Marine Biogeochemistry 2: Nutrient limitation

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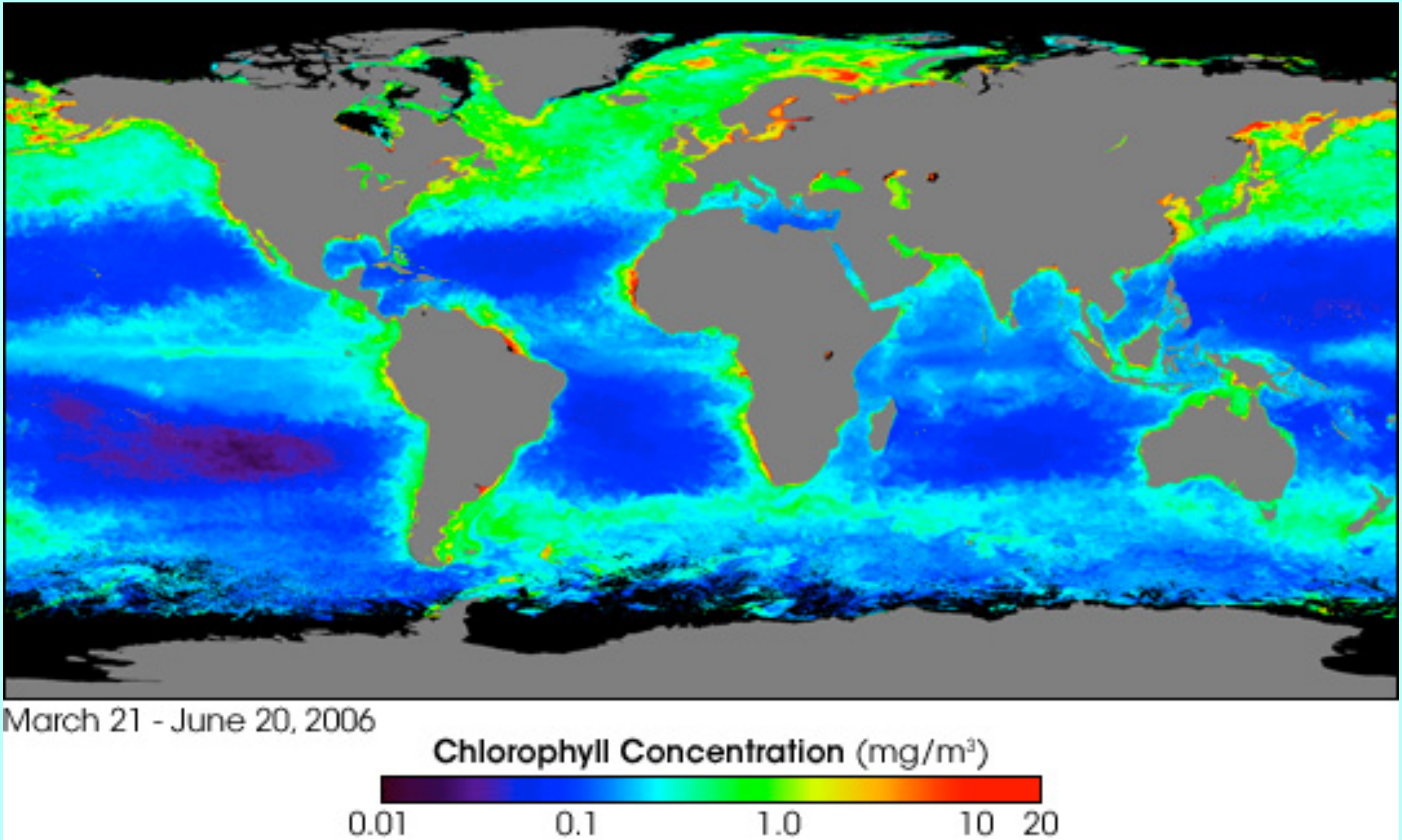
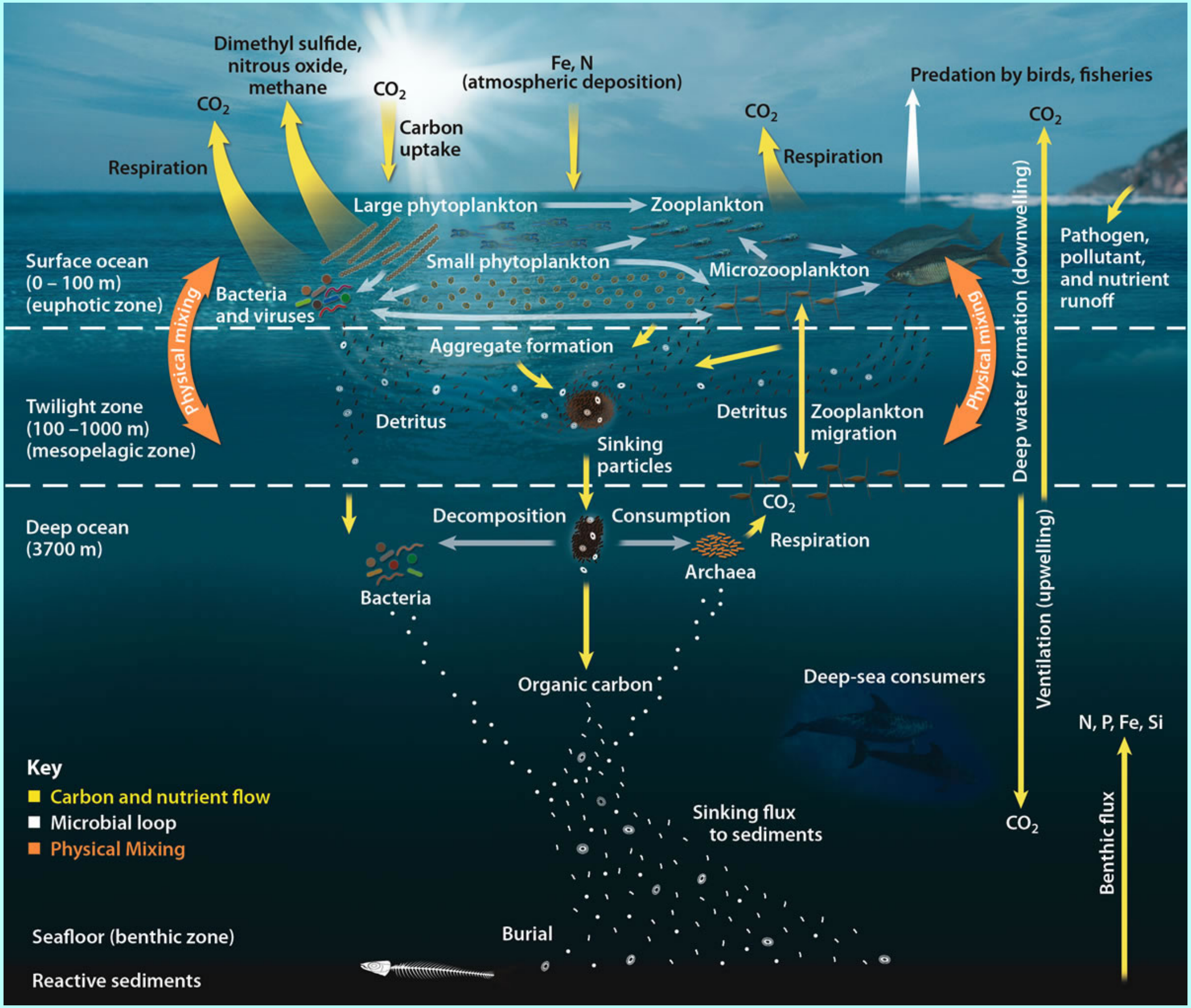
COESSING at University of Ghana

The Ocean is not Homogeneous



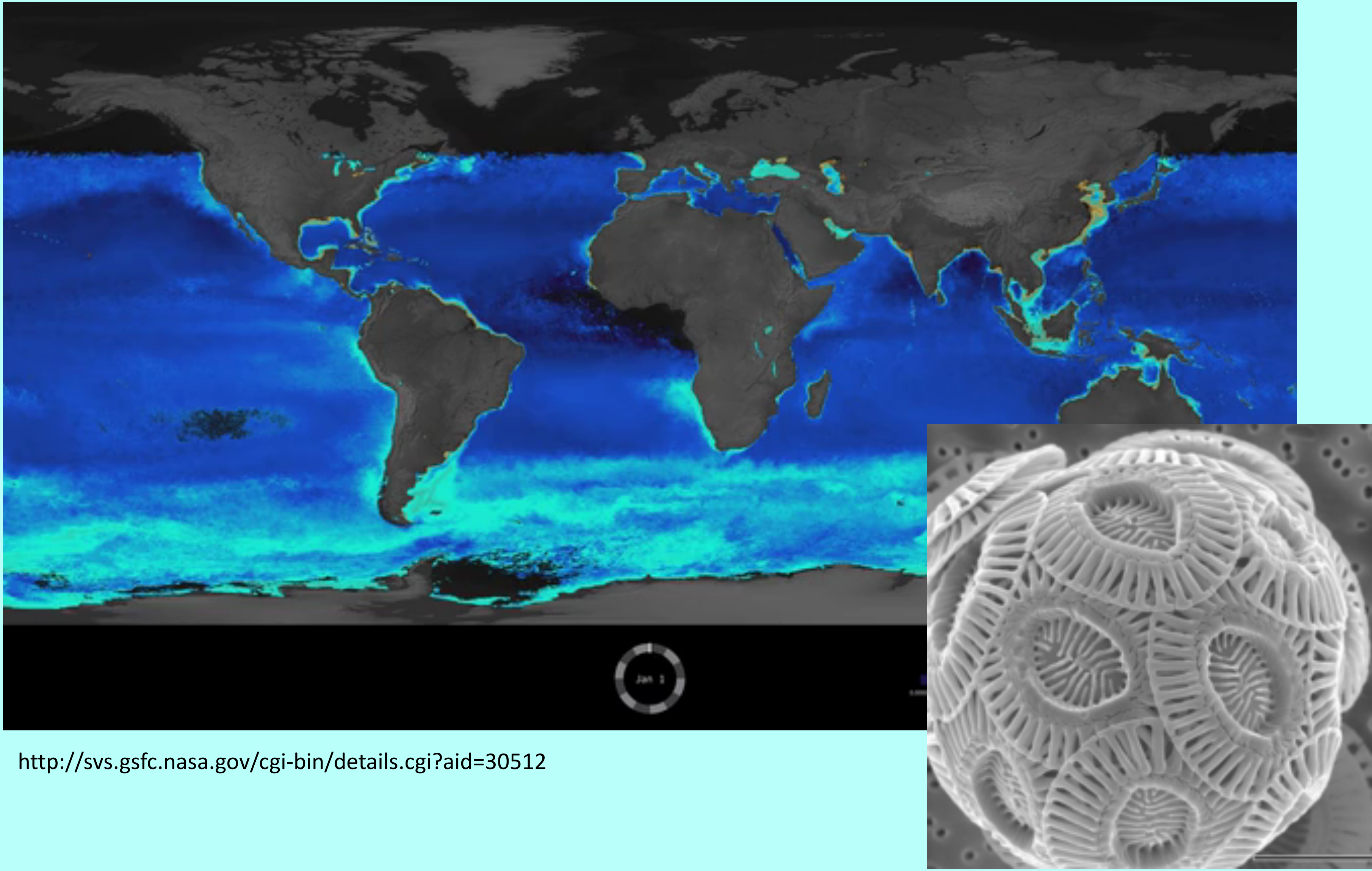
http://earthobservatory.nasa.gov/IOTD/view.php?id=6735

Marine microbial food web



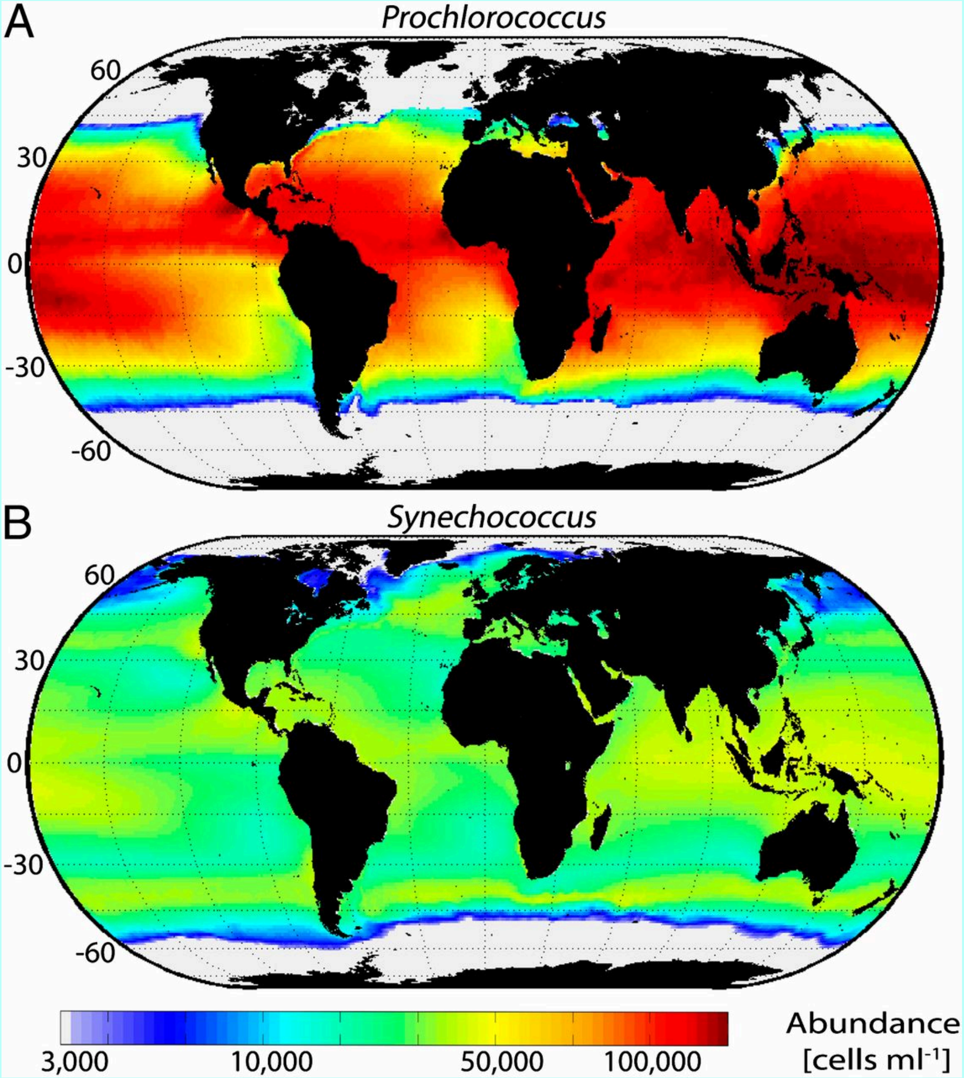
Oak Ridge National Laboratory

Coccolithophores Visible in Satellite Images



http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=30512

Cyanobacteria Distributions

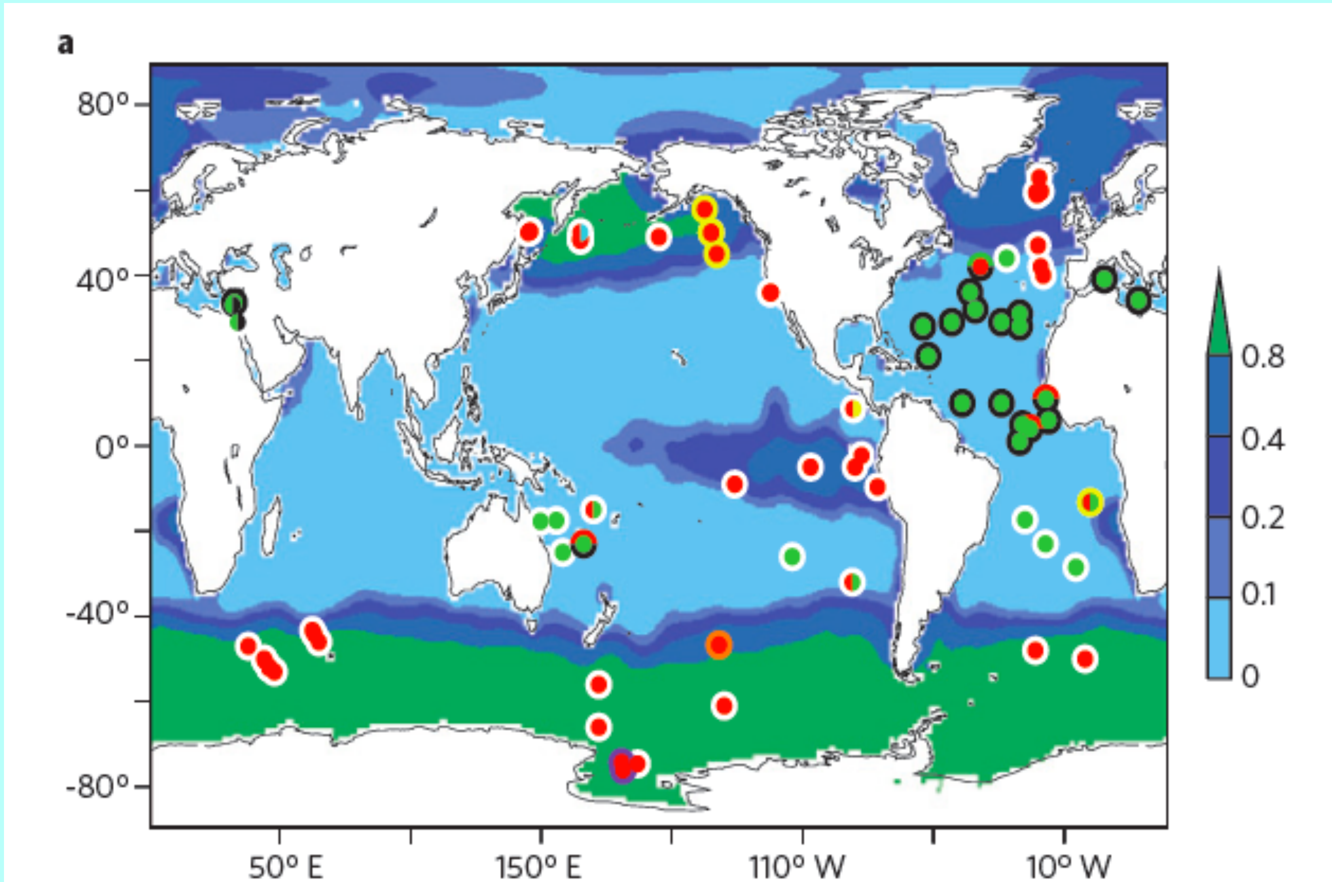


Flombaum et al., 2013

Physiological Requirements for these Nutrients

- N: amino acids / proteins
- P: nucleic acids, phospholipids
- Fe: nitrogenase, nitrate & nitrite reductase, photosystem I, cytochromes, superoxide dismutase
- Si: diatom frustules
- Co: carbonic anhydrase, required for Vitamin B_{12}
- Zn: carbonic anhydrase
- Vitamin B_{12}: methionine synthase

Nutrient Limitation in the Ocean



Moore et al., 2013

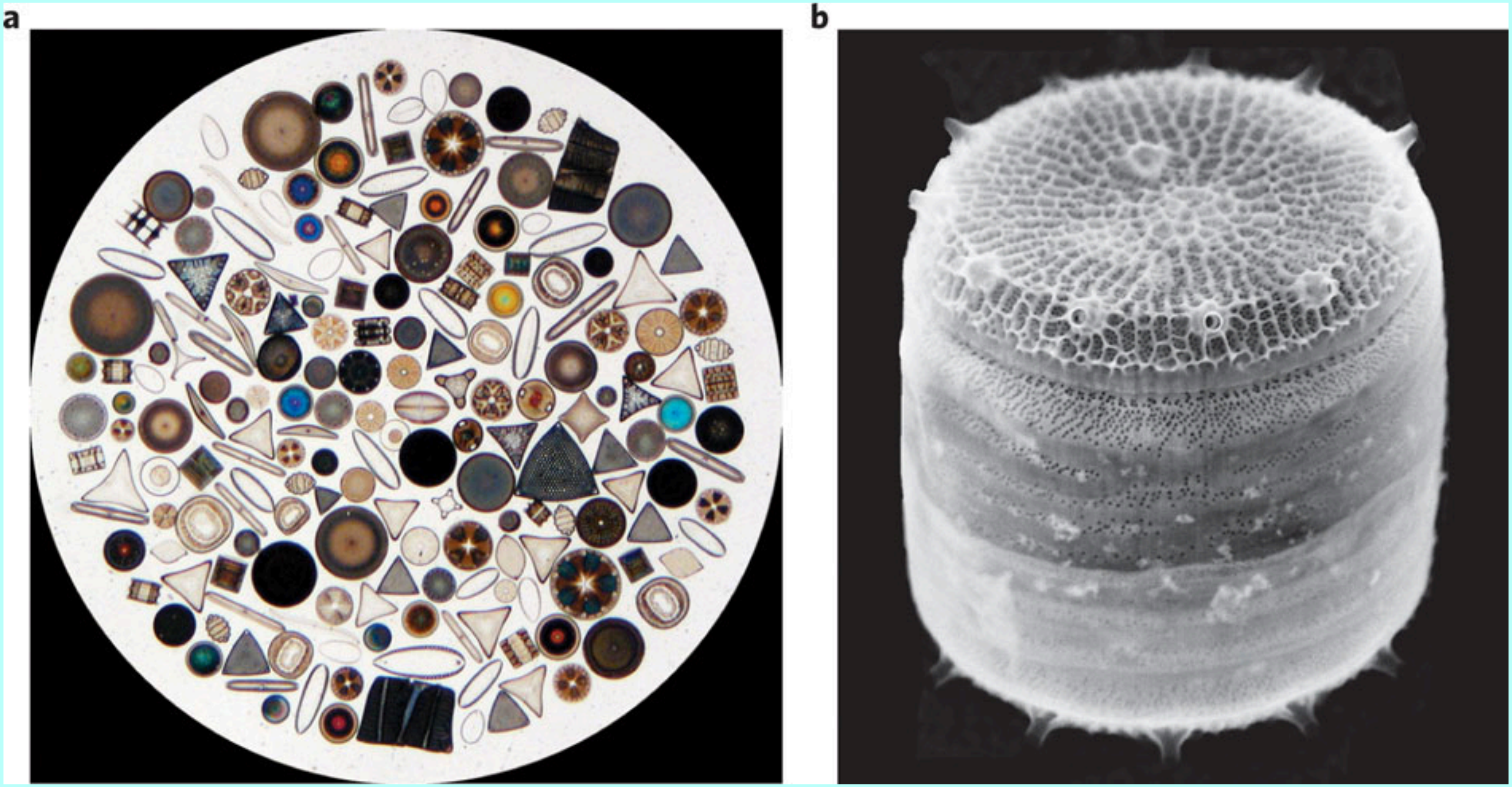
Nitrate Concentration (Scaled to P)

N
P
Fe
Si
Co
Zn
Vitamin B_{12}

Strategies for adapting to oligotrophic conditions

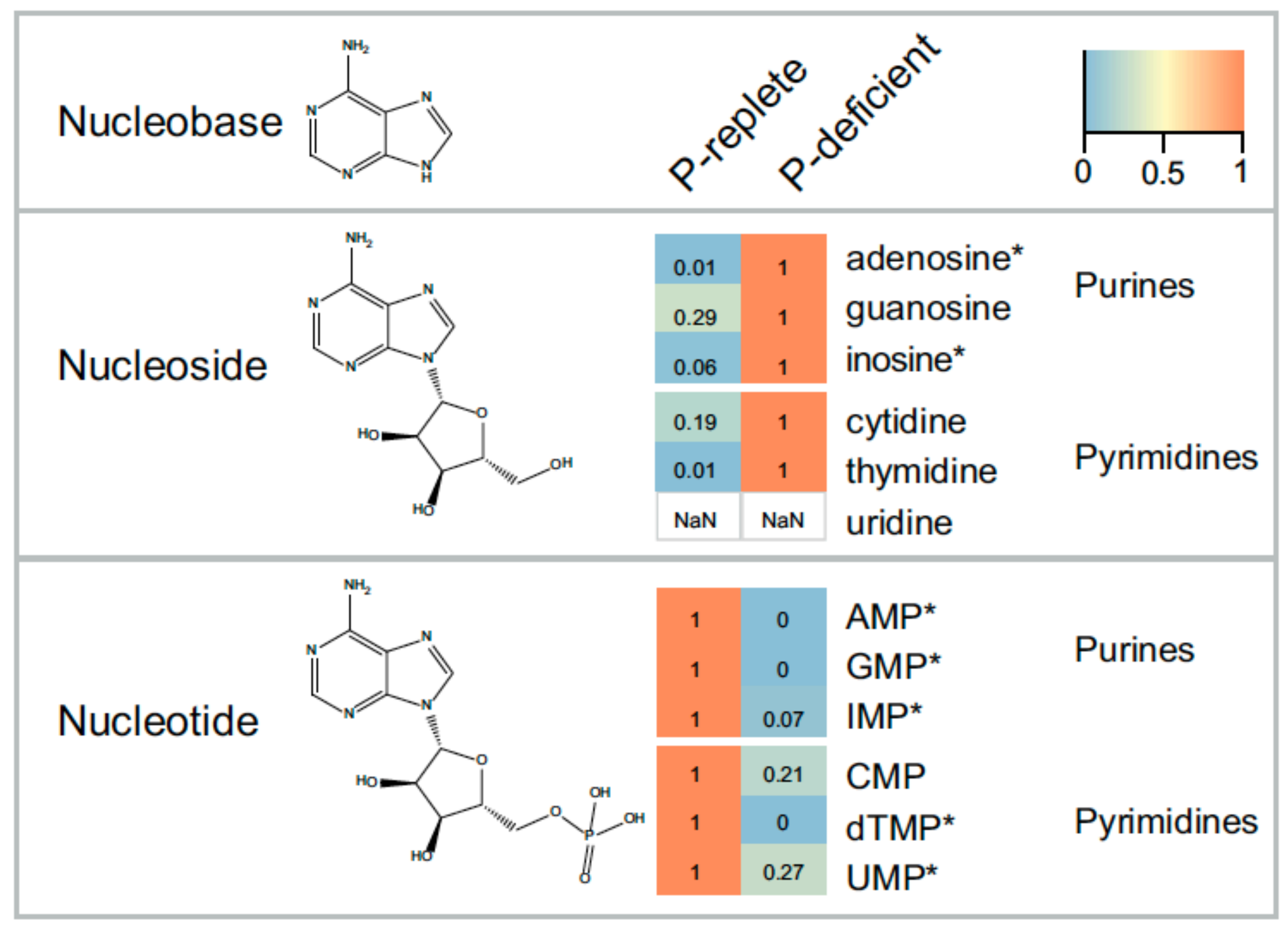
- Reducing P
- Recycling Fe
- Replacing P with S
- Accessing organic matter
- Trading food for vitamins

Thalassiosira pseudonana reduces phosphorus stores



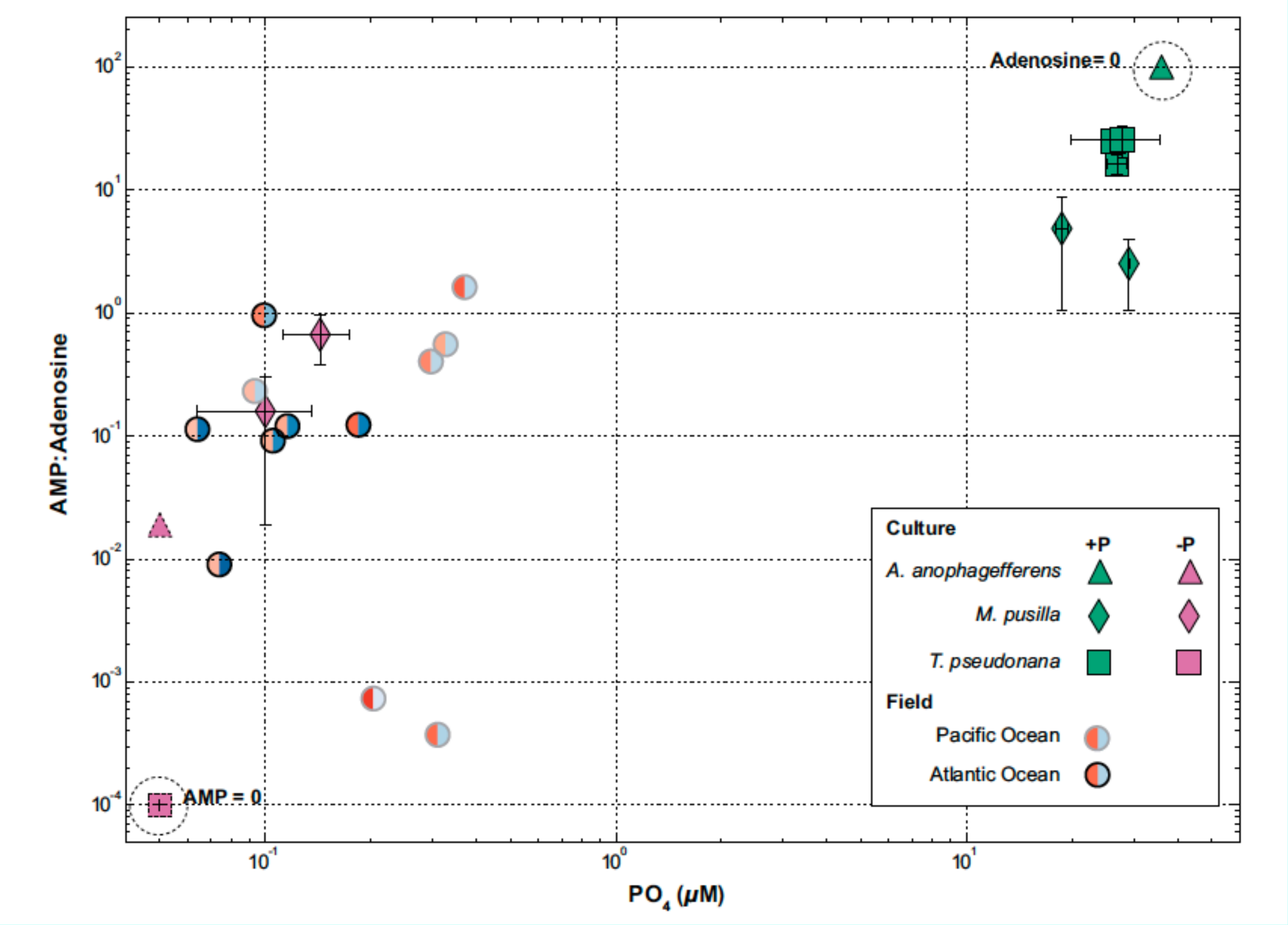
Möller & Hoose, 2011

Under P-limitation *T. pseudonana* reduces nucleotide concentrations



Kujawinski et al., 2017

P-limited ratios also seen in the ocean

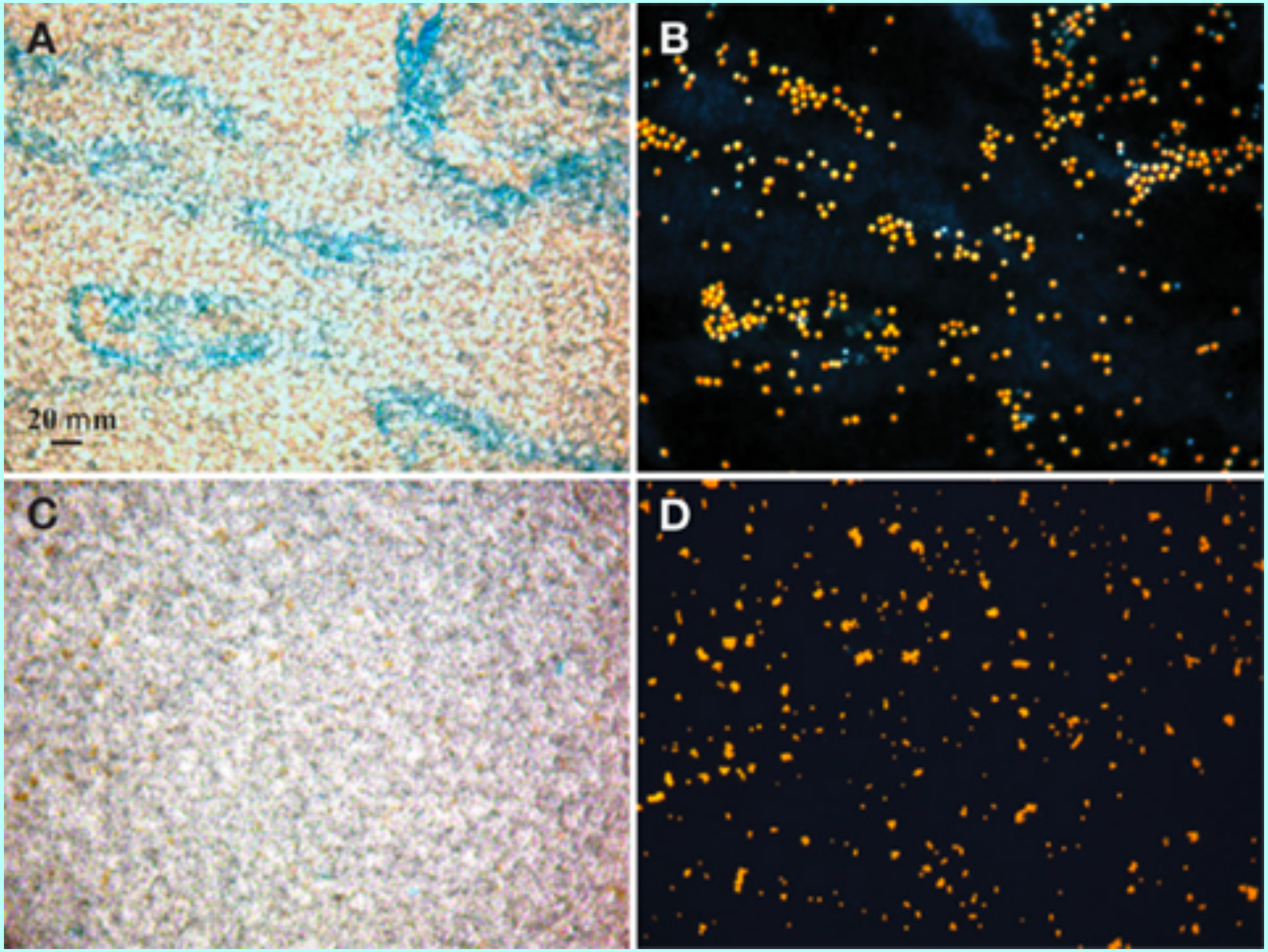


Kujawinski et al., 2017

Fe

"Give me half a tanker of iron, and I'll give you an ice age"
-John Martin

Fe Recycling in *Crocosphaera watsonii*

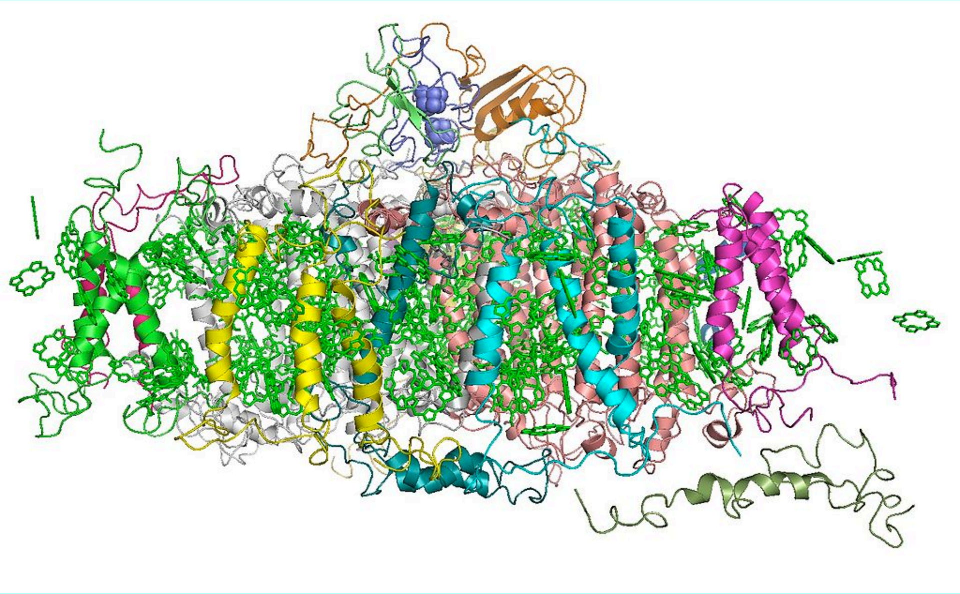


Sohm et al., 2011

Tropical diazotrophic cyanobacterium

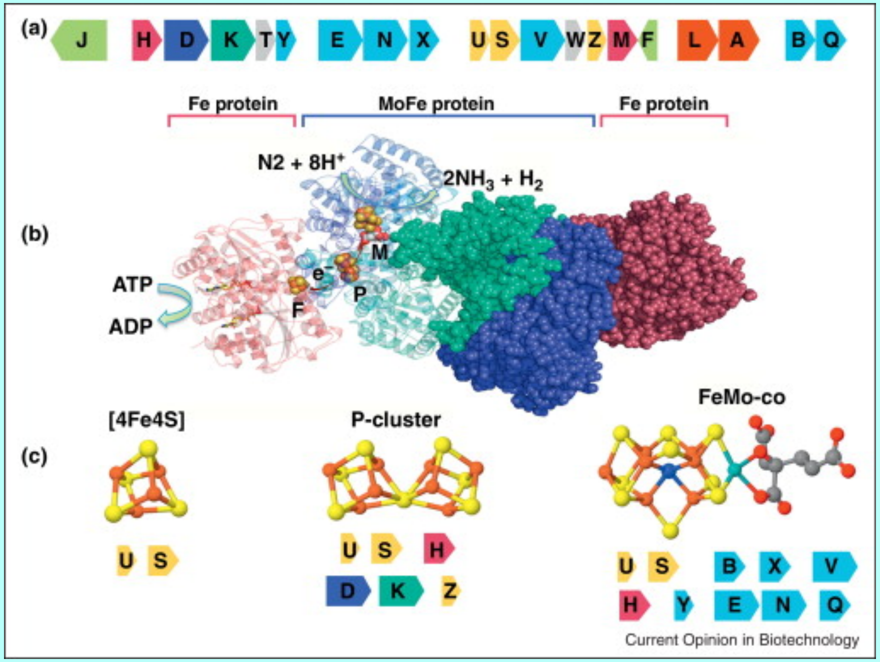
Requires Fe for Photosynthesis & Nitrogen Fixation

Photosystem I



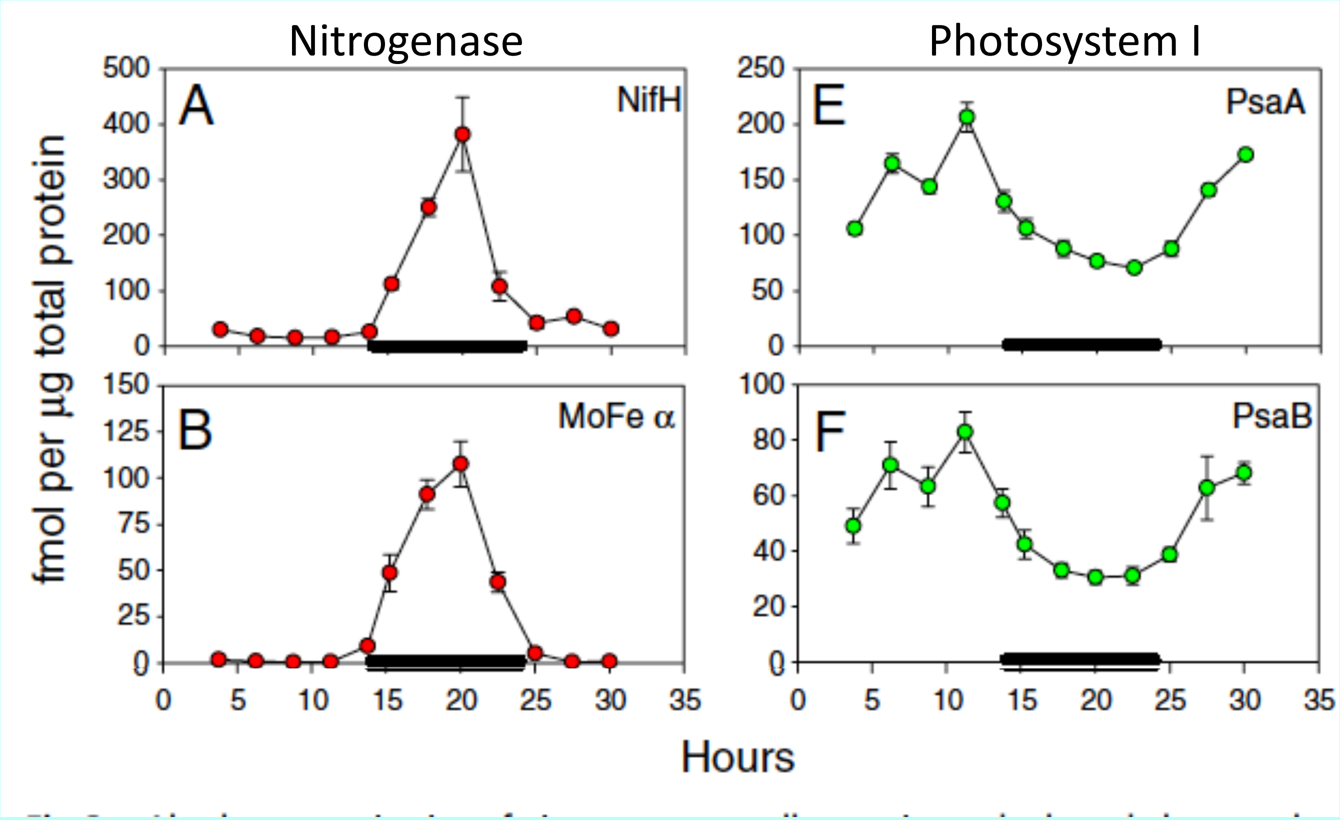
Neveu, 2011

Nitrogenase



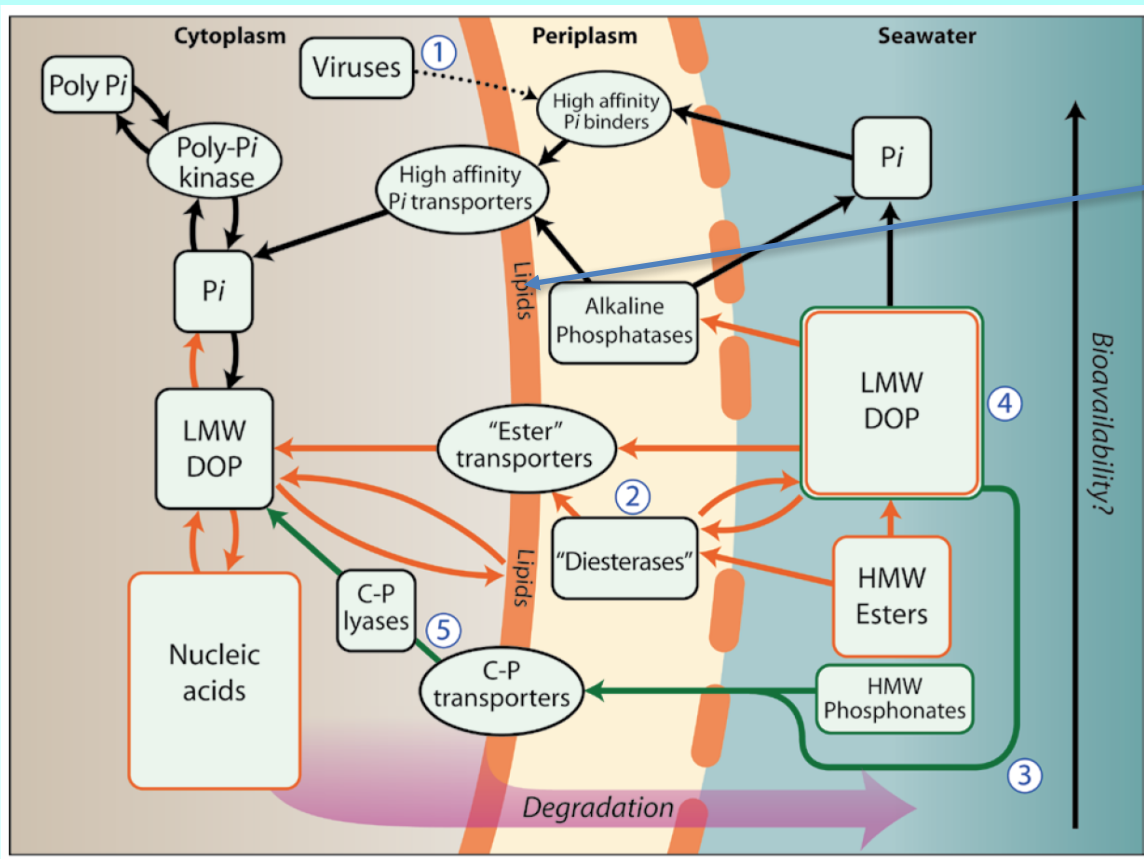
Oldroyd & Dixon, 2014

Proteomic Analysis Finds that Enzymes are Degraded Daily Freeing Fe to be Used by Other Enzymes

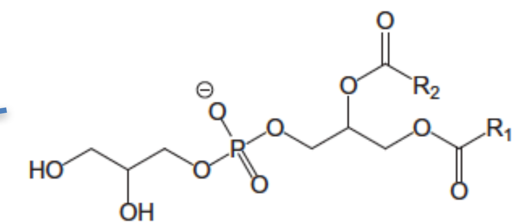


Saito et al., 2011

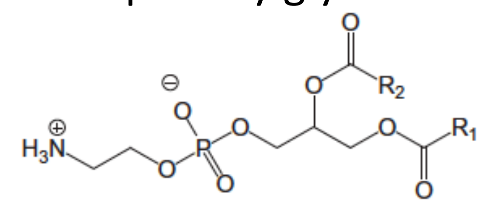
Replacing P with S



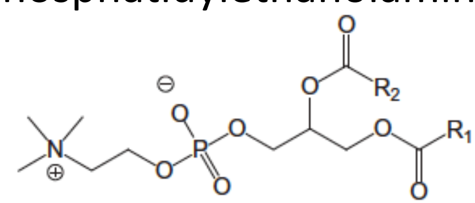
Dyhrman et al., 2007



Phosphatidylglycerol

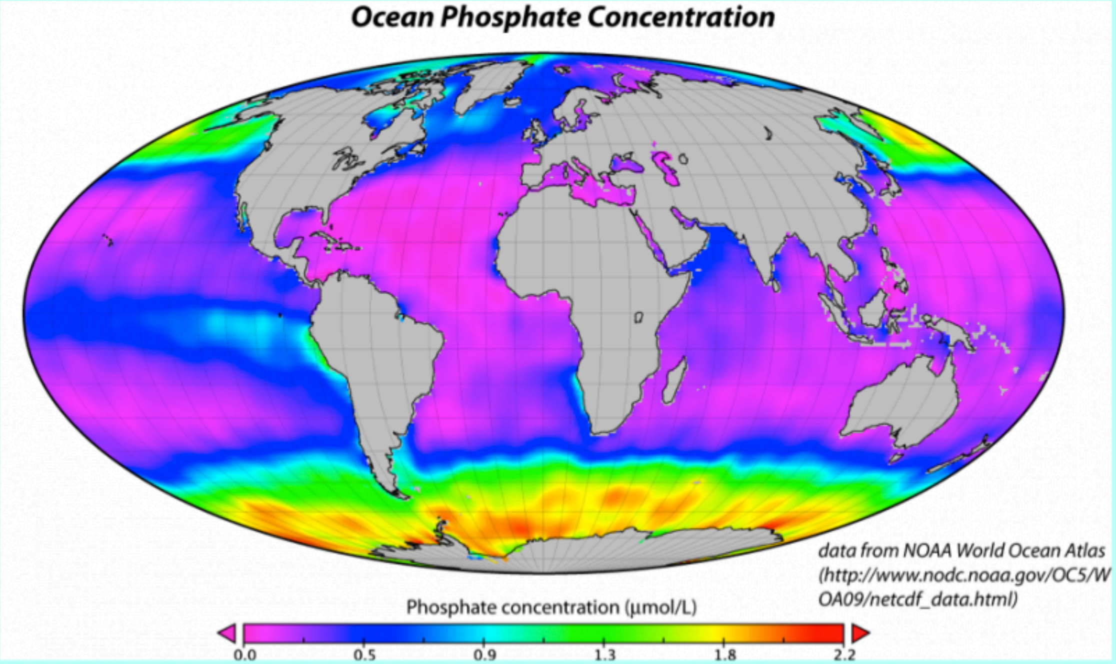


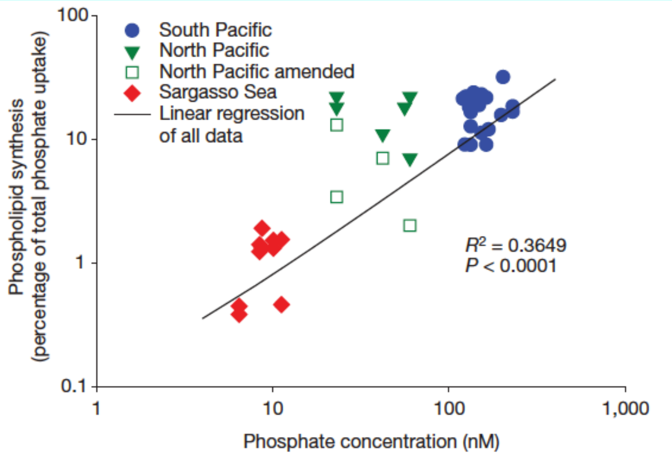
Phosphatidylethanolamine



Phosphatidylcholine

Phospholipid Synthesis Decreases with Lower Phosphate Concentrations





Van Mooy et al., 2009

Phospholipids Replaced with Sulfur Containing Lipids

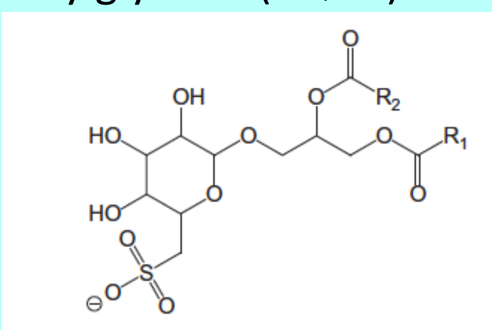
Table 1 | Ratios of substitute lipids to phospholipids in phytoplankton cultures and environmental samples

	SQDG/PG ratio, P-replete	SQDG/PG ratio, P-limited	BL/PC ratio, P-replete	BL/PC ratio, P-limited
Cyanobacteria				
Synechococcus WH8102	**9.9 ± 2.0**	**120.5 ± 7.1**	0†	0†
Synechococcus WH7803	**10.3 ± 0.3**	**61.6 ± 15.4**	0†	0†
Synechococcus WH5701	**6.2 ± 0.5**	**132.0 ± 31.0**	0†	0†
Prochlorococcus MED4	**20.0 ± 1.3**	**34.1 ± 1.6**	0†	0†
Crocosphaera watsonii	4.0	5.8	0†	0†
Trichodesmium erythreum	**7.8 ± 1.0**	**18.5 ± 4.9**	0†	0†
Eukaryotic phytoplankton				
Thalassiosira pseudonana	**3.0 ± 0.9**	**394.8 ± 48.2**	<0.01‡	>500§
Chaetoceros affinis	**10.5 ± 3.6**	**26.3 ± 9.0**	**0.9 ± 0.2**	**27.8 ± 8.3**
Emiliania huxleyi	<0.01*	<0.01*	0.7	1.3
Communities				
South Pacific	**3.6 ± 0.8**	NA	**3.6 ± 1.7**	NA
Sargasso Sea	NA	**4.5 ± 1.1**	NA	**13.1 ± 4.0**

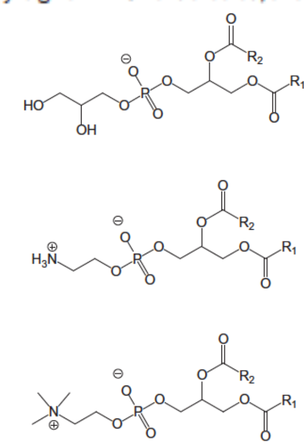
Bold type indicates significant differences between phosphorus-replete and phosphorus-limited conditions as indicated by directional Mann–Whitney *U*-tests ($P \leq 0.05$). Cultures were analysed in triplicate or greater except for *C. watsonii* and *E. huxleyi*, which were analysed once. In the South Pacific, five discrete samples of the total planktonic community (>0.2 µm) were collected and analysed; there were six samples from the Sargasso Sea. NA, not applicable; BL, betaine lipid; PC, phosphatidylcholine; SQDG, sulphoquinovosyldiacylglycerol; PG, phosphatidylglycerol. *SQDG not detected; analytical sensitivity is given. †BLs not detected and are not known to be produced by cyanobacteria. ‡BLs not detected; analytical sensitivity is given. §PC not detected; analytical sensitivity is given.

Van Mooy et al., 2009

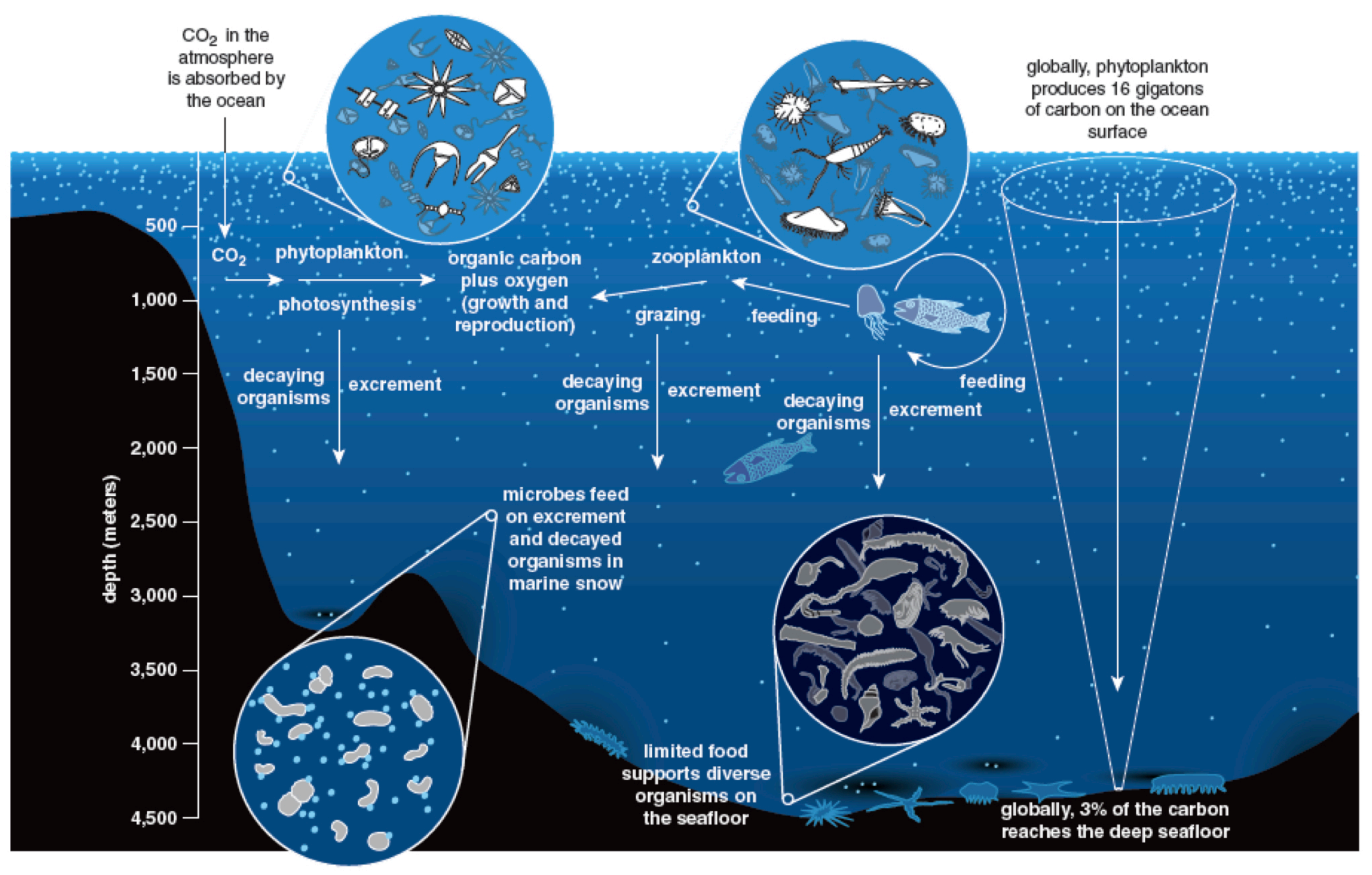
Sulfoquinovosyldiacylglycerol (SQDG):



Betaine Lipids (BL):



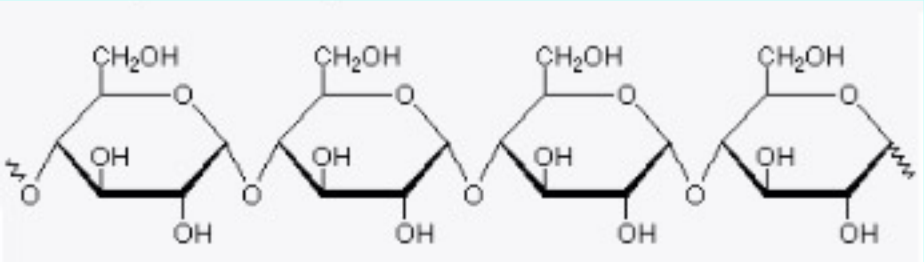
Seeking Labile Organic Matter



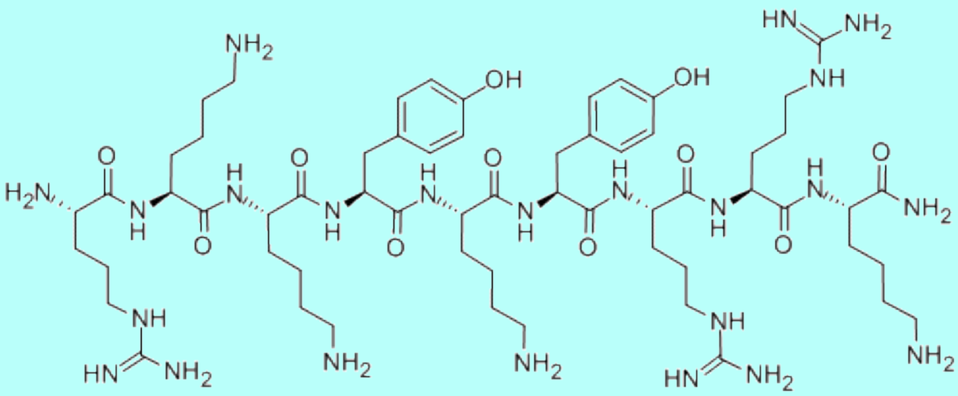
American Scientist

Large Biopolymers

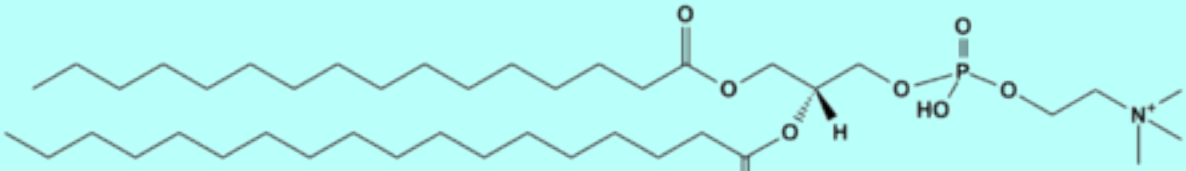
Sugars



Peptides/Proteins

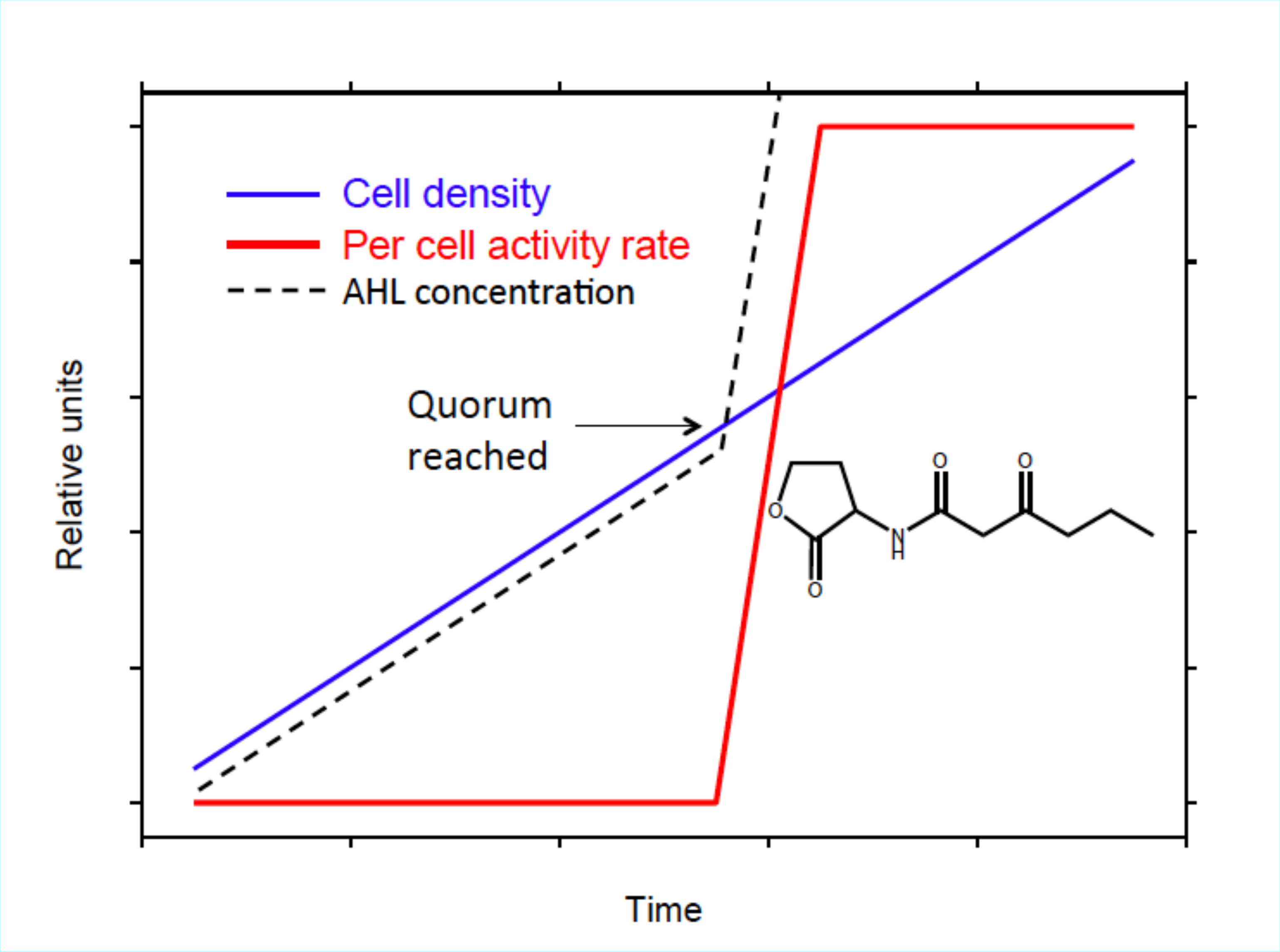


Lipids



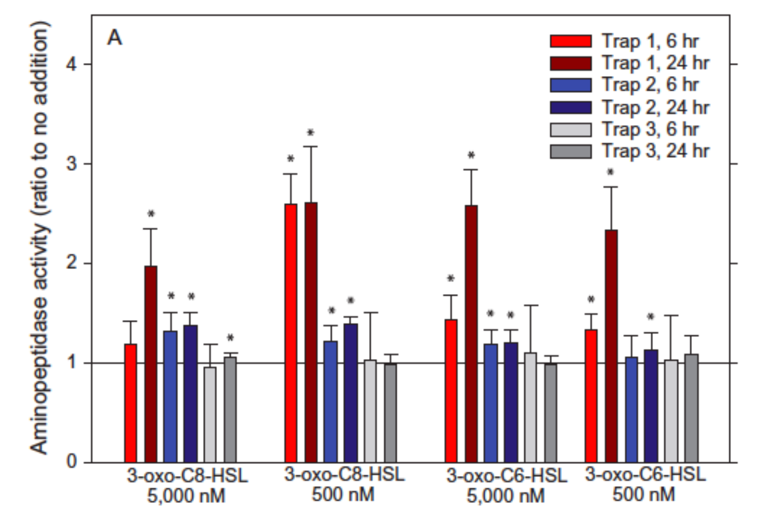
A phospholipid

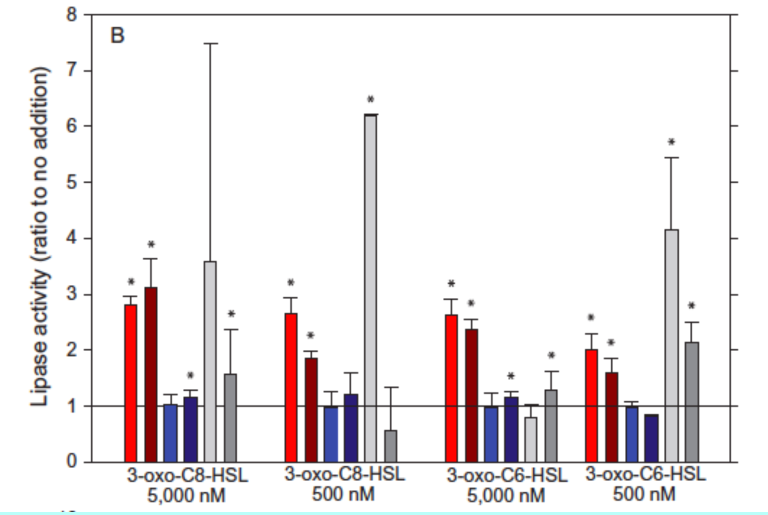
Quorum Sensing



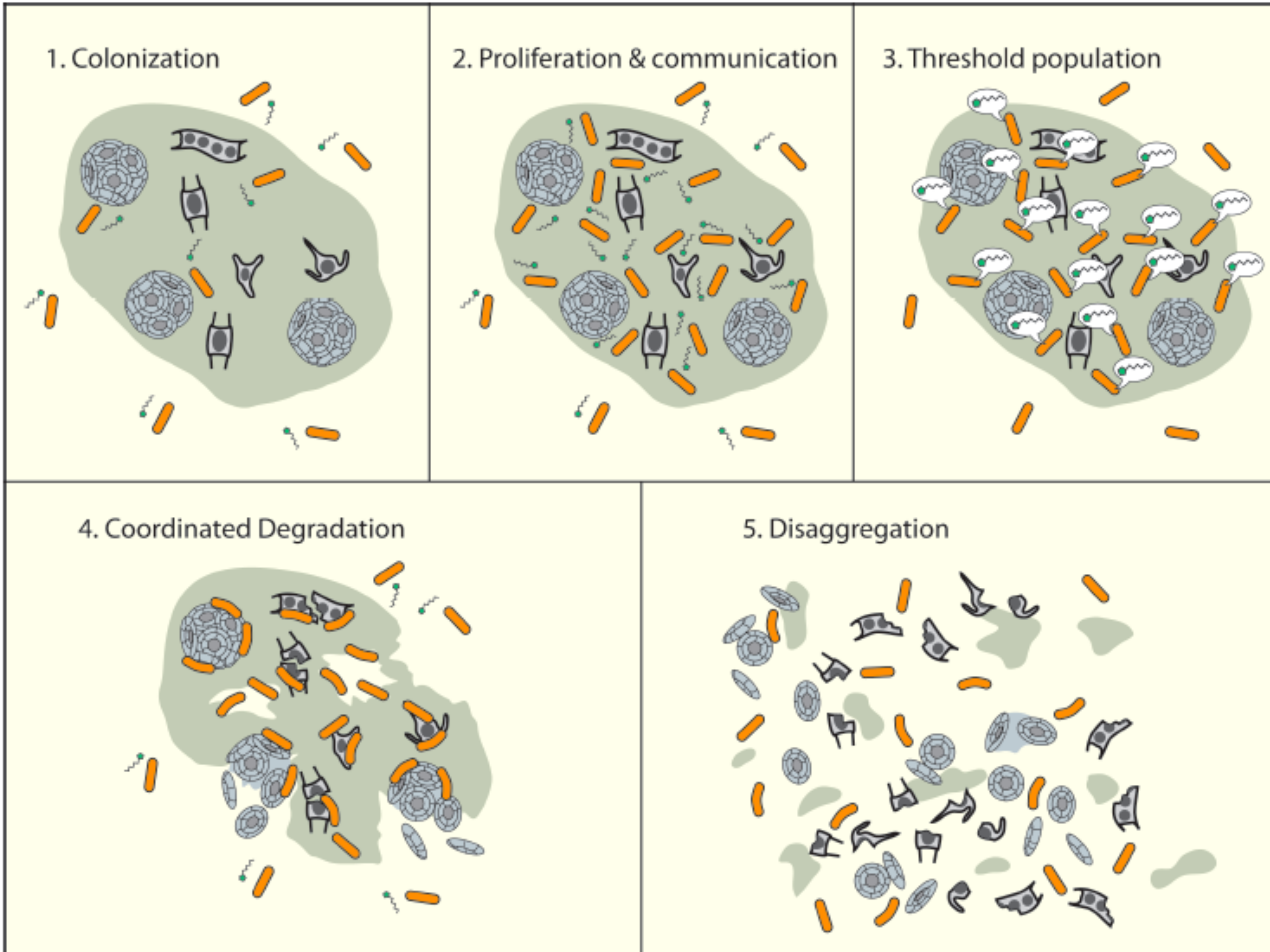
Van Mooy

Using Signals to Coordinate Exoenzyme Production





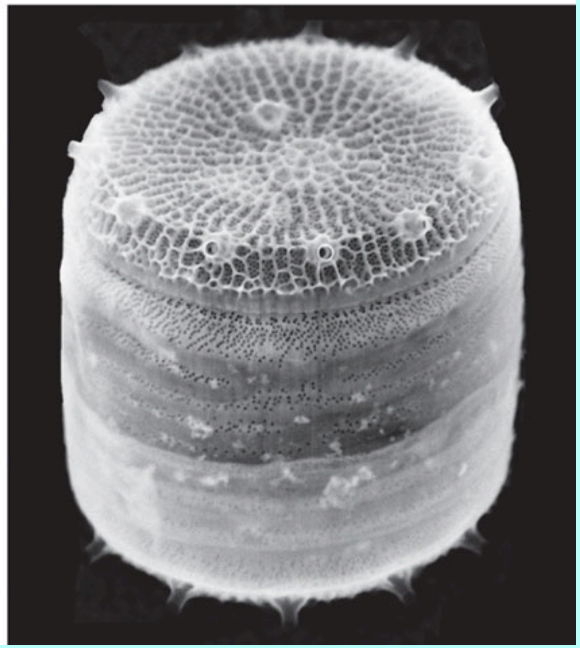
Hmelo et al., 2011



Hmelo et al., 2011

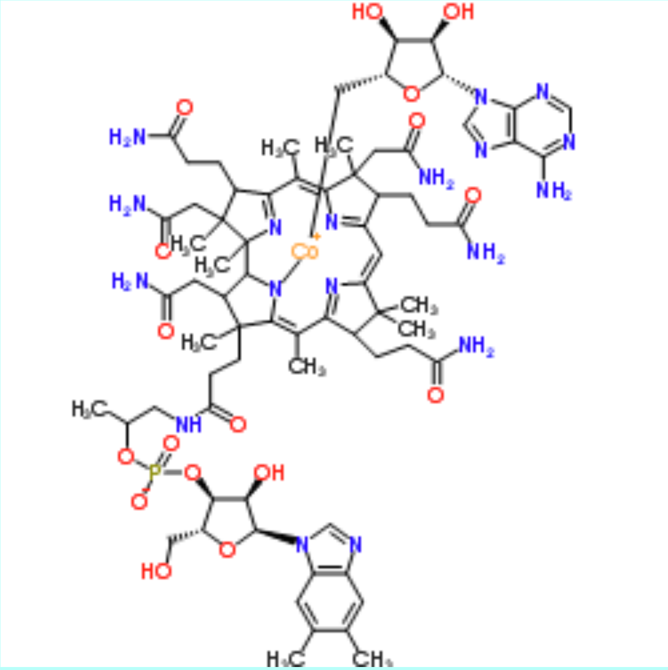
Exchanging carbon substrates for vitamins

Thalassiosira pseudonana

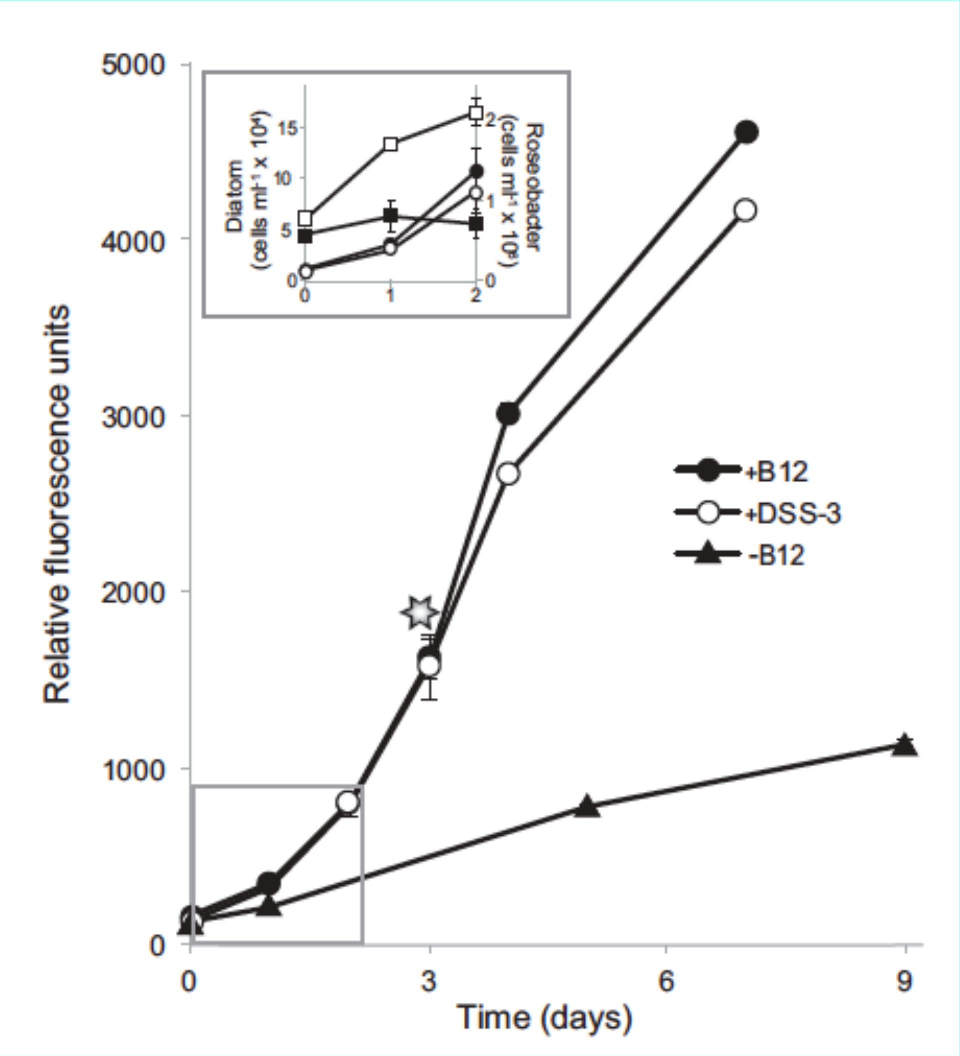


Möller & Hoose, 2011

Vitamin B_{12}

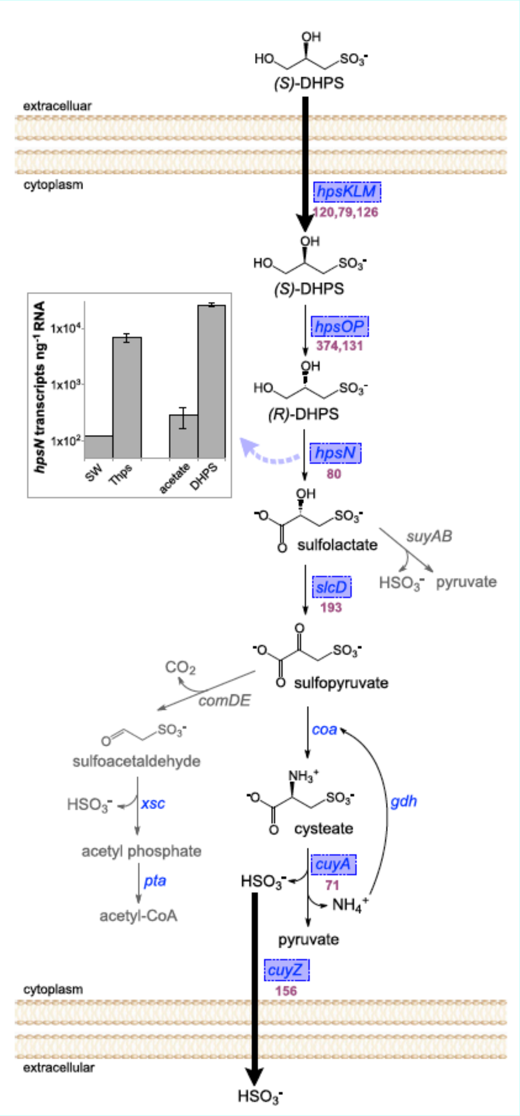


T. pseudonana grows when the heterotroph, *Ruegeria pomeroyi* is present



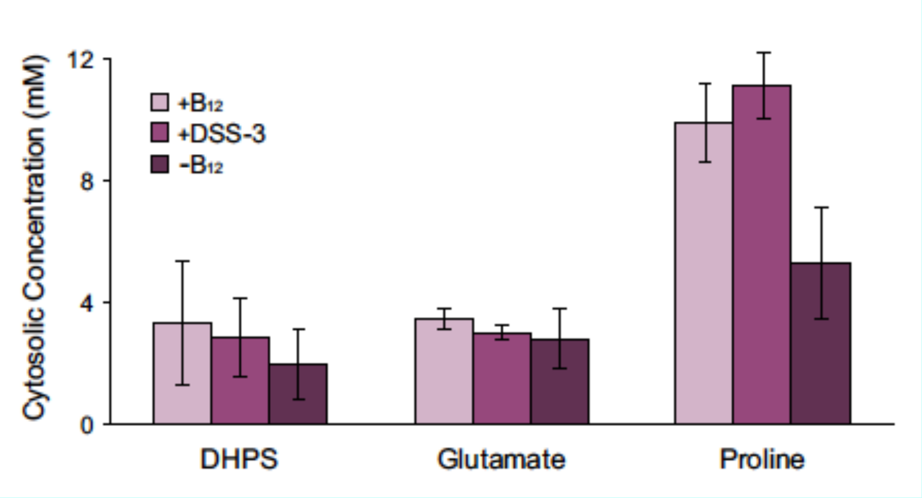
Durham et al., 2015

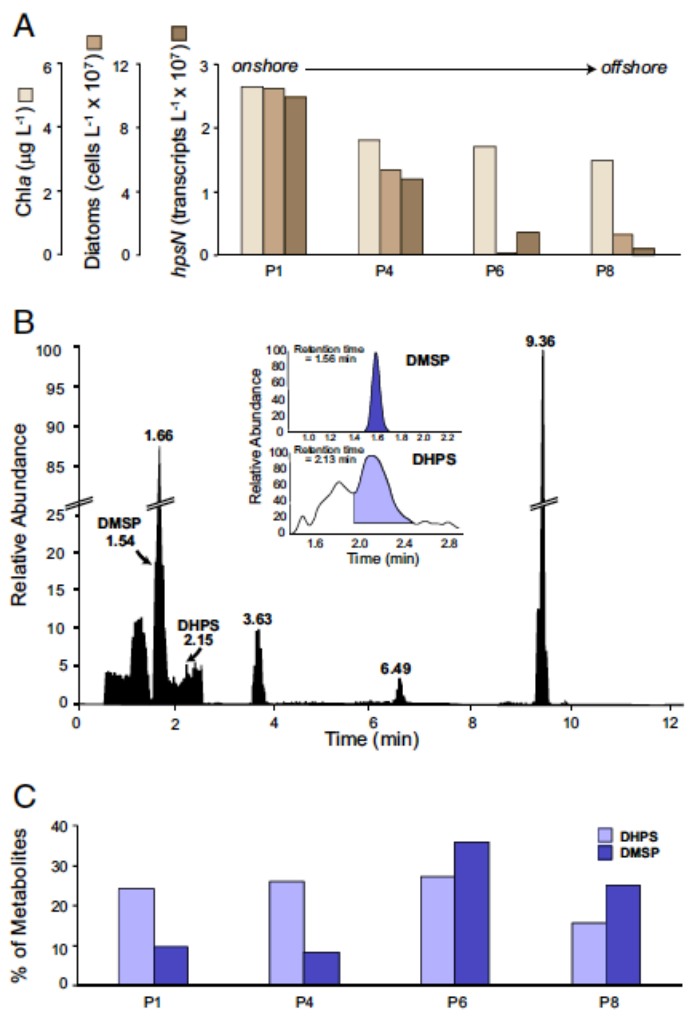
When *R. pomeroyi* is co-cultured with *T. pseudonana* it responds by consuming DHPS



Durham et al., 2015

T. pseudonana produces DHPS





Durham et al., 2015

Conclusions

- Marine microbial distributions shaped by ocean chemistry
- Marine microorganisms adapt their physiology to respond to the chemistry of their environment
- Chemical distributions and microbial activity in the ocean are inextricably linked

Questions?