seminar

this semester, we'll explore

1. out of thin air (light harvesting)
2. dependencies (nutrients)



3. on math, models, & traits
4. setting a global stage
5. I'll have it both ways (mixotrophy)



6. teamwork makes the dream work (symbioses & competition)

7. till death do us part (mortality)
8. an aquatic pandemic? (viruses)

9. individual stoichiometry
10. an evolving process
11. biogeography & what's next?

from the lens of classic & modern literature

Schedule of Readings

- Week 2
  - Geider 1987: Light and Temperature Dependence of the Carbon to Chlorophyll a Ratio in Microalgae and Cyanobacteria: Implications for Physiology and Growth of Phytoplankton
  - Masuda 2021: Photoacclimation by phytoplankton determines the distribution of global subsurface chlorophyll maxima in the ocean
- Week 3
  - Geider 2002: Redfield revisited: variability of C:N:P in marine microalgae and its biochemical basis
  - Morel 2008: The co-evolution of phytoplankton and trace element cycles in the oceans
- Week 4
  - Riley 1946: Factors Controlling Phytoplankton Populations on Georges Bank
  - Siegel 2002: The North Atlantic Spring Phytoplankton Bloom and Sverdrup's Critical Depth Hypothesis
- Week 5
  - Litchman 2015: Global biogeochemical impacts of phytoplankton: a trait-based perspective
  - Finkel 2009: Phytoplankton in a changing world: cell size and elemental stoichiometry
- Week 6
  - Stoecker 2017: Mixotrophy in the Marine Plankton
  - Caron 2016: Mixotrophy stirs up our understanding of marine food webs

Schedule of Readings

- Week 7
  - Burson 2018: Competition for nutrients and light: testing advances in resource competition with a natural phytoplankton community
  - Seymour 2017: Zooming in on the phycosphere: the ecological interface for phytoplankton–bacteria relationships
- Week 8
  - Hansen 1994: The size ration between planktonic predators and their prey
- Week 9
  - Menge 2009: Dangerous nutrients: Evolution of phytoplankton resource uptake subject to virus attack
  - Suttle 1990: Infection of phytoplankton by viruses and reduction of primary productivity
- Week 10
  - Inomura 2016: A quantitative analysis of the direct and indirect costs of nitrogen fixation: a model based on Azotobacter vinelandii
  - Klausmeier 2008: Phytoplankton stoichiometry

Schedule of Readings

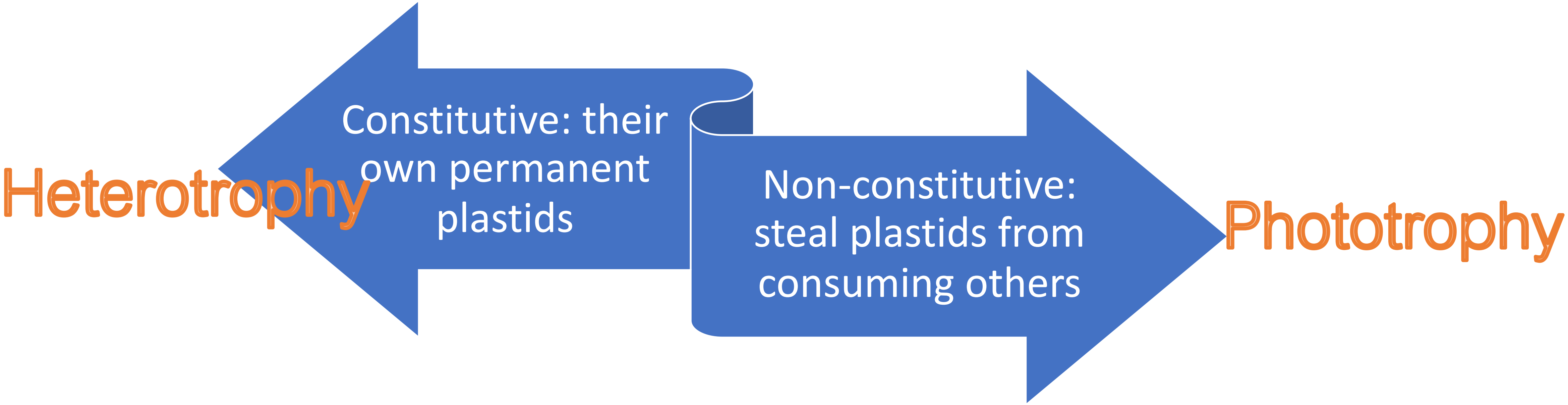
- Week 11
  - Martiny 2020: Genomic adaptation of marine phytoplankton populations regulates phosphate uptake
- Week 12
  - Cermeno 2008: Resource levels, allometric scaling of population abundance, and marine phytoplankton diversity
  - Litchman 2008: Trait-based community ecology of phytoplankton

Mixotrophy

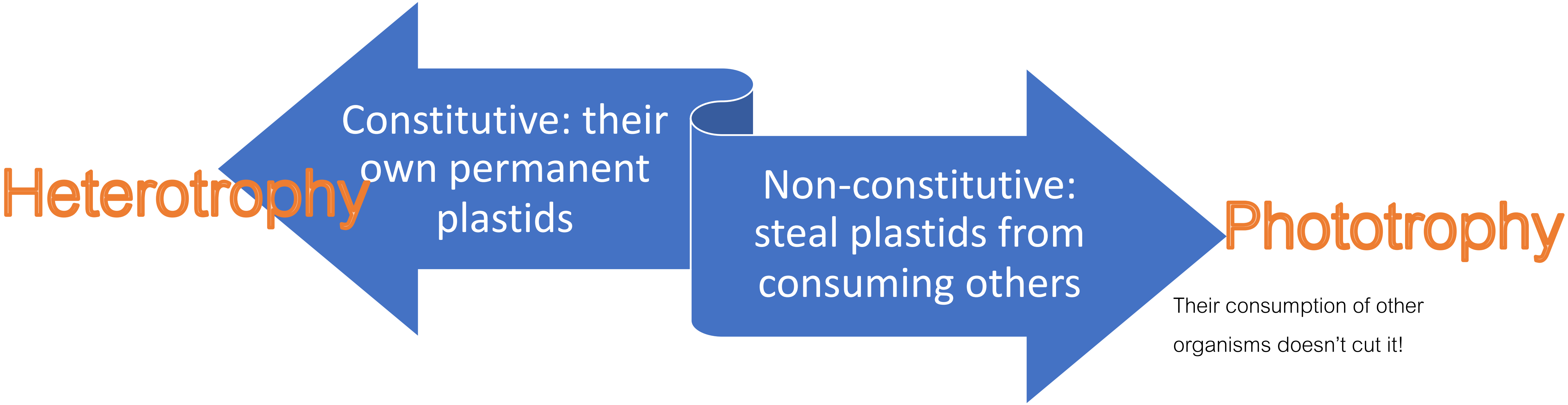
Constitutive: their own permanent plastids

Non-constitutive: steal plastids from consuming others

Mixotrophy


Heterotrophy
Constitutive: their own permanent plastids
Non-constitutive: steal plastids from consuming others
Phototrophy

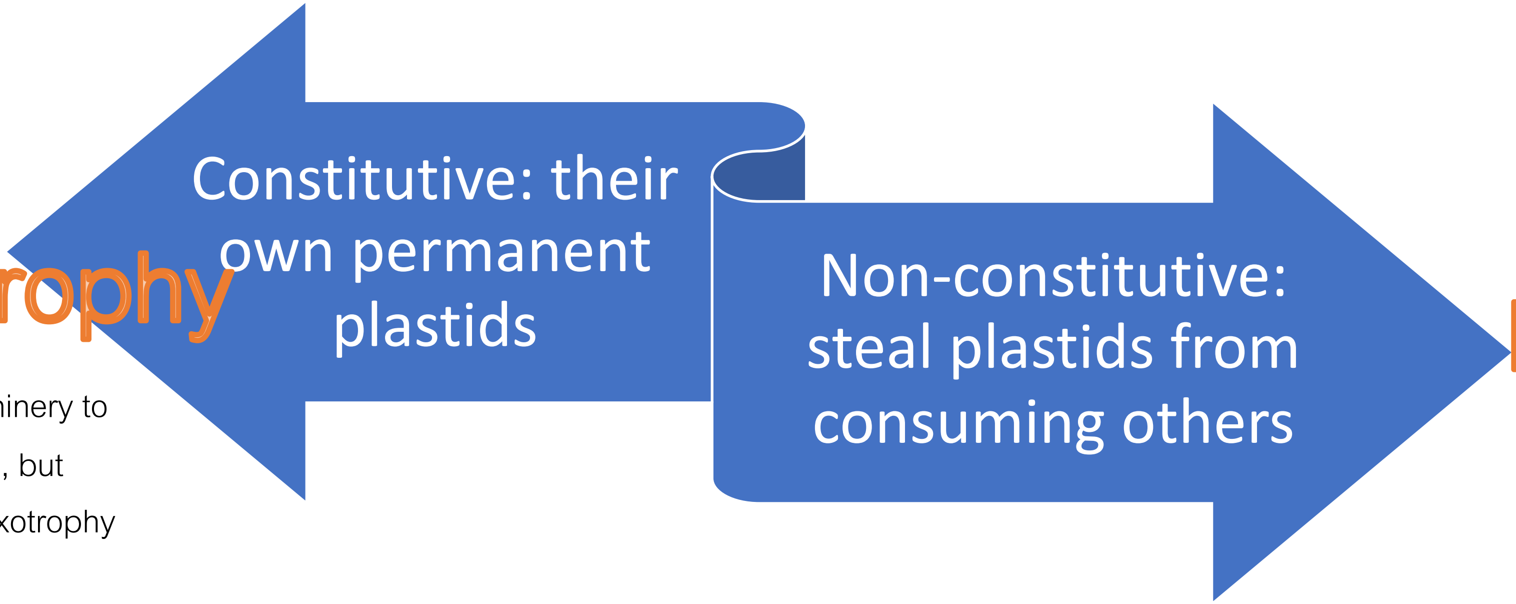
Mixotrophy



Their consumption of other organisms doesn't cut it!

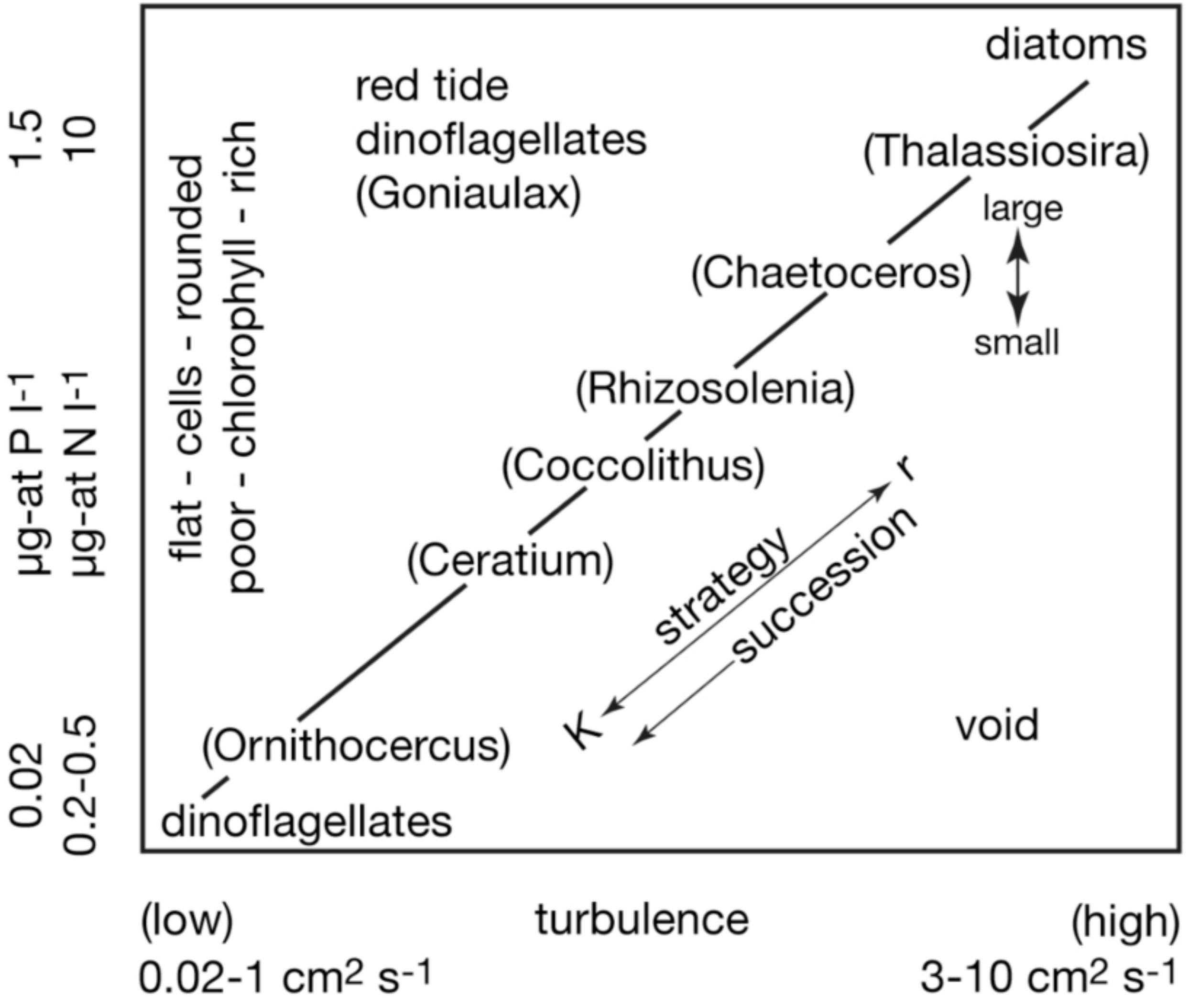
Mixotrophy

Heterotrophy



Phototrophy

They have all the machinery to provide for themselves, but they're engaging in mixotrophy on the side!



Margalef's Mandala

Plankton are in the Charles River, too!