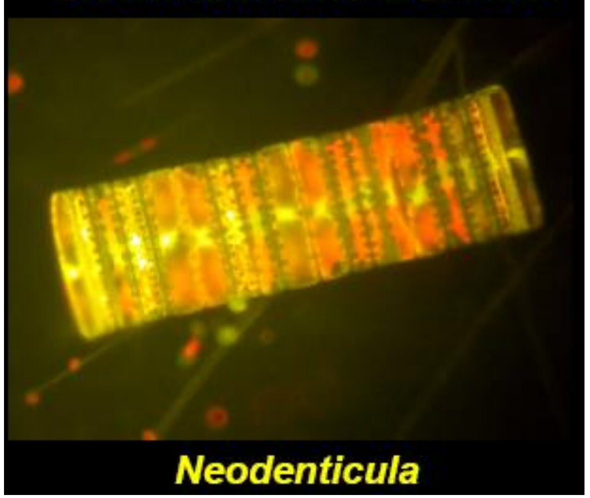
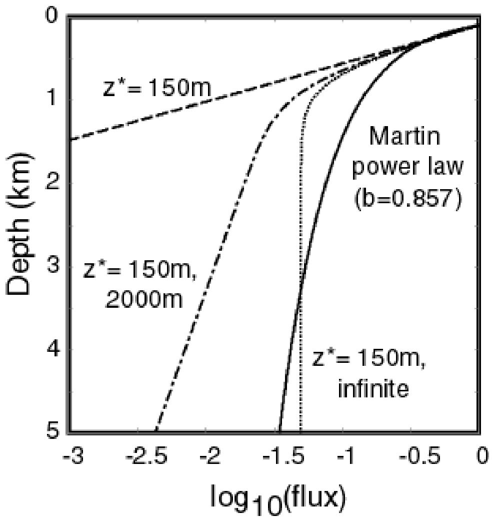
Planktonic community structure and the biological pump

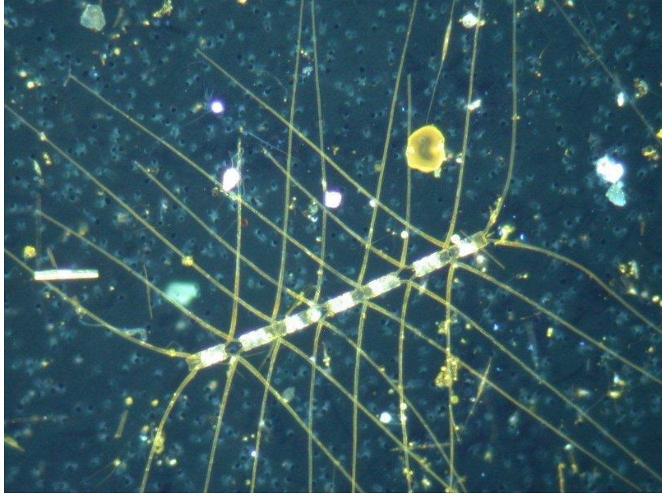


Philip Boyd

Institute for Marine & Antarctic Studies



2014



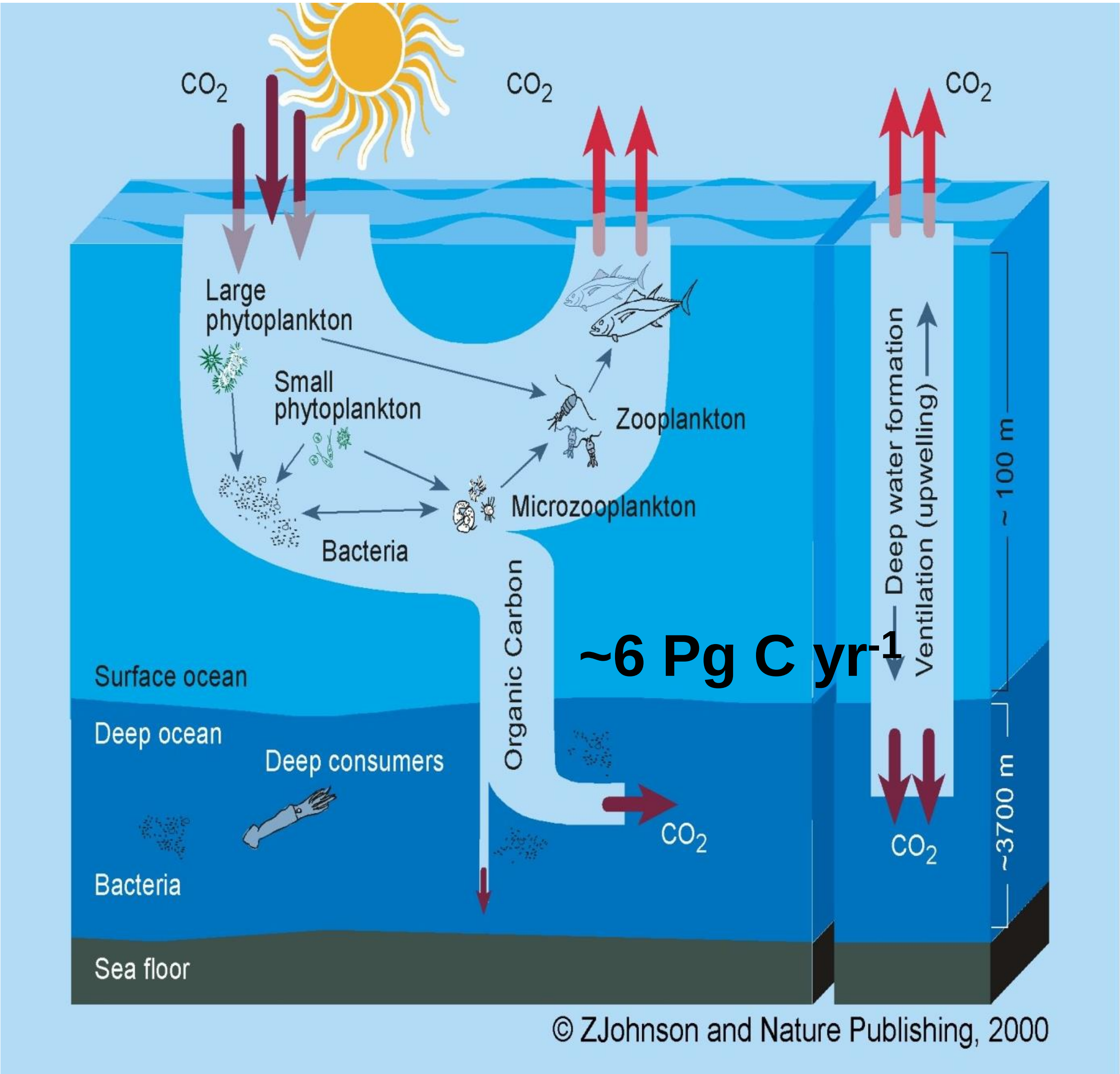
OUTLINE
Multiple roles of the biological pump
What goes up must come down?

Particle transformations and foodwebs
Surface ocean
Subsurface ocean – zooplankton
- microbes

Particle attenuation – surface vs. subsurface waters
Biological pump – at a cellular level

Conclusions

Multiple roles of the biological pump



~6 Pg C yr^{-1}

Carbon export

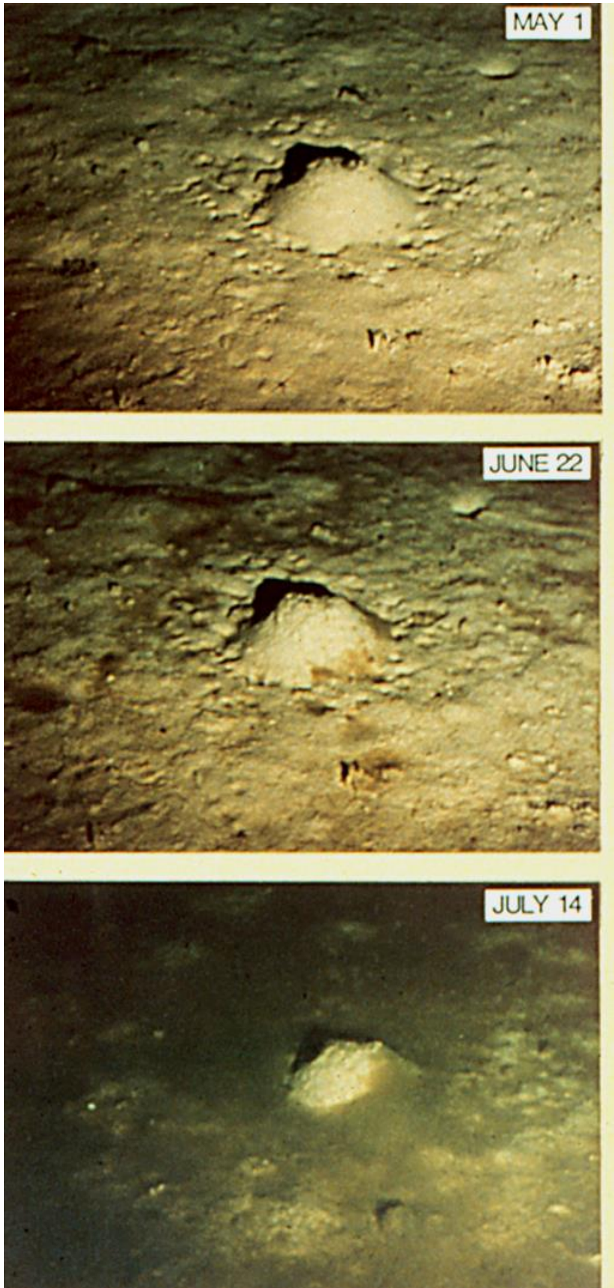
3.4 to 4.7 × 10^9 tons C yr^{-1} (Eppley & Peterson) New production

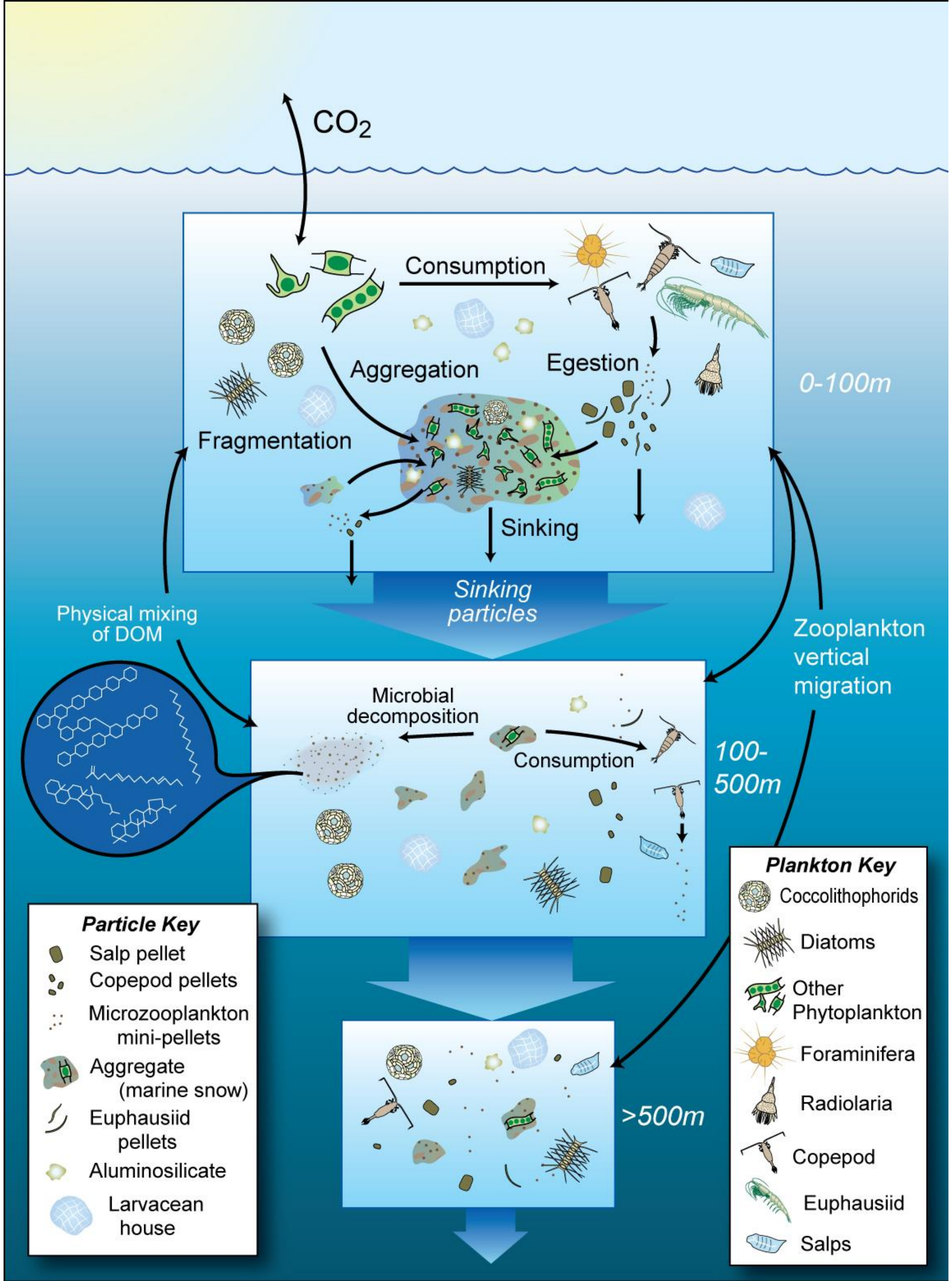
Multiple roles of the biological pump

Nutrition of the deep ocean & benthos

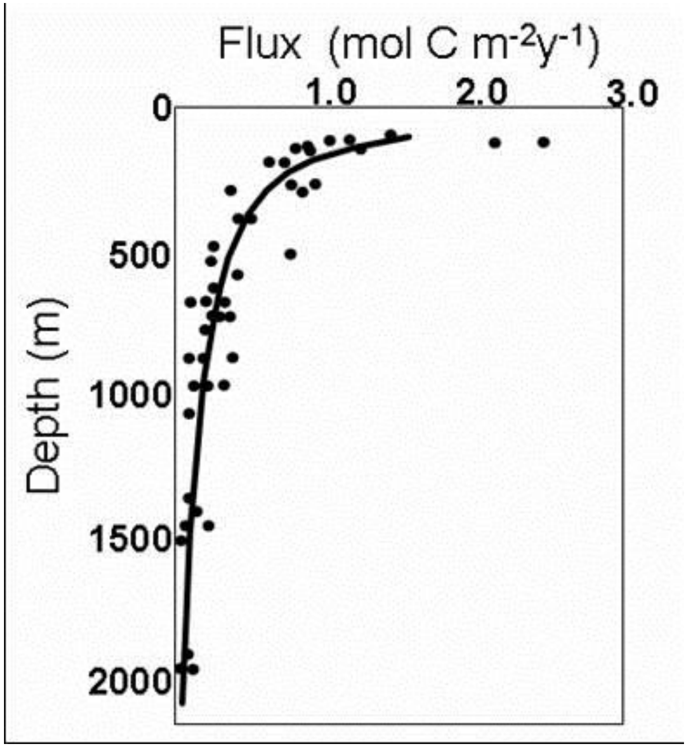
"…deep-sea organisms are nourished by a "rain" of organic detritus from overlying surface waters."

Alexander Agassiz (1888)





CO_2
Consumption
Aggregation
Egestion
Fragmentation
Sinking
0-100m
Sinking particles
Physical mixing of DOM
Zooplankton vertical migration
Microbial decomposition
Consumption
100-500m
>500m
Particle Key
Salp pellet
Copepod pellets
Microzooplankton mini-pellets
Aggregate (marine snow)
Euphausiid pellets
Aluminosilicate
Larvacean house
Plankton Key
Coccolithophorids
Diatoms
Other Phytoplankton
Foraminifera
Radiolaria
Copepod
Euphausiid
Salps



Flux (mol C $m^{-2}y^{-1}$)
0
1.0
2.0
3.0
500
1000
1500
2000
Depth (m)

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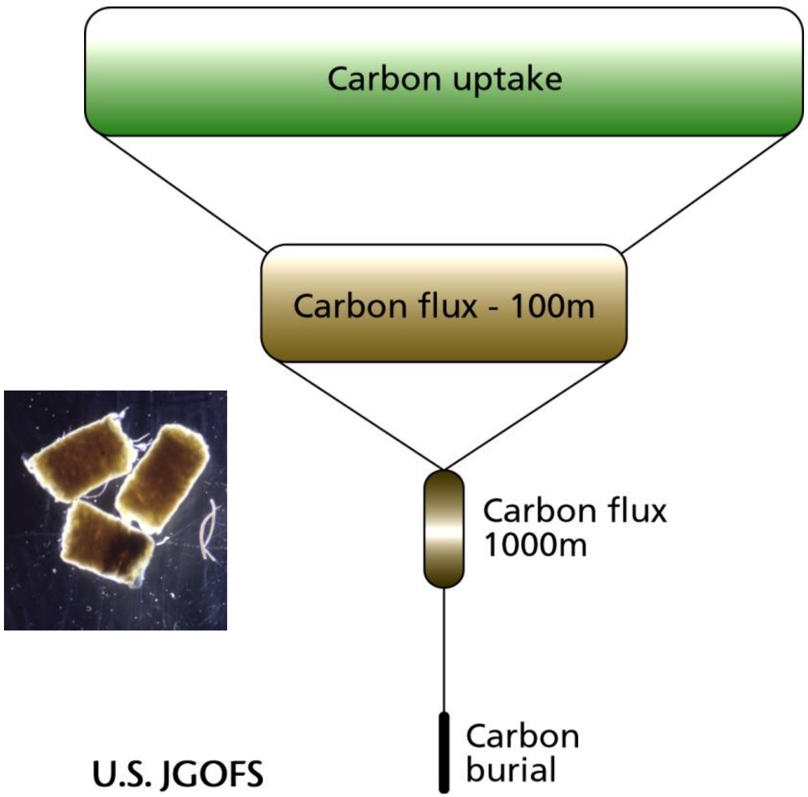
Sinking flux - vertical attenuation of particles



Mixed layer

<5 to >50% (decades)

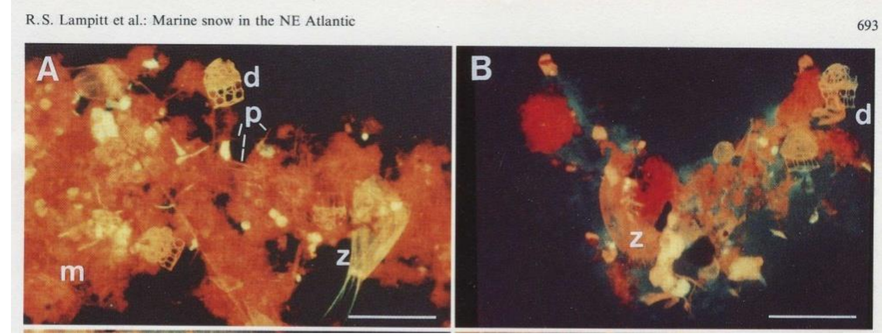
~1-10% (centuries)

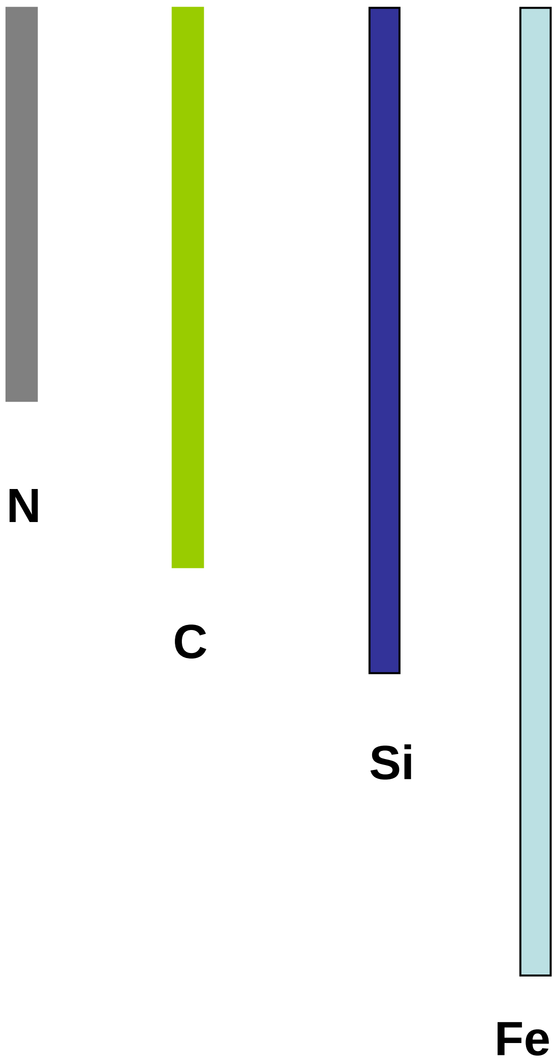
~0.1% (millennia)

U.S. JGOFS

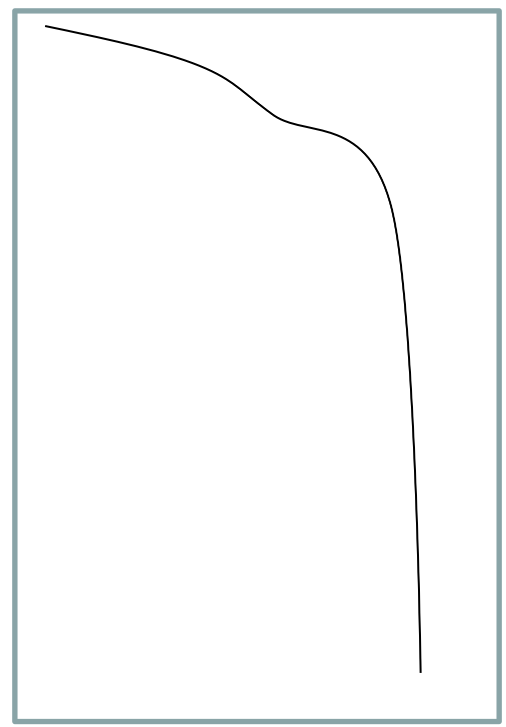
The rain of sinking particles scavenges dissolved materials

Nutrient regeneration

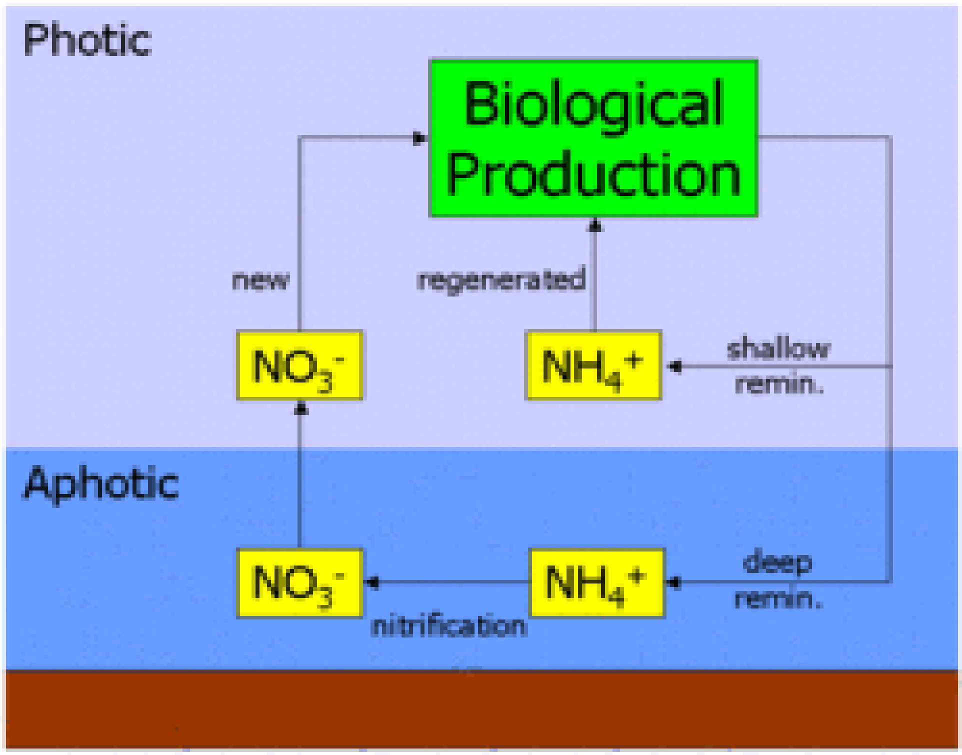




Remineralization length scales
Of major & minor elements



What goes up must come down?

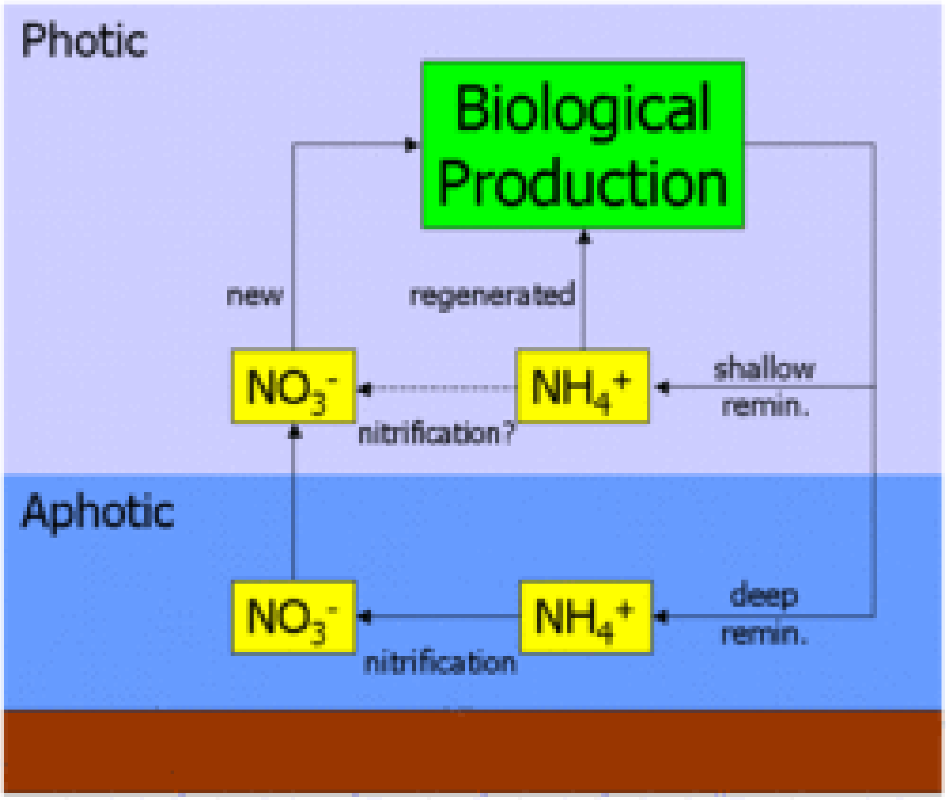


Particulate organic matter flux and planktonic new production in the deep ocean
Richard W. Eppley & Bruce J. Peterson

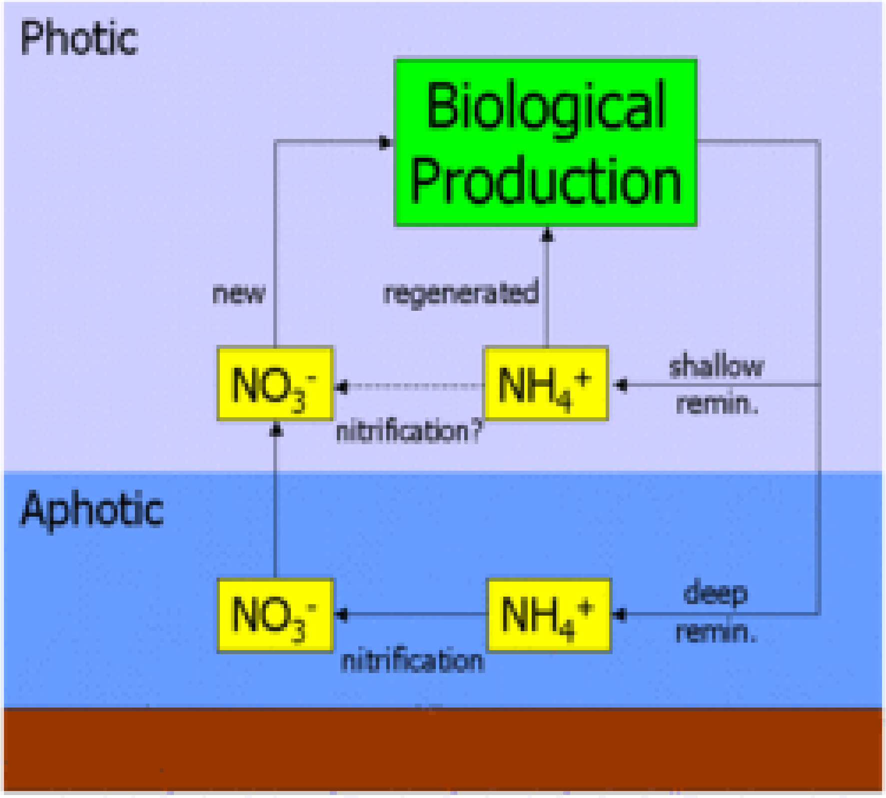
“Global new production is of the order of 3.4−4.7 × 10^9 tons of carbon per year and approximates the sinking flux of particulate organic matter to the deep ocean.”

$$\mathbf{NH_3} + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$$

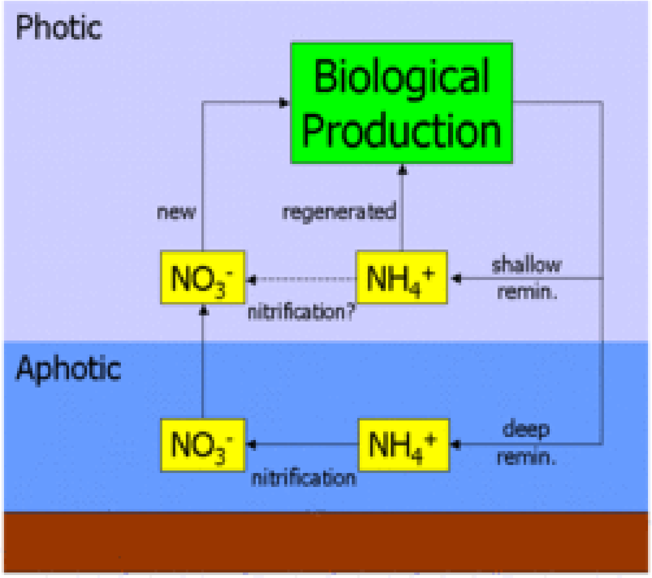
$$NO_2^- + H_2O \rightarrow \mathbf{NO_3^-} + 2H^+ + 2e^-$$



"To relate new production to export requires that nitrification in the euphotic zone be negligible“.



Yool et al. predict that up to 50% of surface nitrate is supplied by surface nitrification rather than vertically.



Yool et al. (2007).
"The significance of nitrification for oceanic new production".

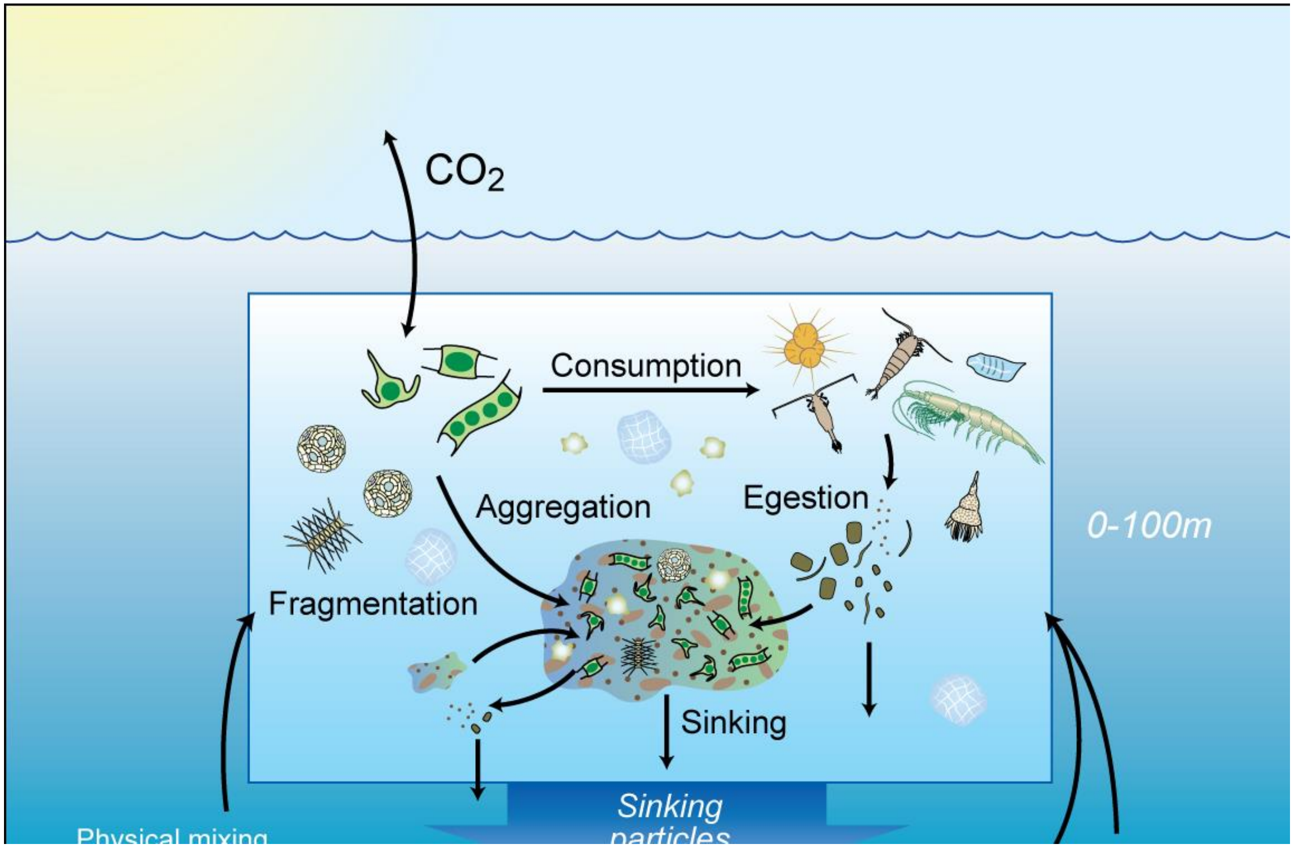
So what metric(s) should we use to compare surface mixed layer productivity to downward particulate export?

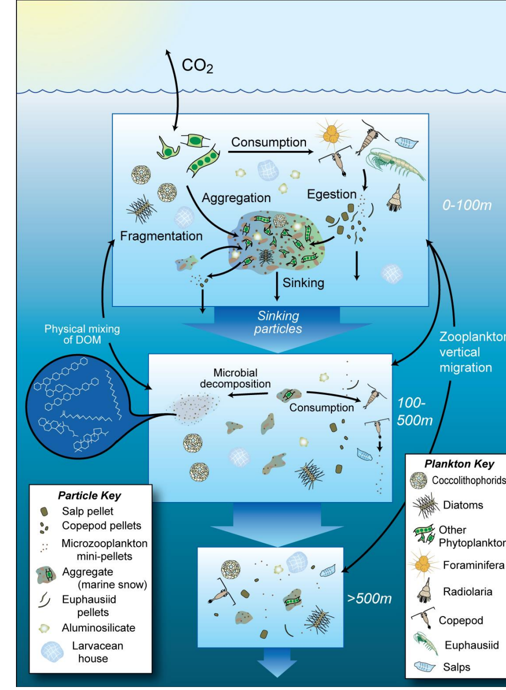
Back to NPP – the pe ratio of Dunne et al. (2005) GBC?

Clark DR et al. 2008. Ammonium regeneration and nitrification rates in the oligotrophic Atlantic Ocean: Implications for new production estimates. Limnology and Oceanography, 53(1), 52-62.

Yool, Andrew (2011) Modeling the Role of Nitrification in Open Ocean Productivity and the Nitrogen Cycle.

Particle transformations and foodwebs
Surface ocean





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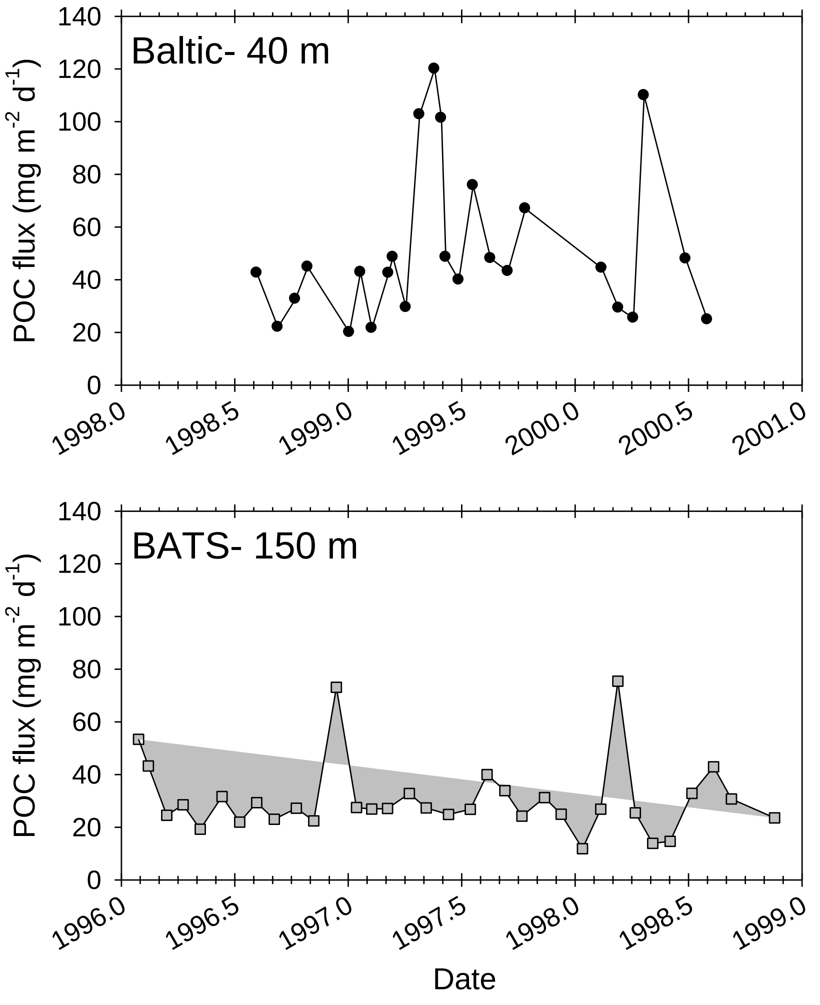
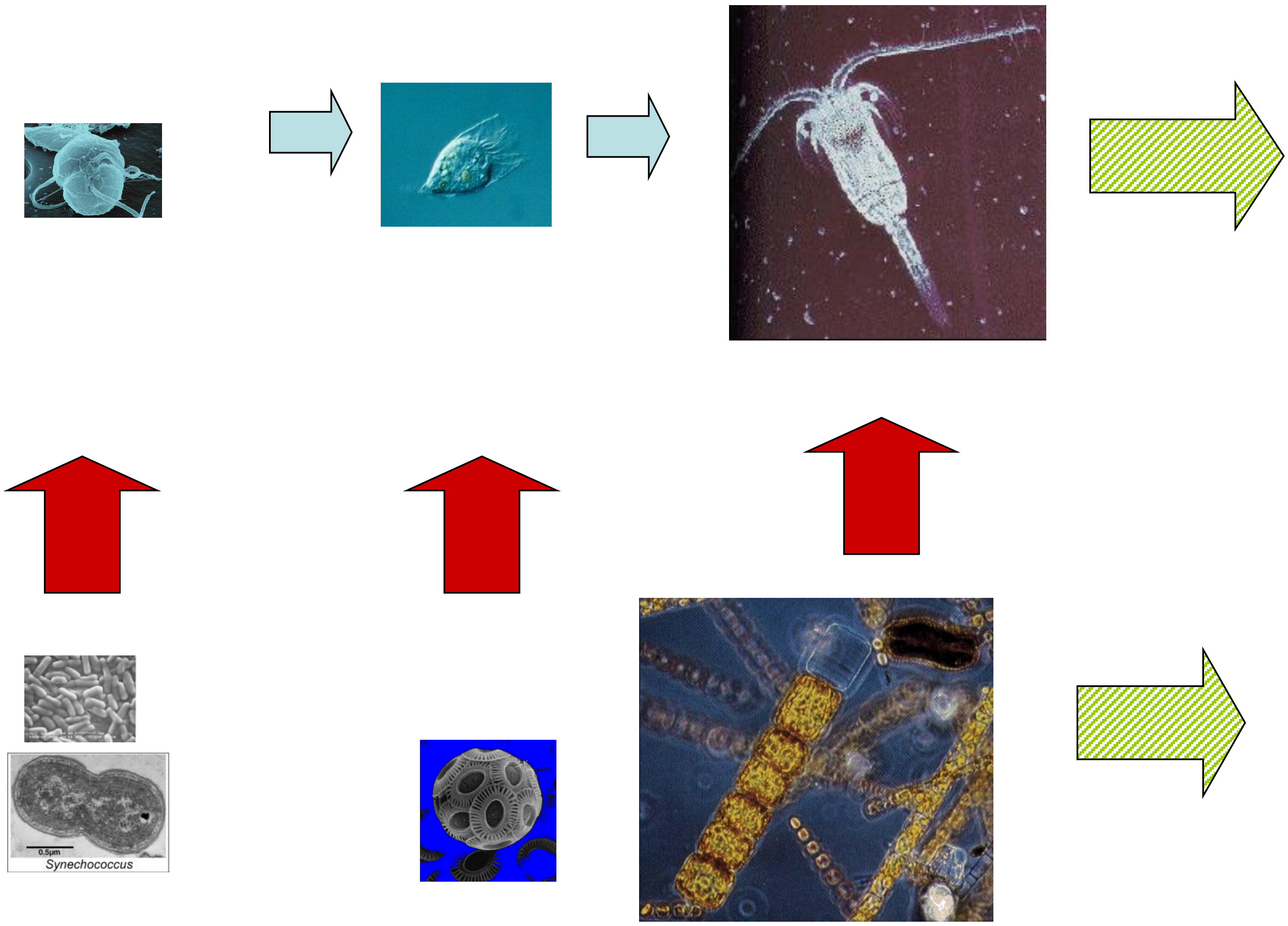
What is the imprint of the biological pump Just below the surface mixed layer?

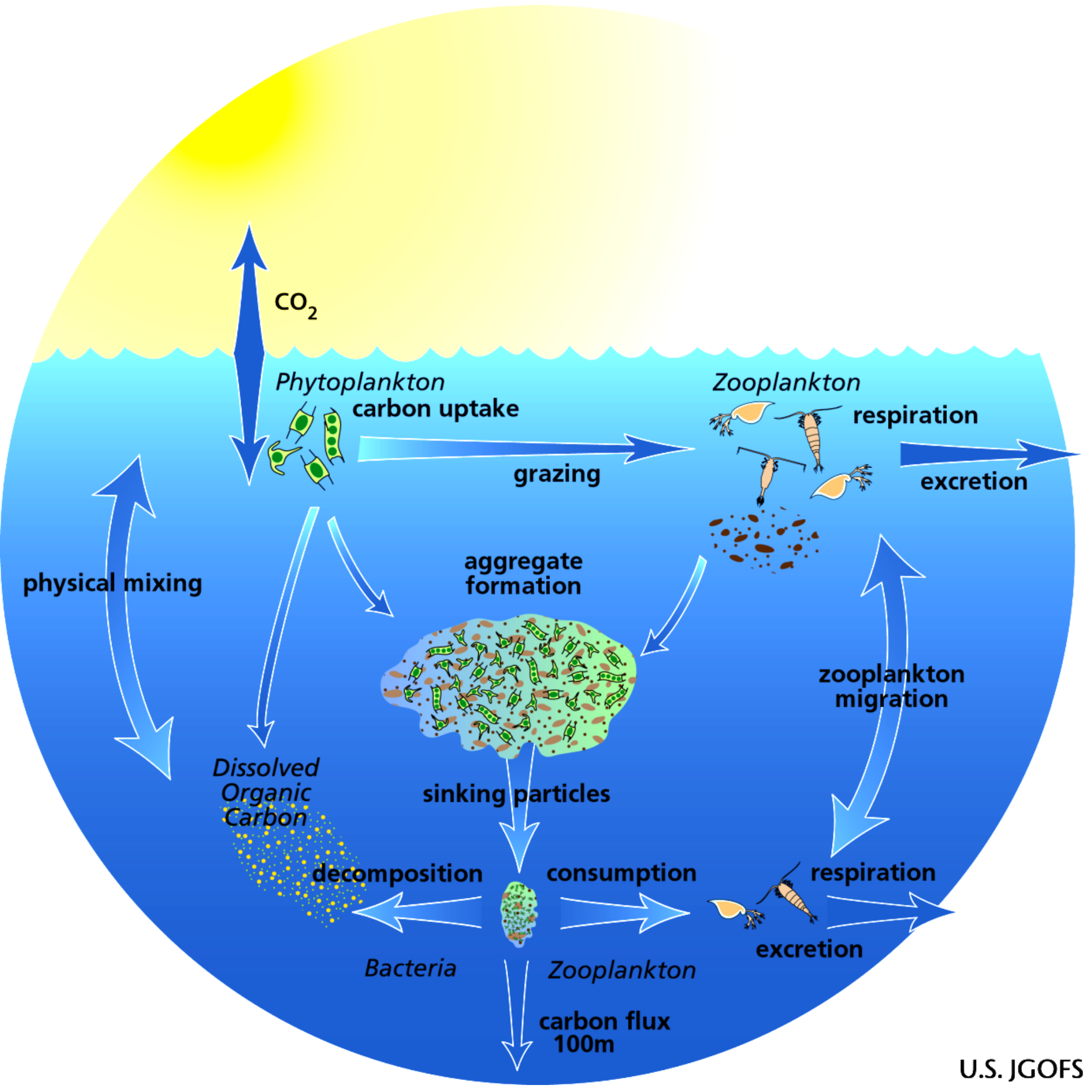


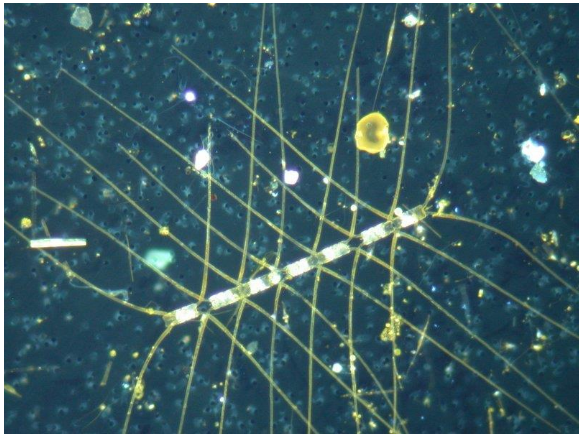
From Asper 1997

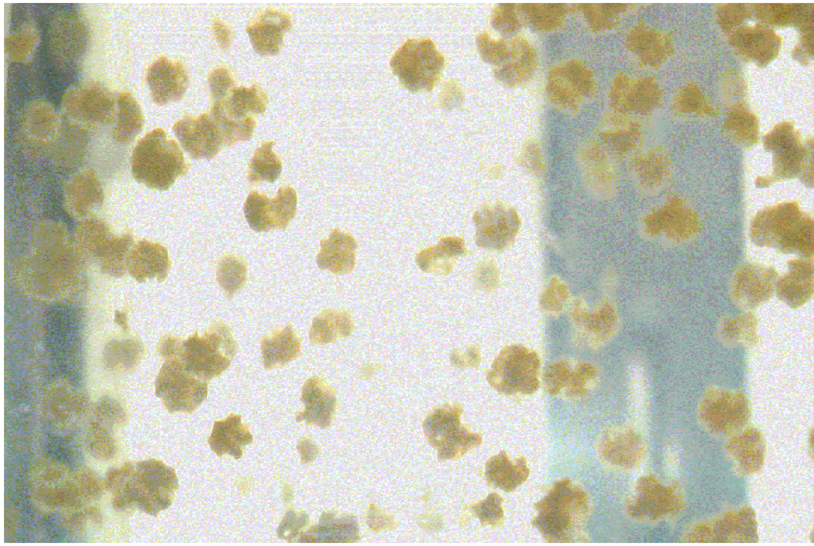
The foodweb – controlling particle transformations

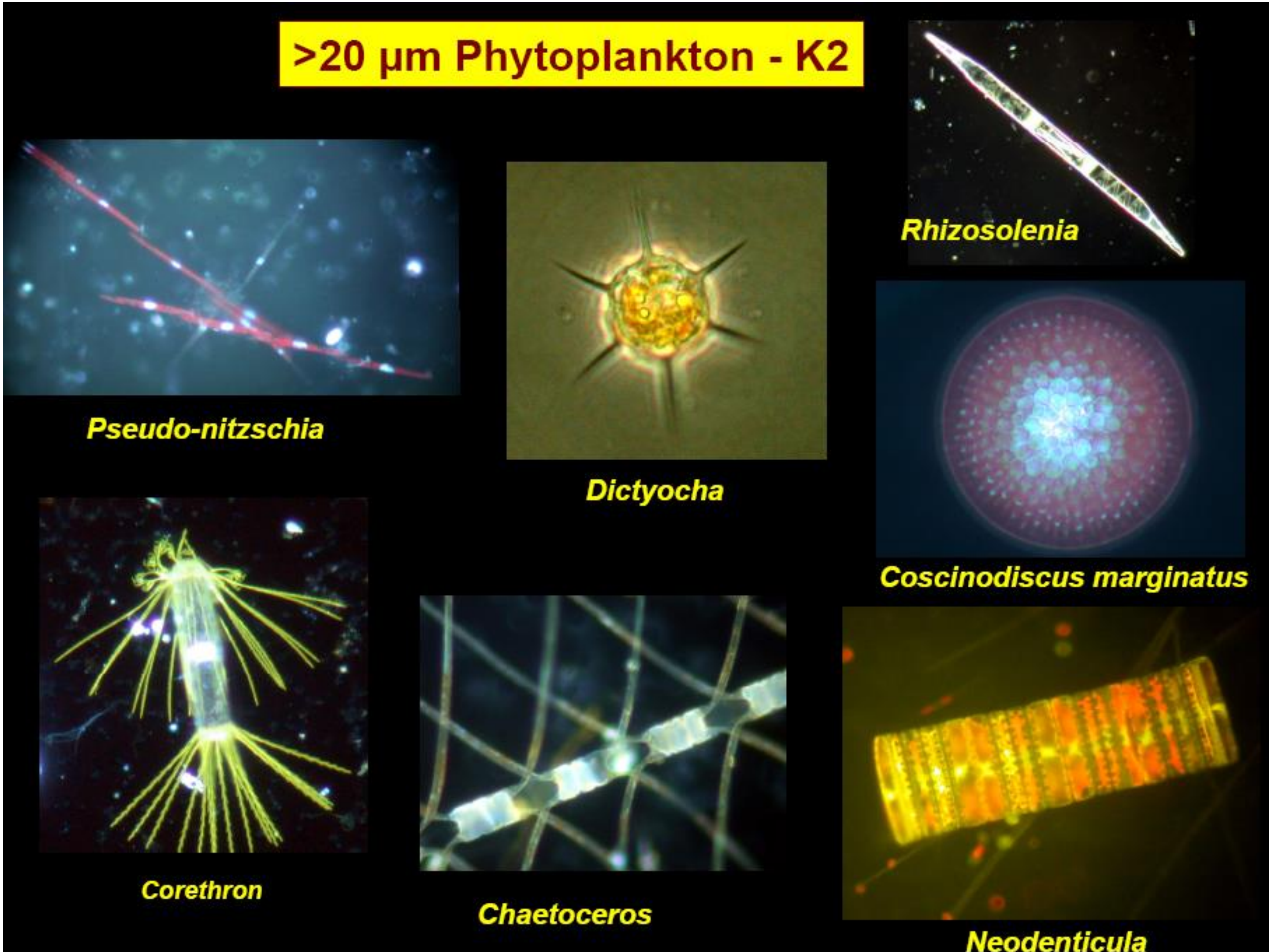


DIRECT ALGAL SINKING

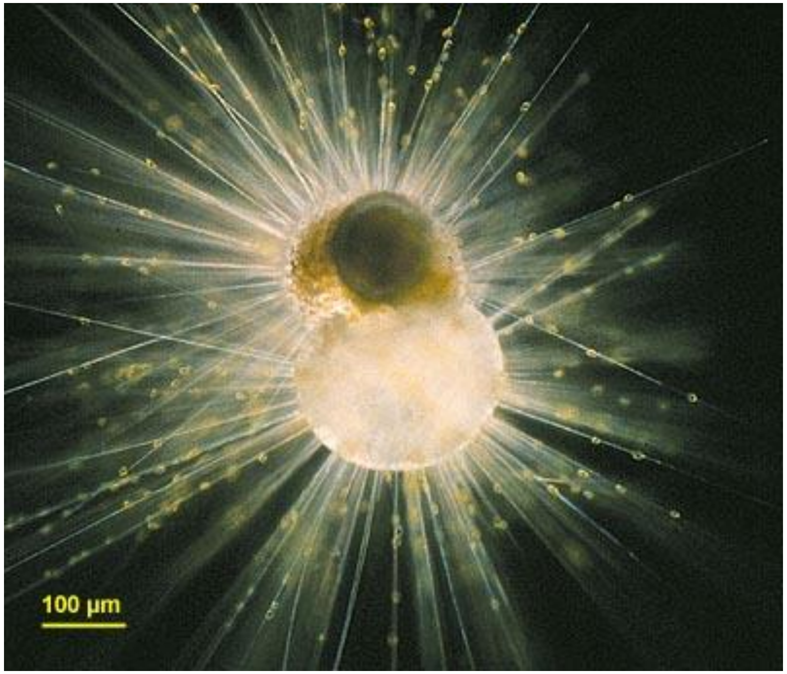


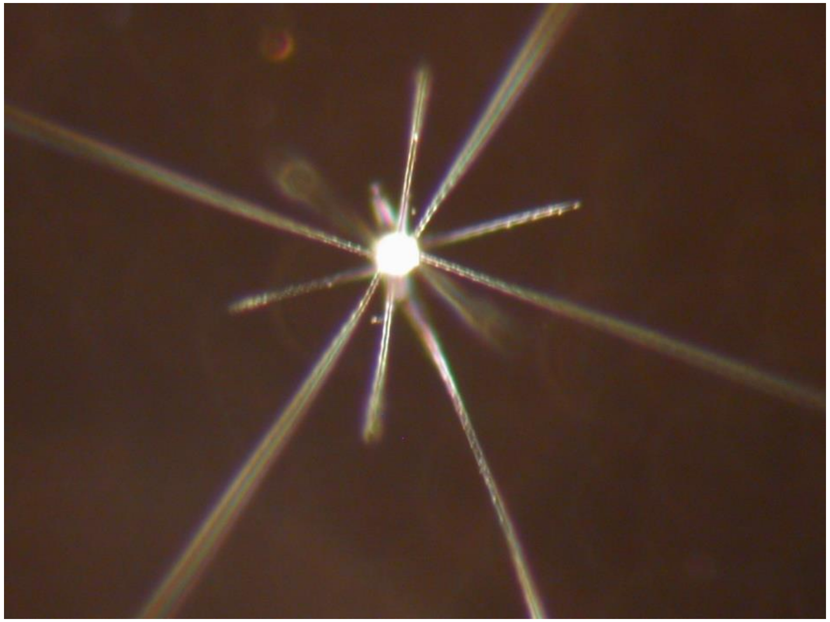


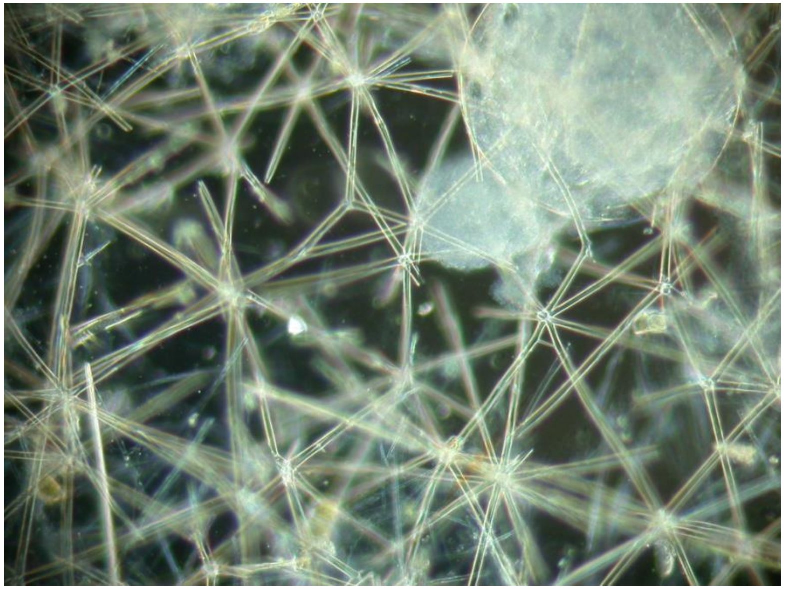


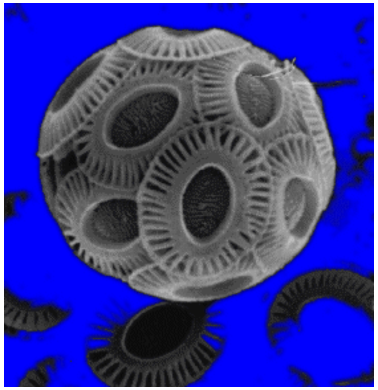


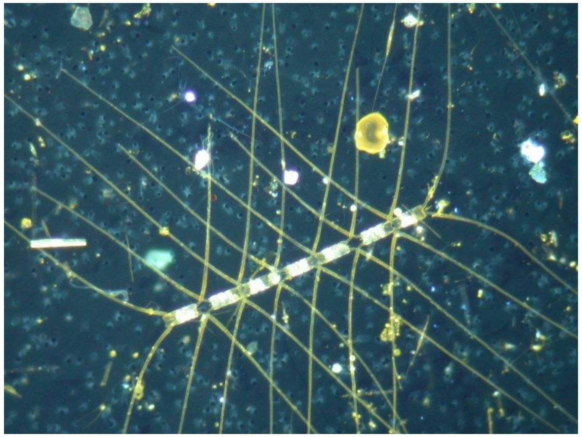
Images Mary Silver UCSB





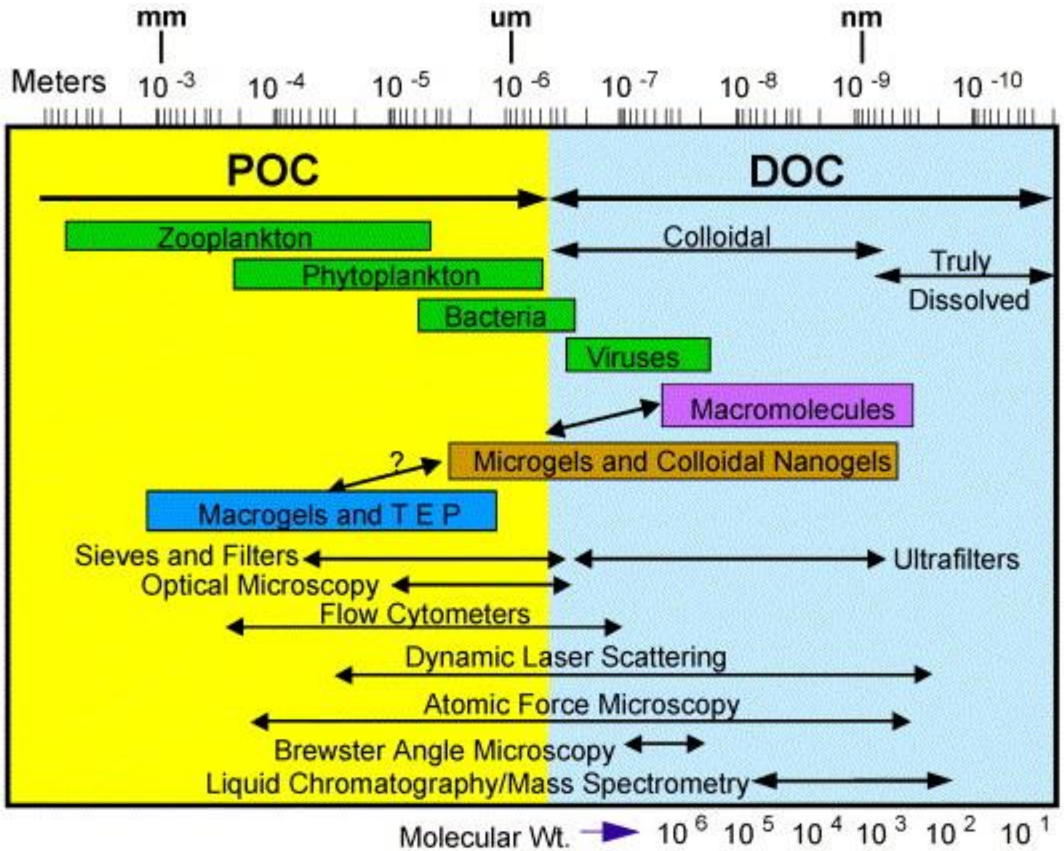


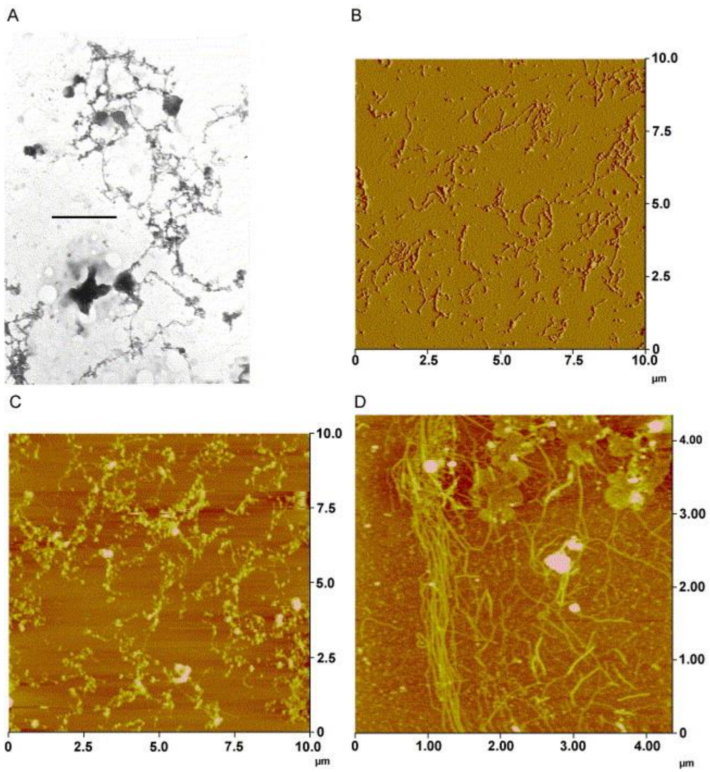




Agents of mineral ballast – opal and calcite

Gels and Biological glues

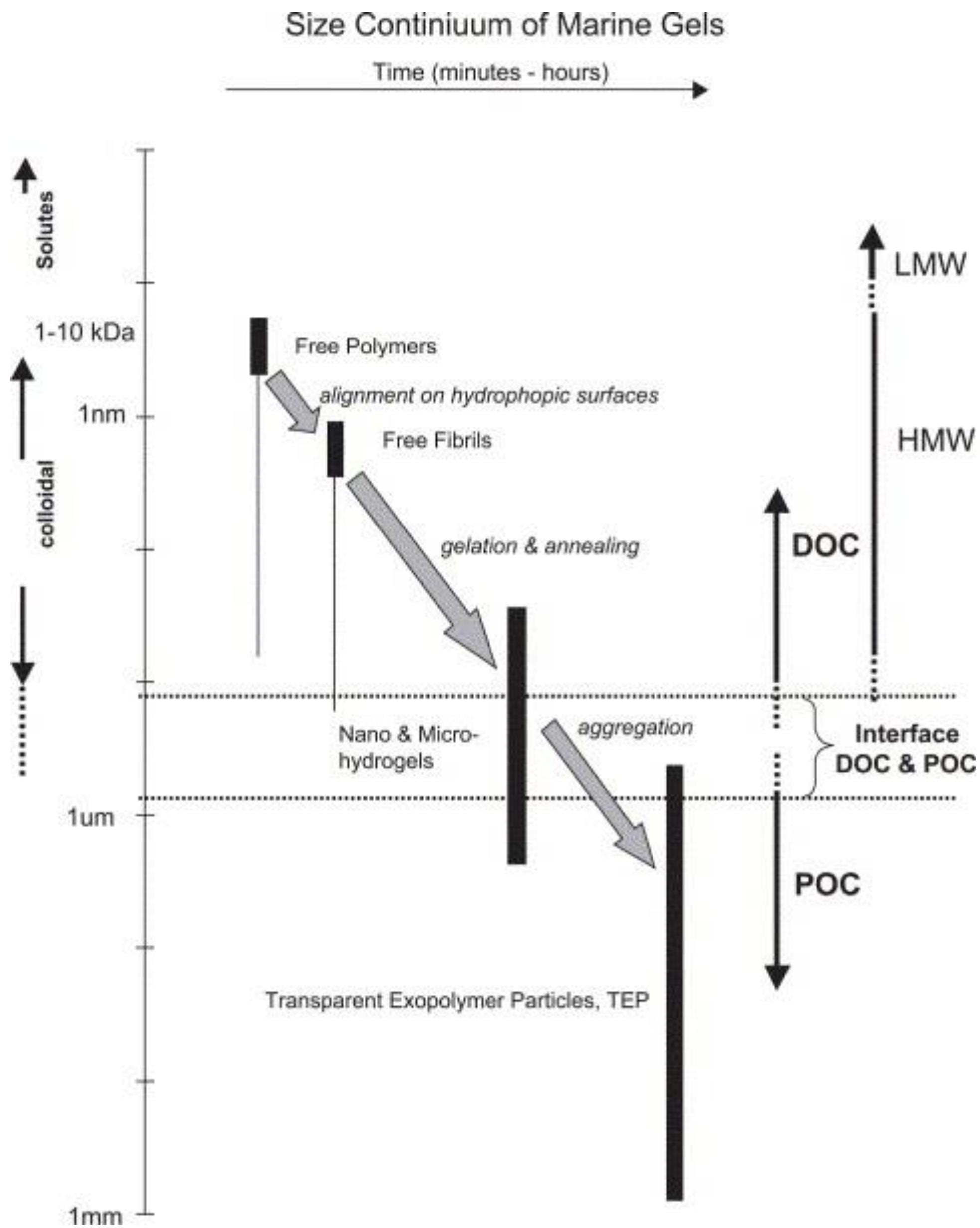




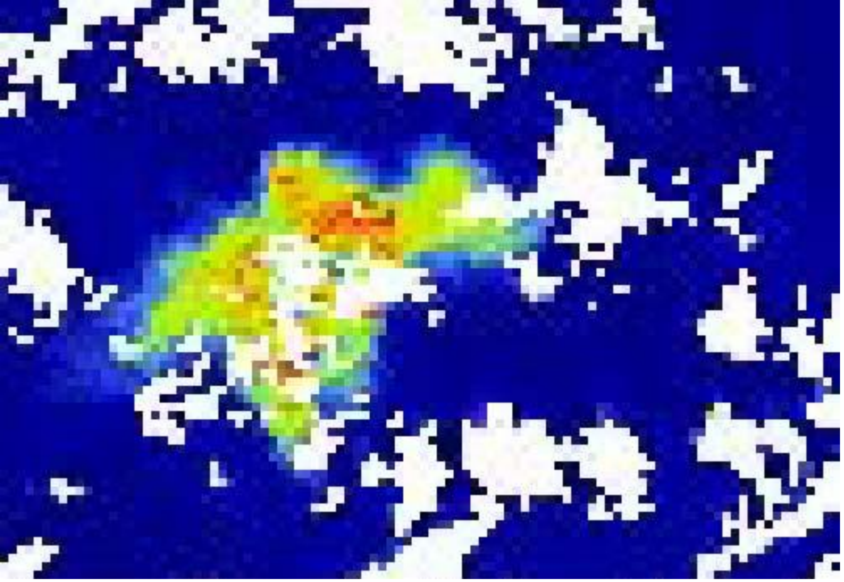
VERDUGO et al, (2004)

Exudation

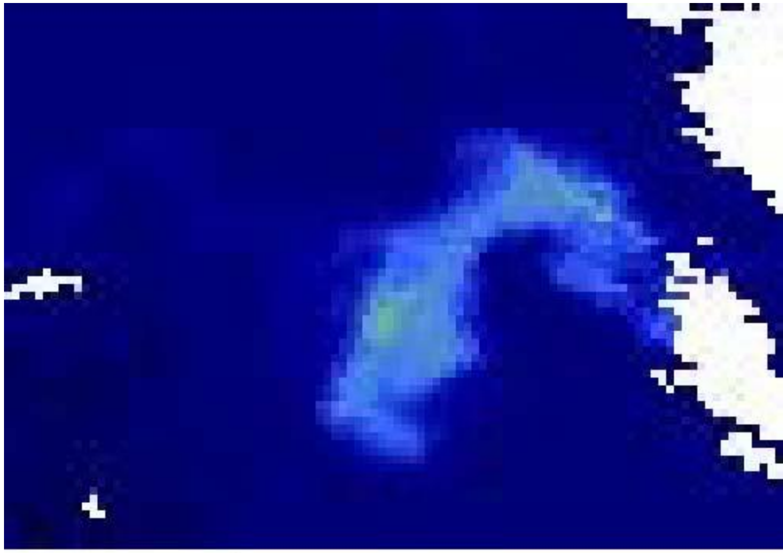
TEP – Passow and Alldredge



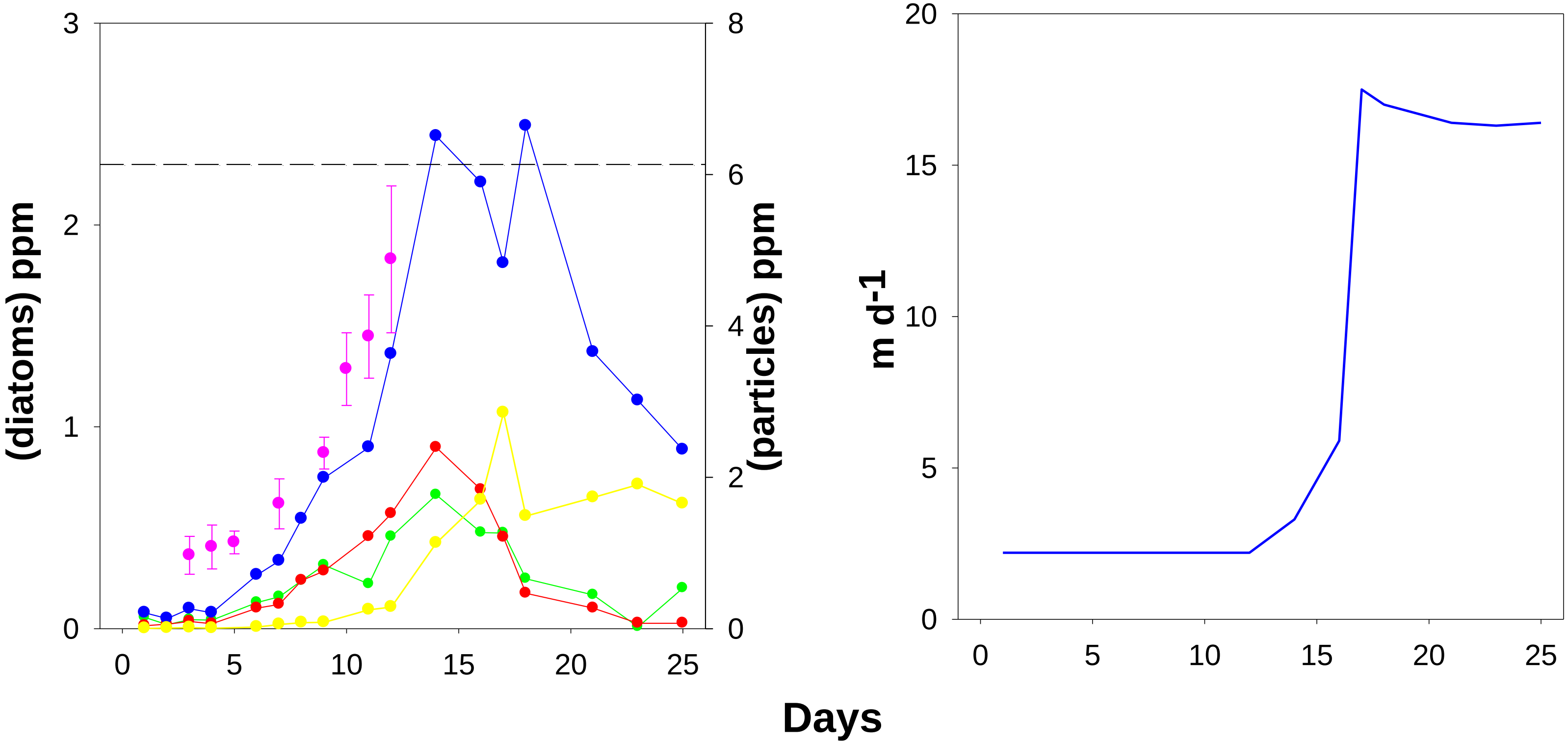
VERDUGO et al, (2004)



A case study – the SERIES mesoscale in situ Fe enrichment
What halts bloom development and initiates bloom decline?

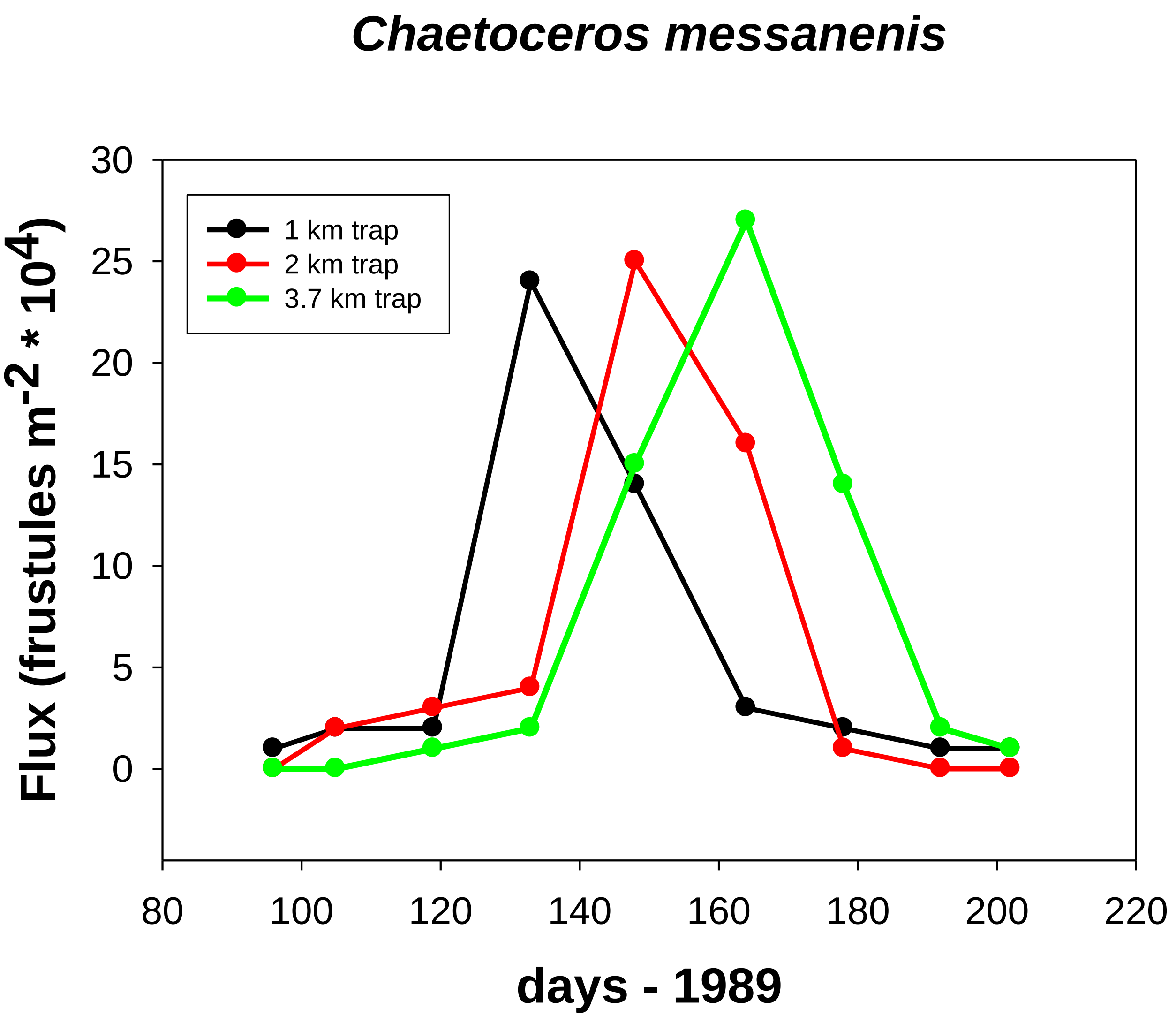


Boyd et al. (2005)

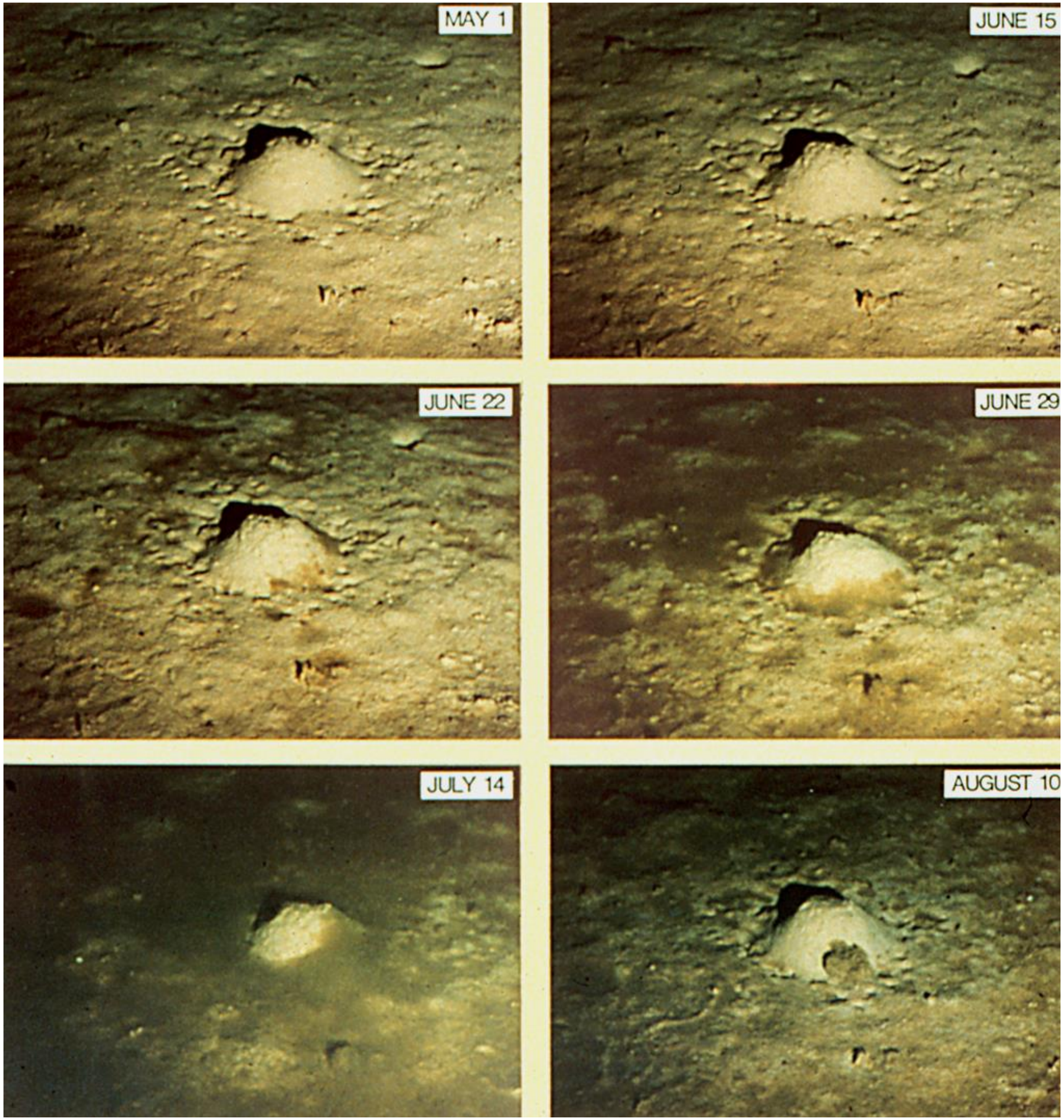


Boyd et al. (2005)

TRACKING THE ALGAL AGGREGATION SIGNATURE TO DEPTH
Honjo and Manganini (1993) NABE site

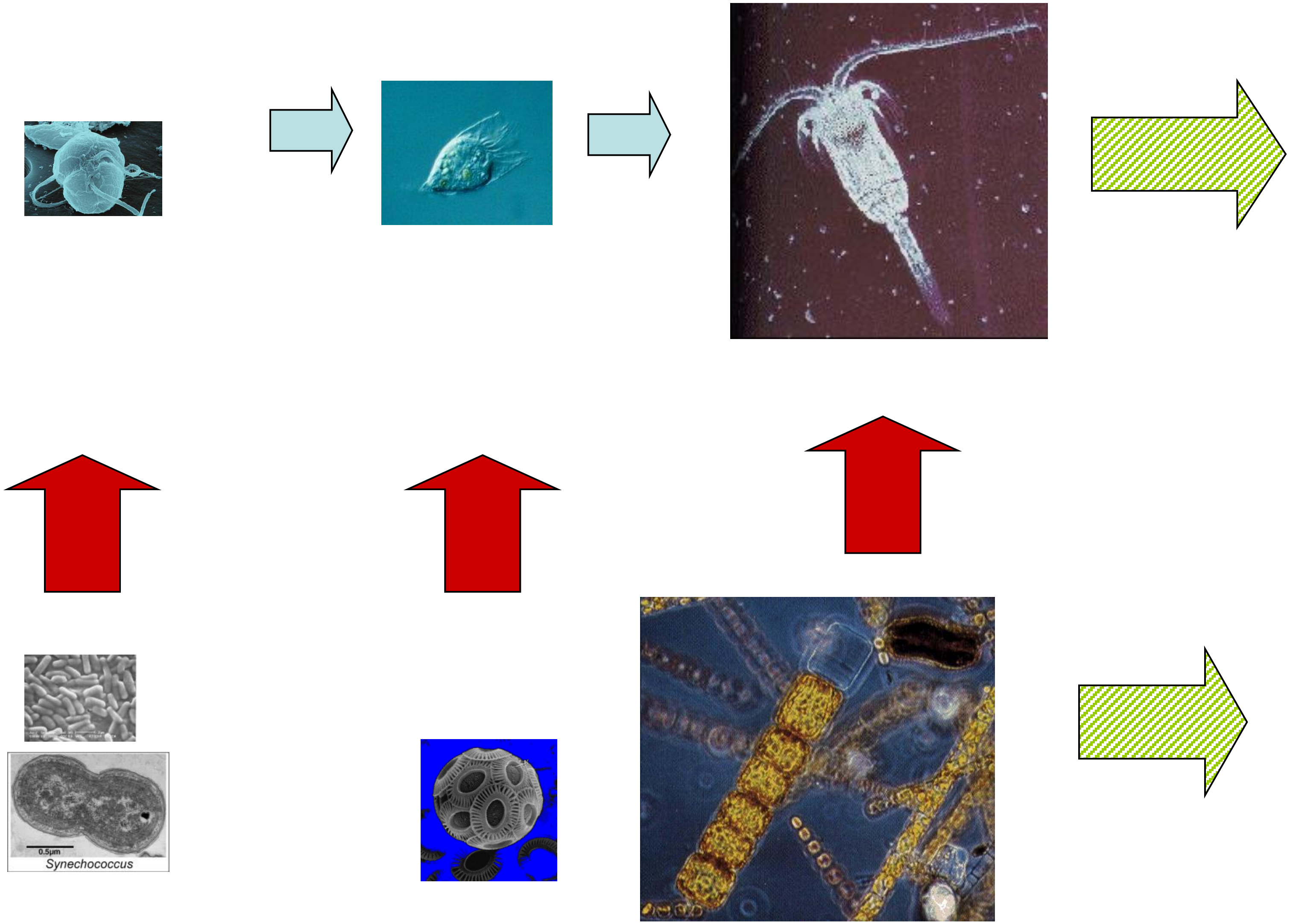


Impact of direct algal sinking

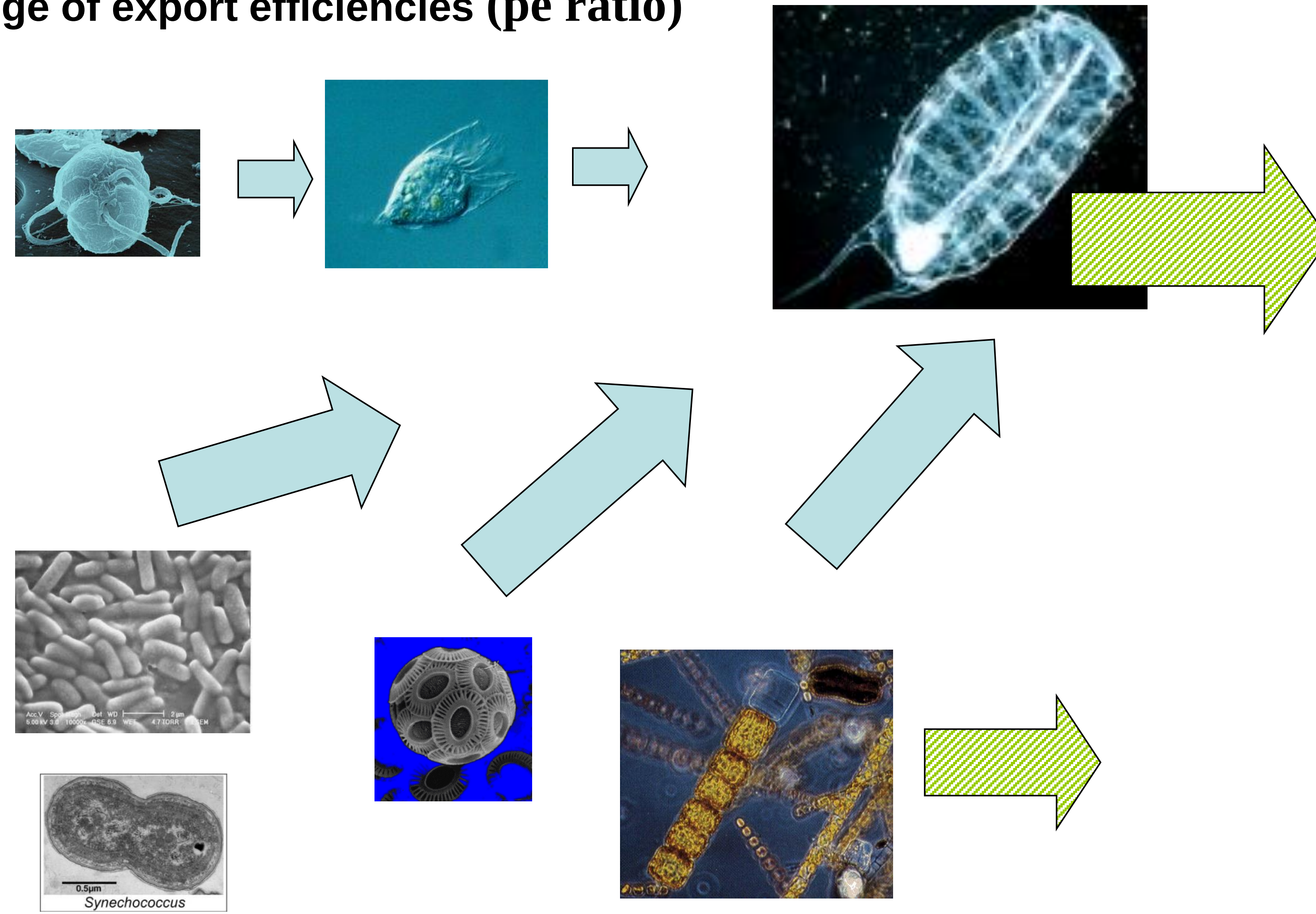


Images Richard Lampitt NOC UK

The foodweb – controlling particle transformations

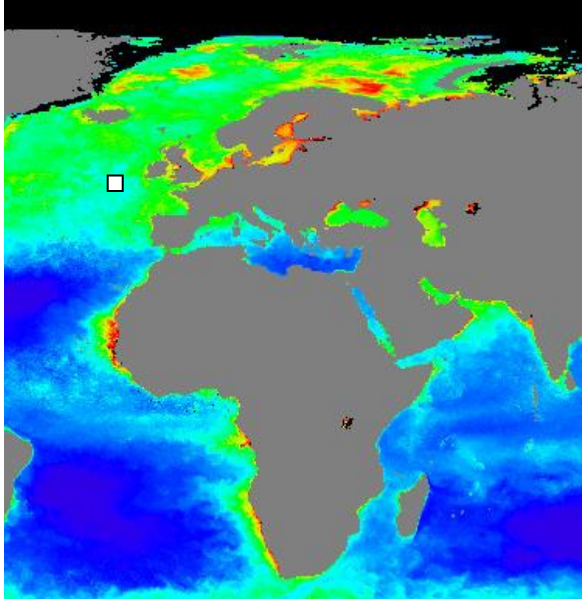


Different foodweb structures result in
A range of export efficiencies (pe ratio)



pe ratio = particle export/NPP

SALPS CRASH BLOOM



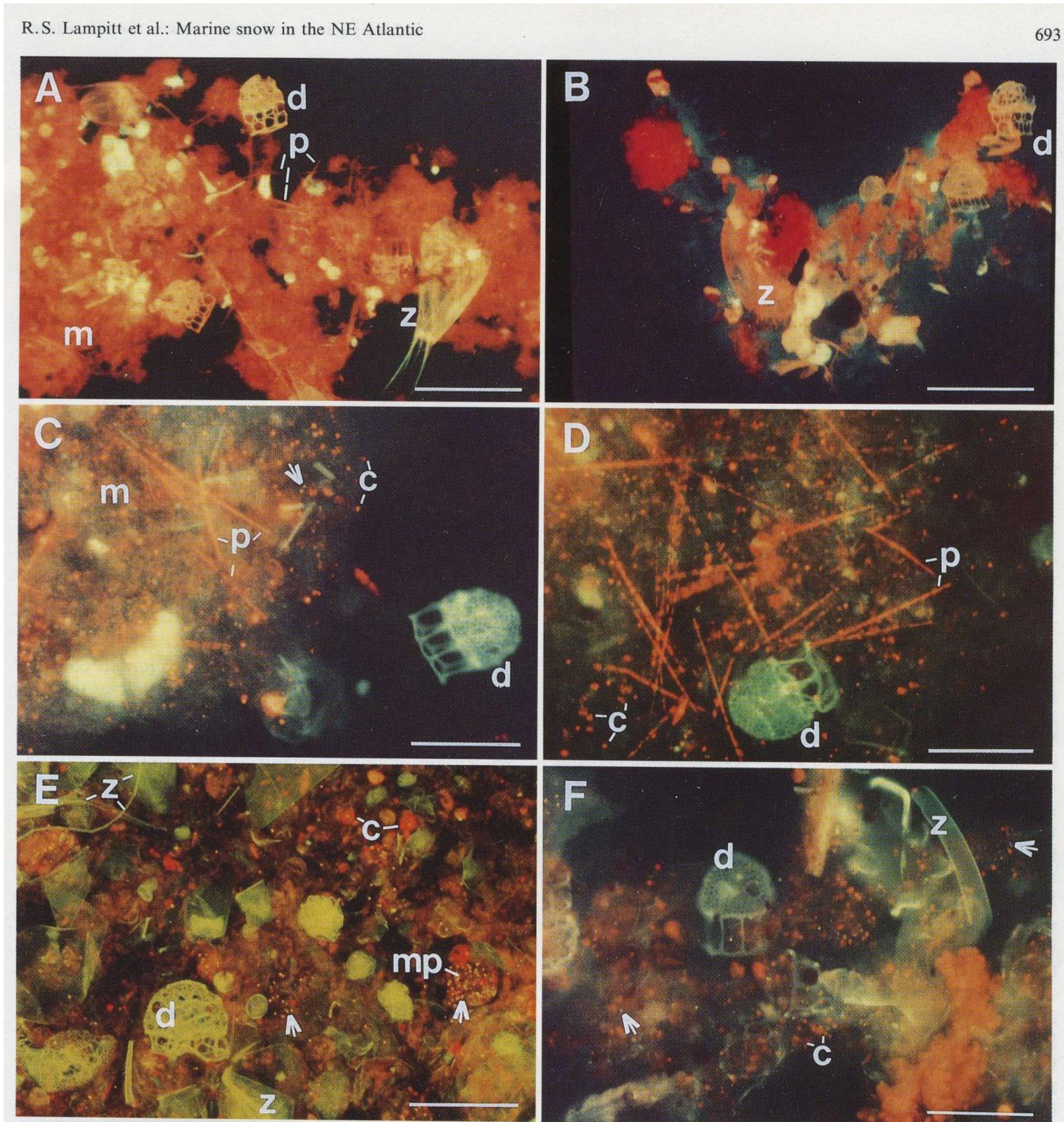
Biomass of Salpa fusiformis
of up to 360 mg C m^{-3}

Herbivory during the diatom bloom ended the bloom before nutrients had run out.

Sedimentation of diatom-rich salp fecal pellets
> 1 mm long, 350 µm wide, 10 µg C per pellet

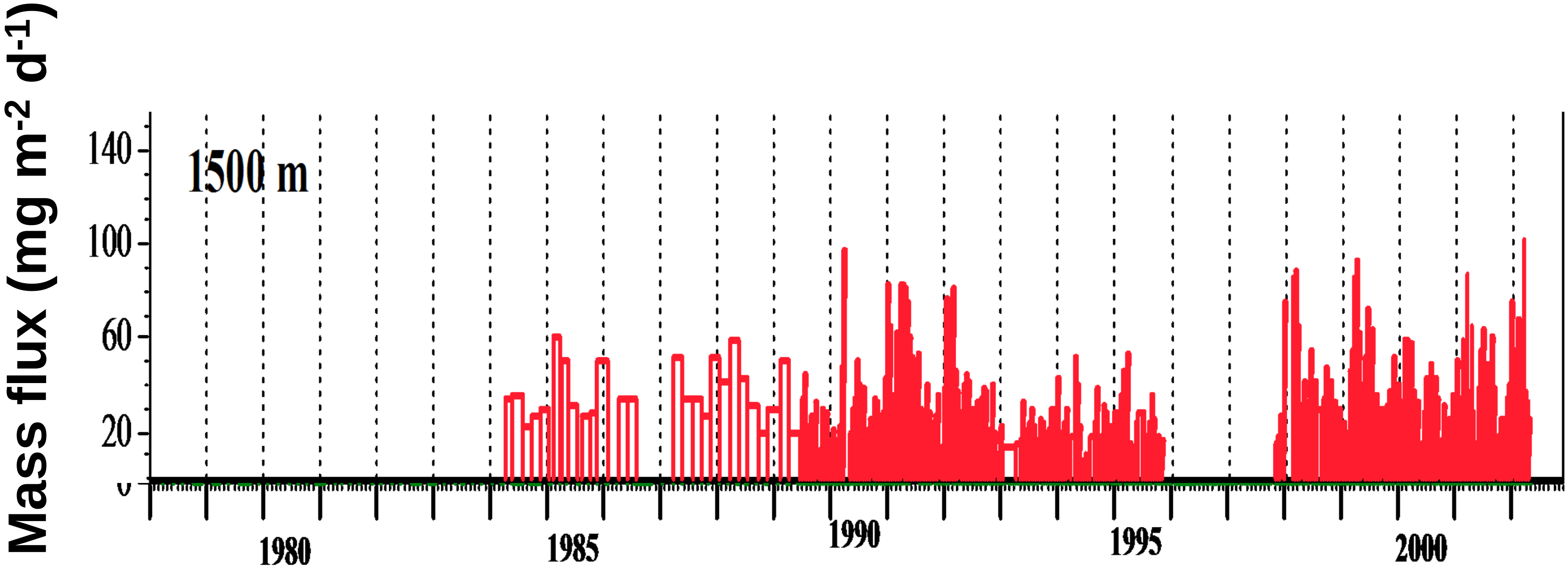
BATHMANN (1988)

Particle transformations and foodwebs
Subsurface ocean – zooplankton & microbes

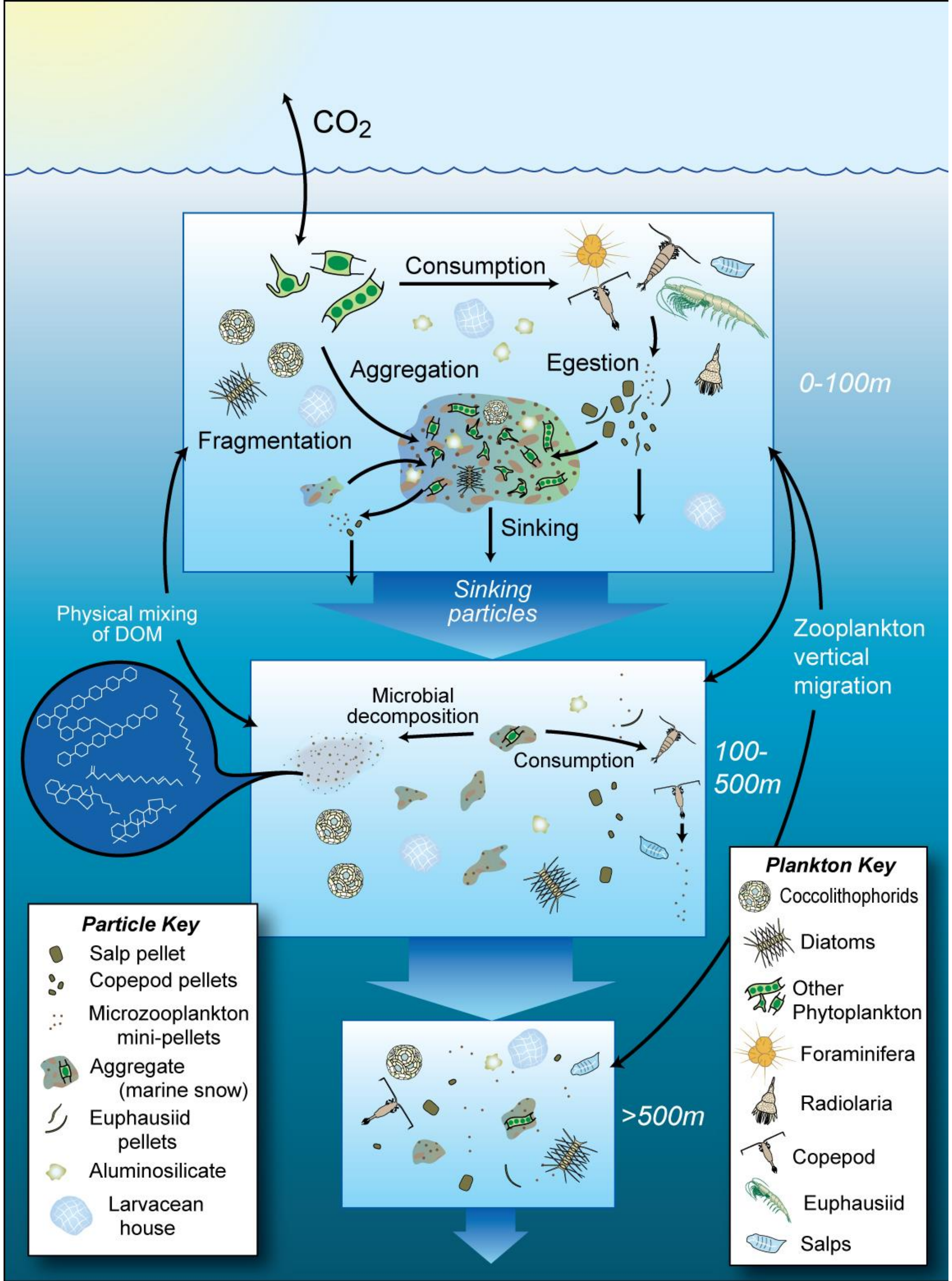


Images
Richard Lampitt
NOC UK

Seasonality in particle export is still evident in deep water



Courtesy Scott Nodder NIWA NZ



Factors controlling Export fluxes

Particle size

Particle composition

Particle geometry

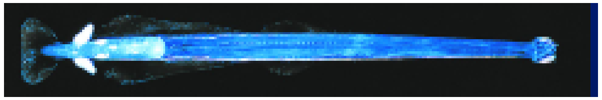
Particle specific gravity

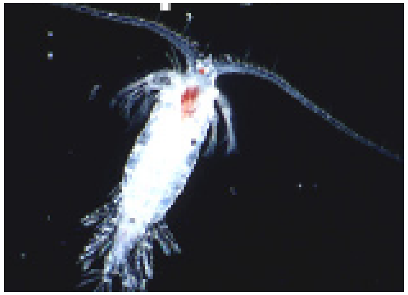
Particle sinking rate

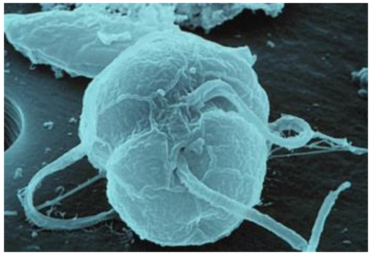
Many of these processes are biologically-mediated

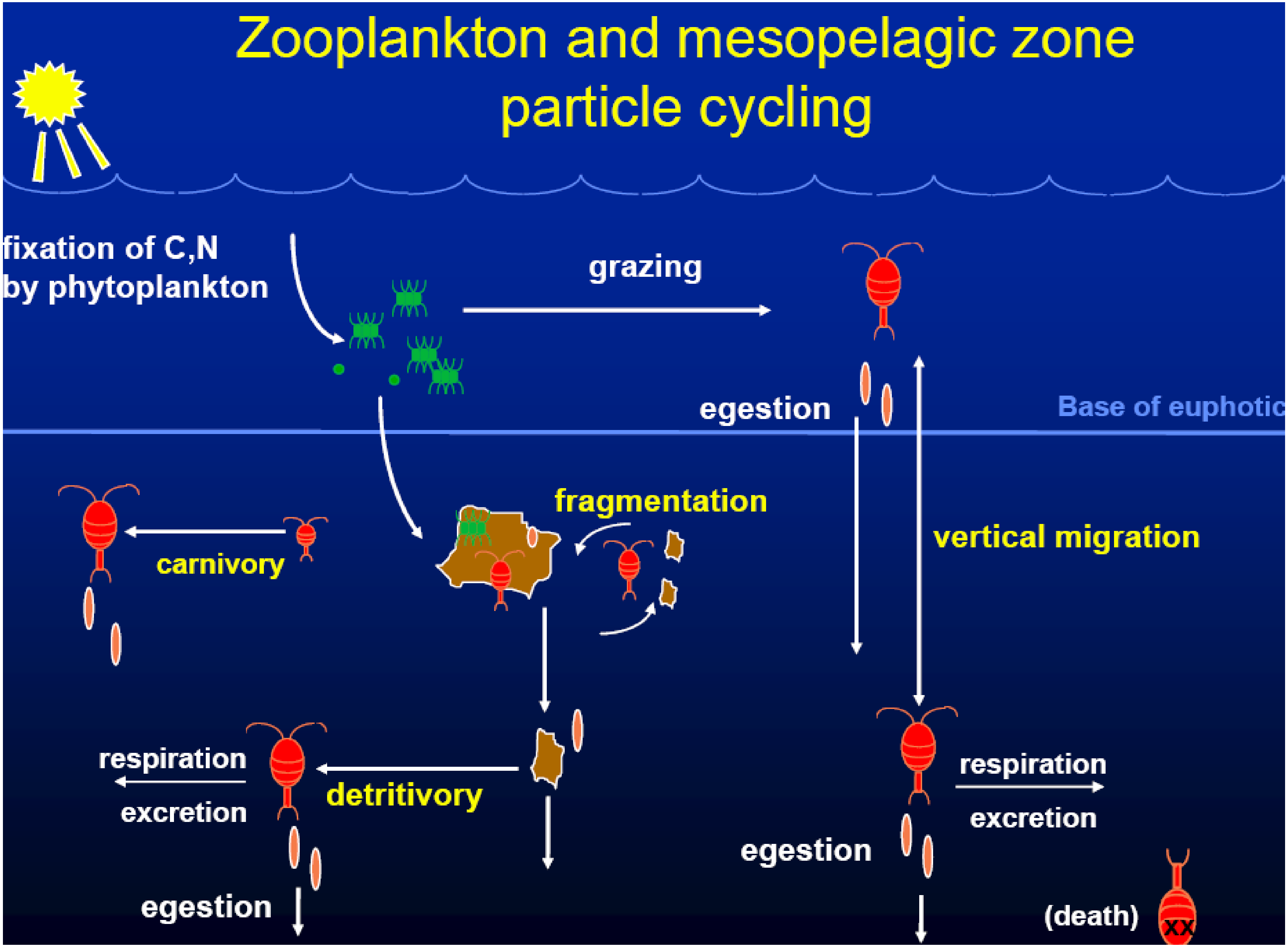
IPCC 2014

The grazers



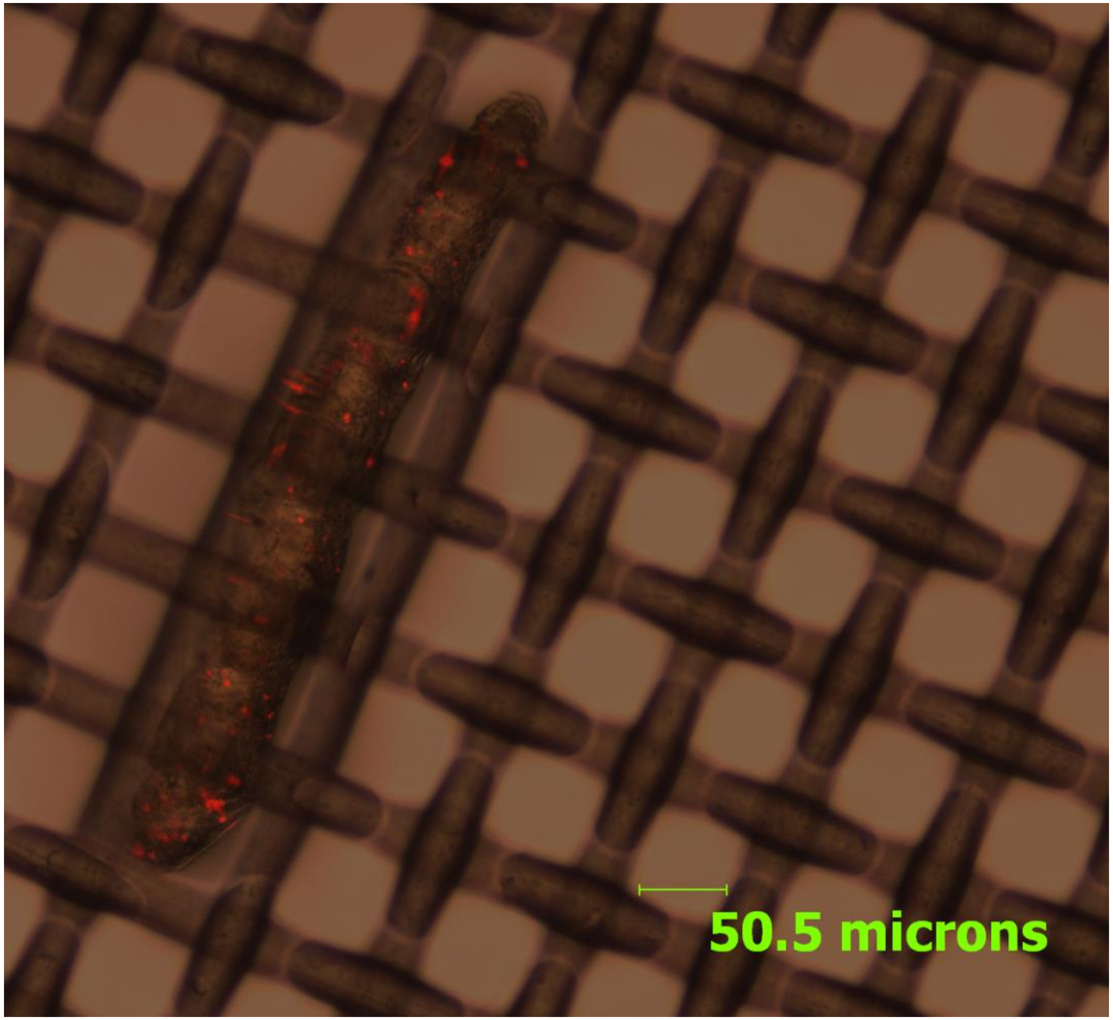






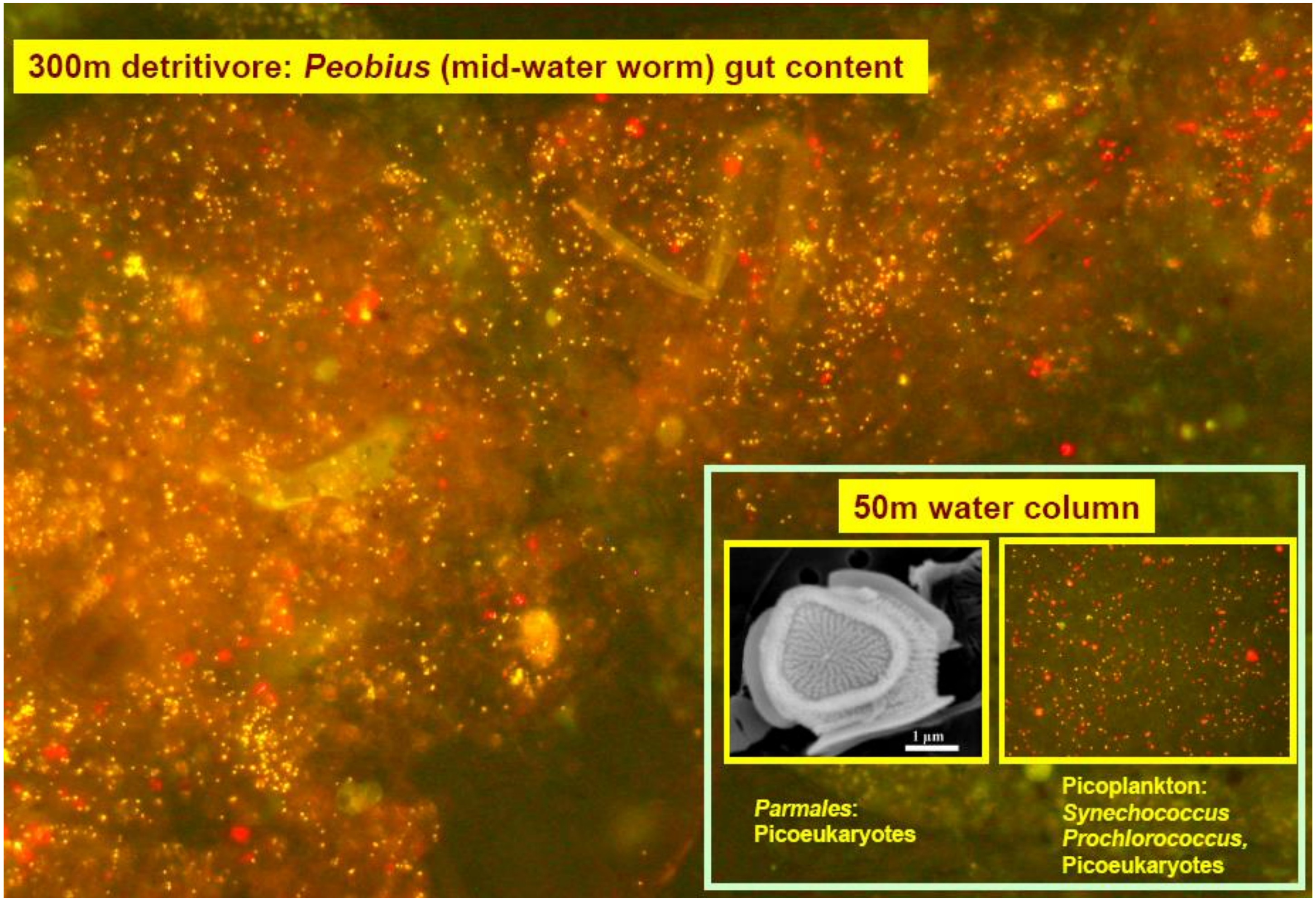
Courtesy Debbie Steinberg VIMS USA

Particle repackaging by mesozooplankton



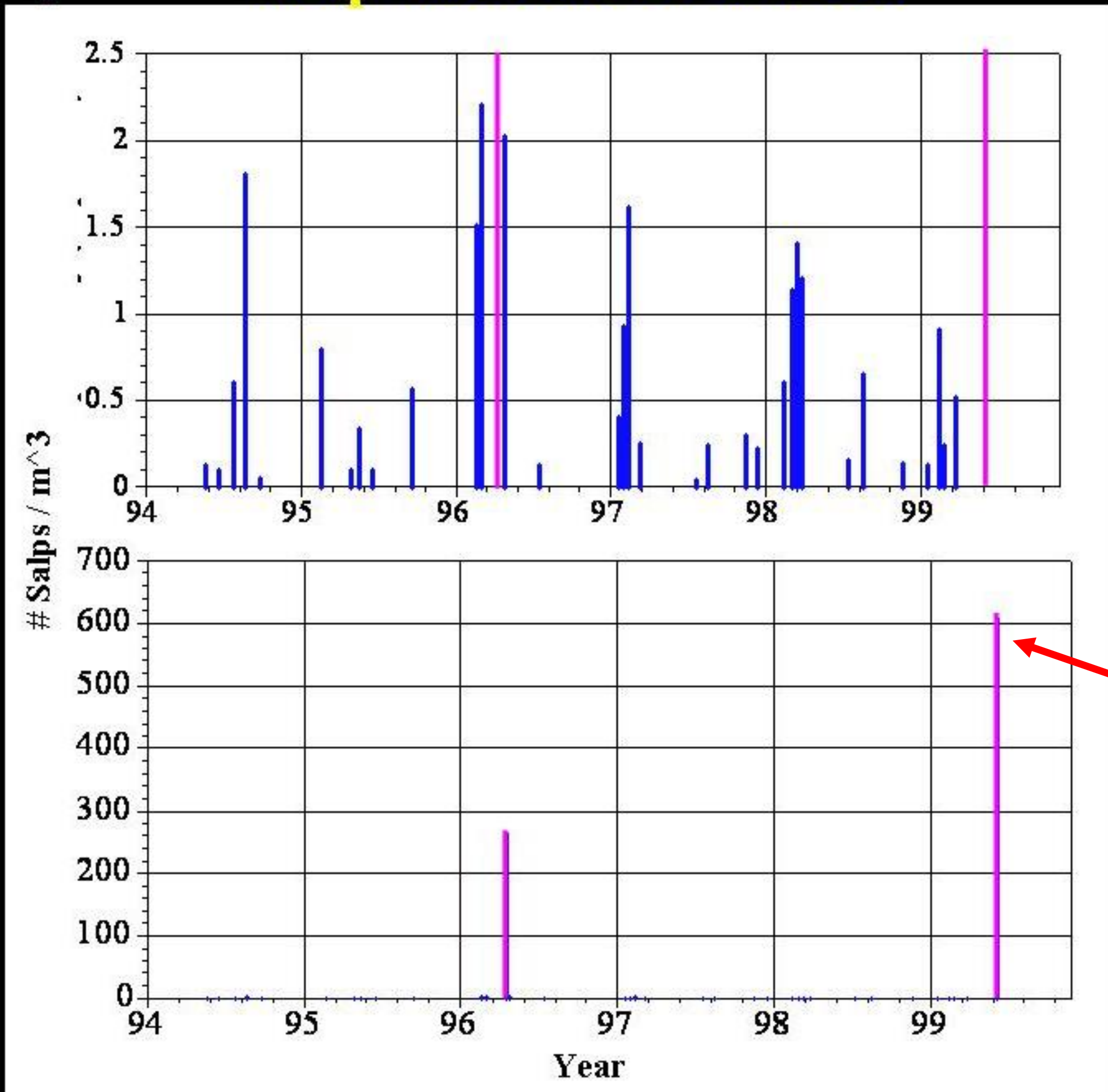
Boyd et al. (2012)

A mixed diet……………………….



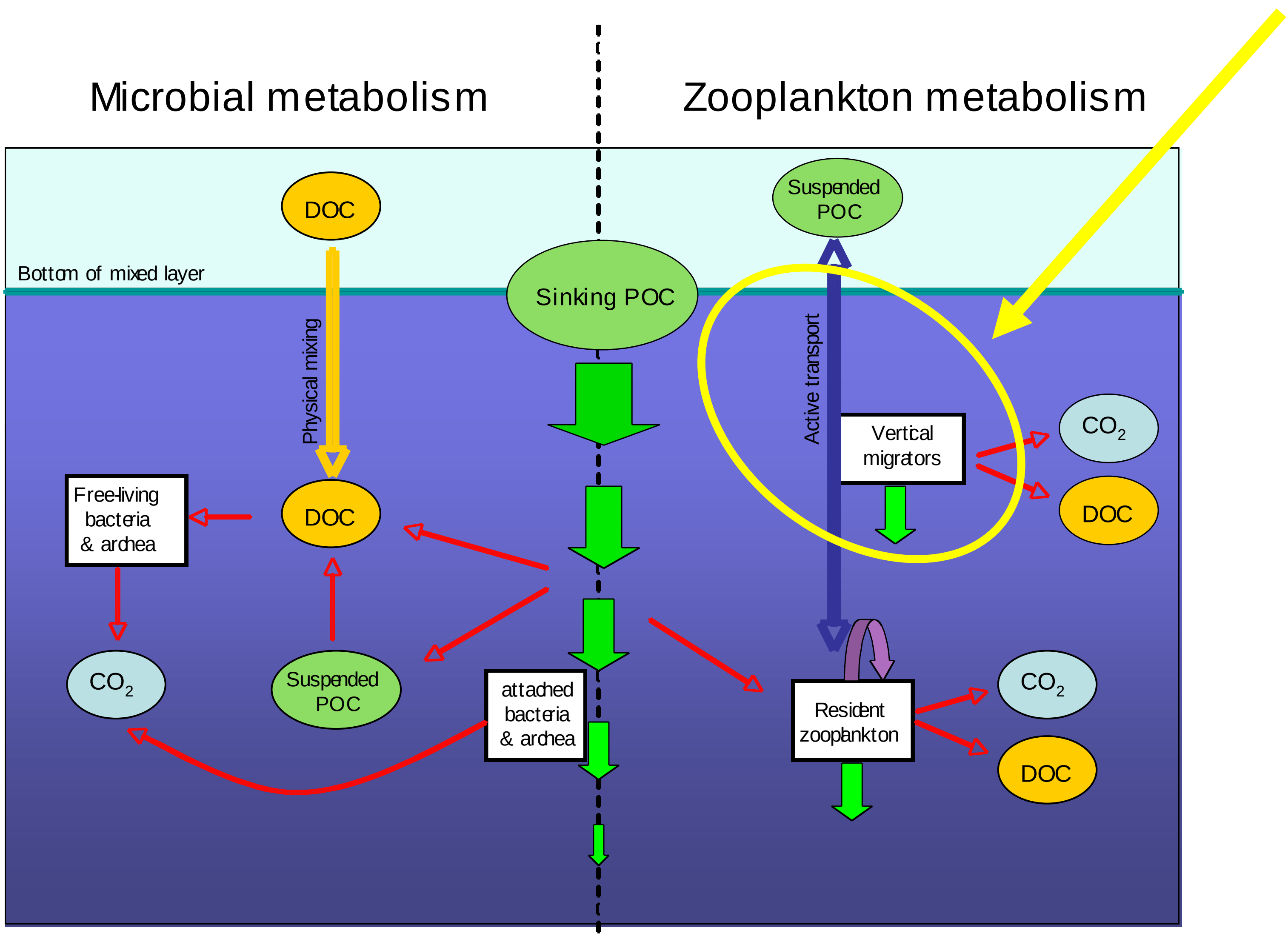
Courtesy Mary Silver UCSB

Salp blooms at BATS



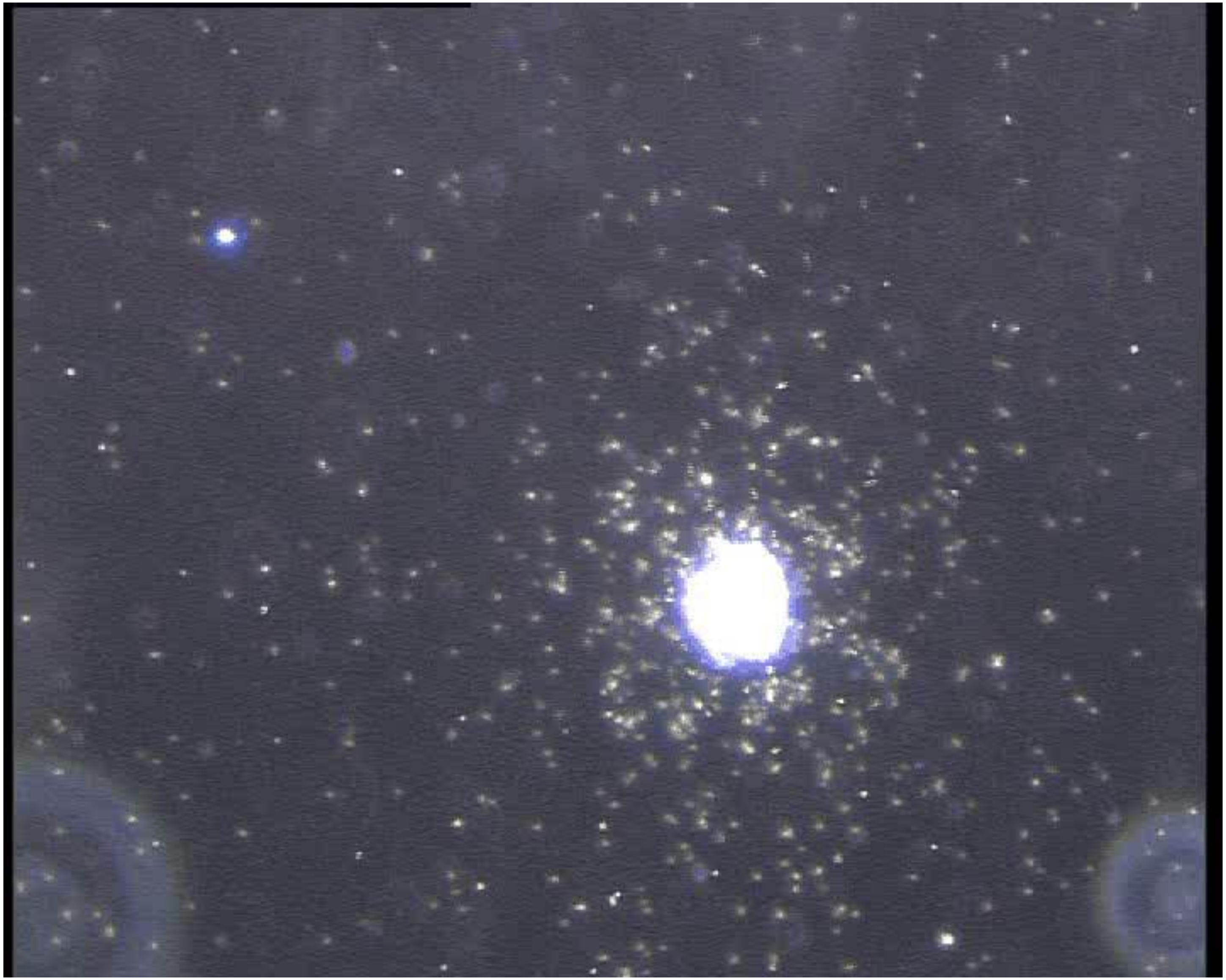
Steinberg & Madin

Surface feeding and zooplankton transport is large source of C required to feed mesopelagic bacteria & zooplankton carnivores



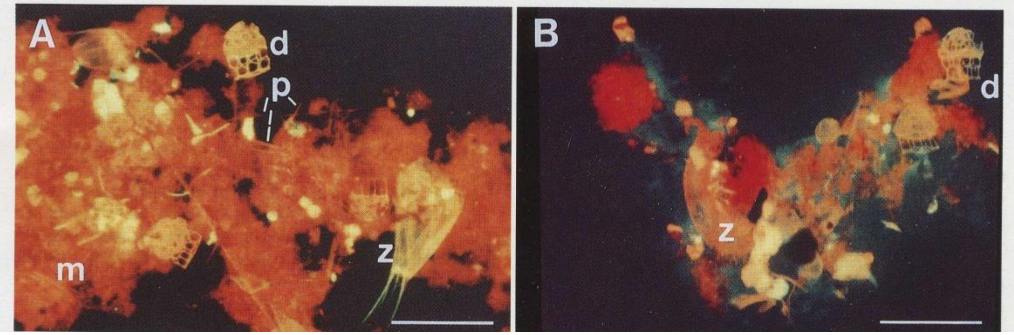
Steinberg et al., (2009)

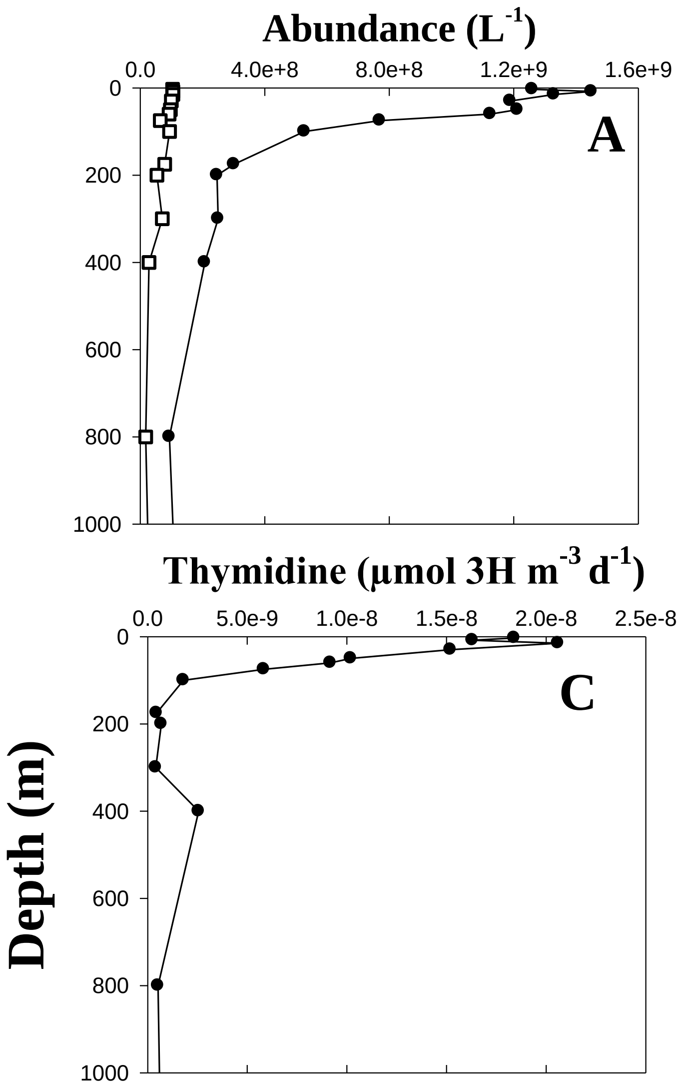
Particle transformations and foodwebs
Subsurface ocean - microbes

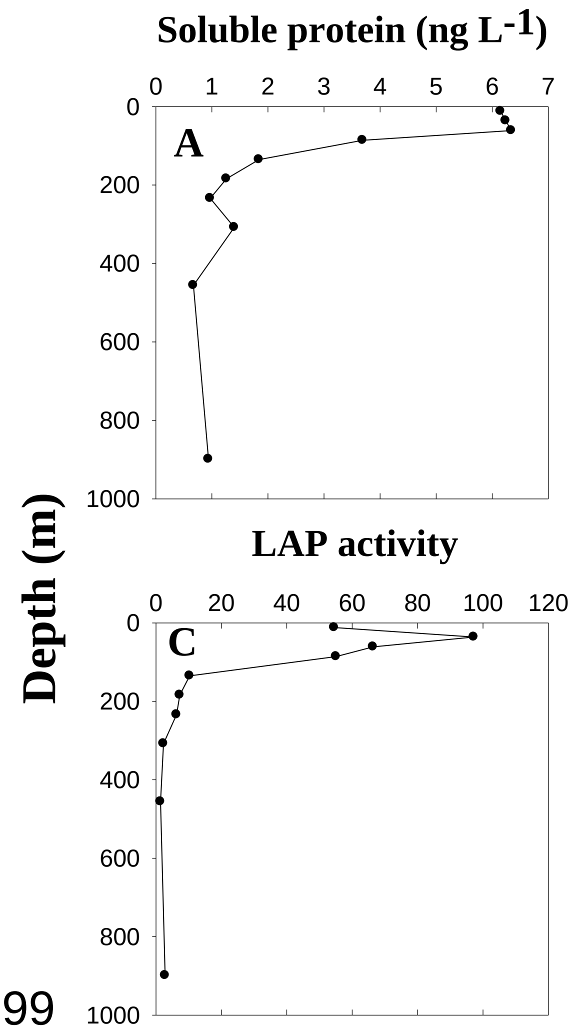


Courtesy Thomas Kiorboe Denmark

Bacteria solubilize particles

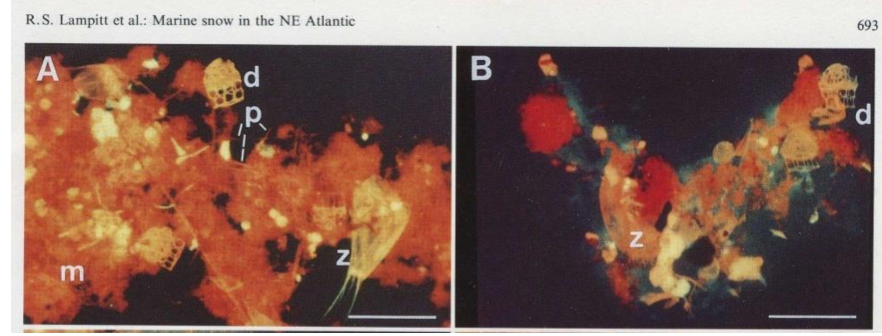


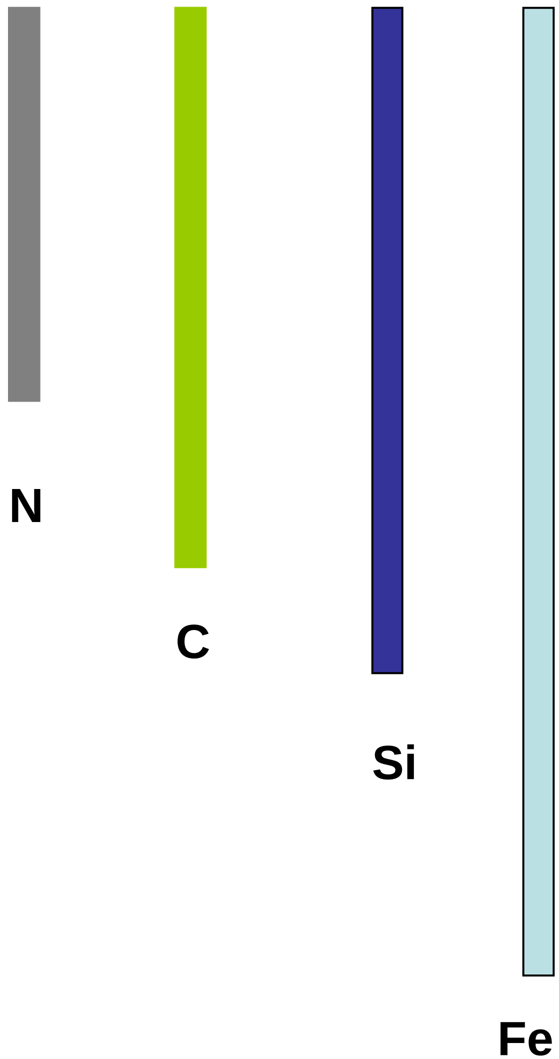




Boyd et al. 1999

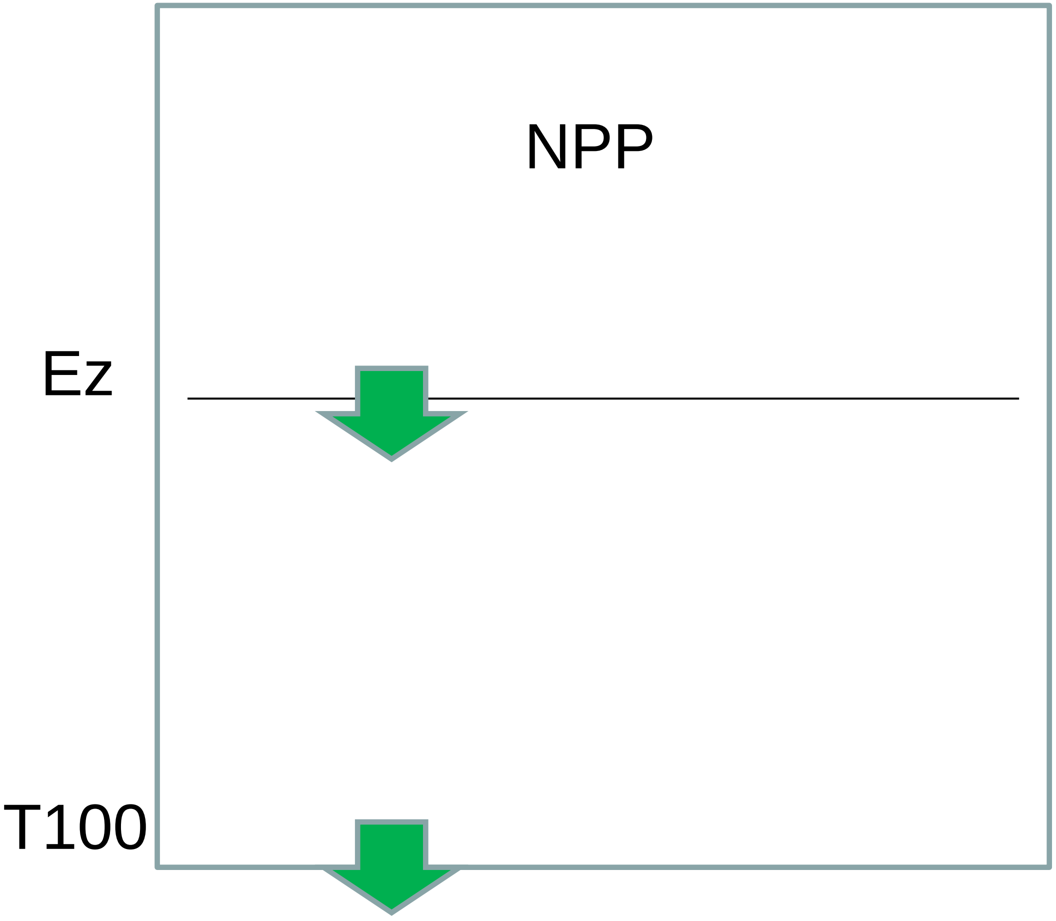
Nutrient regeneration

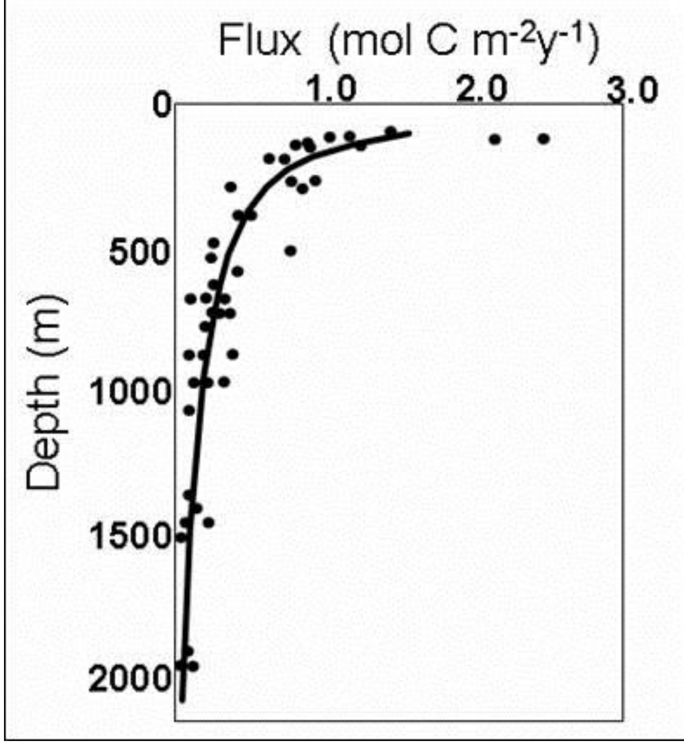


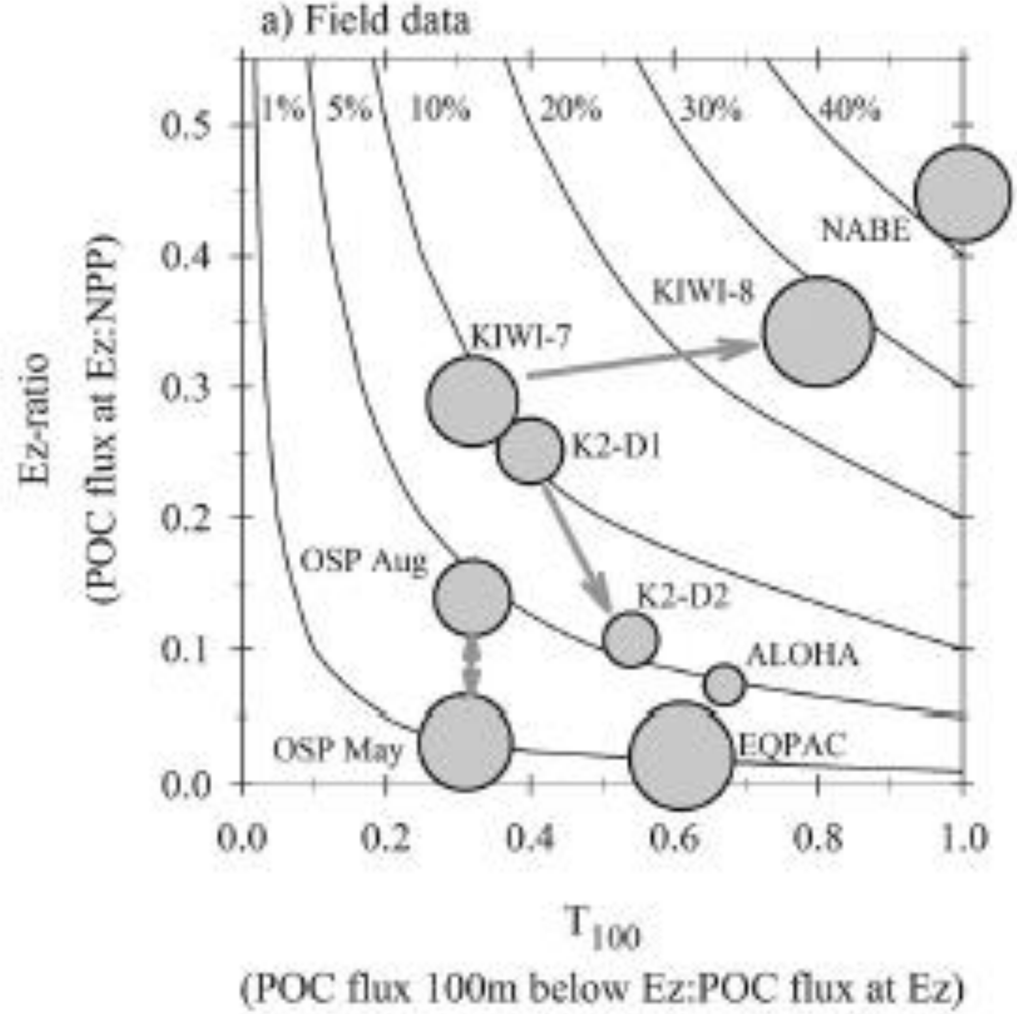


Remineralization length scales of major & trace elements are microbially mediated

Particle attenuation
surface vs. subsurface waters

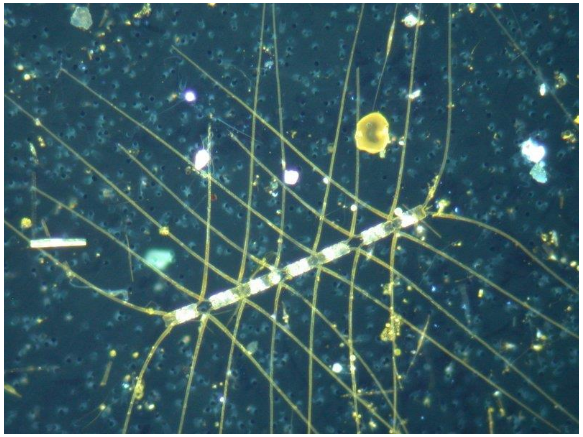


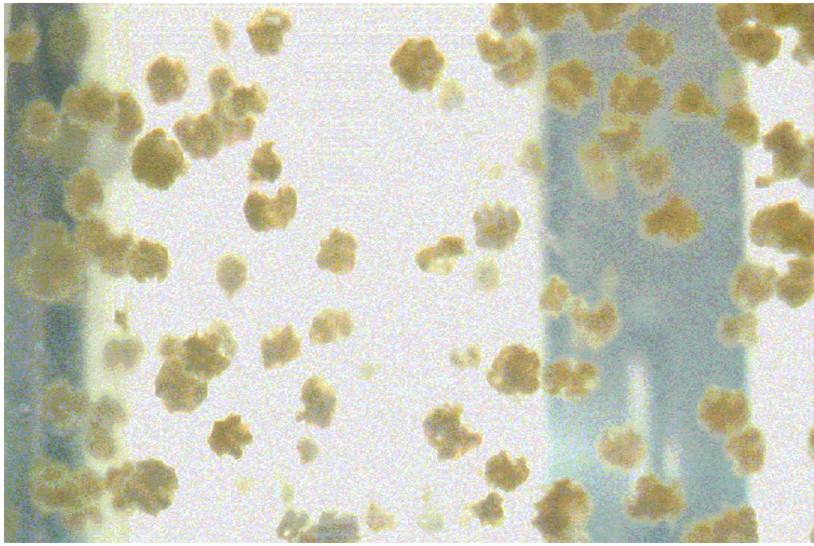




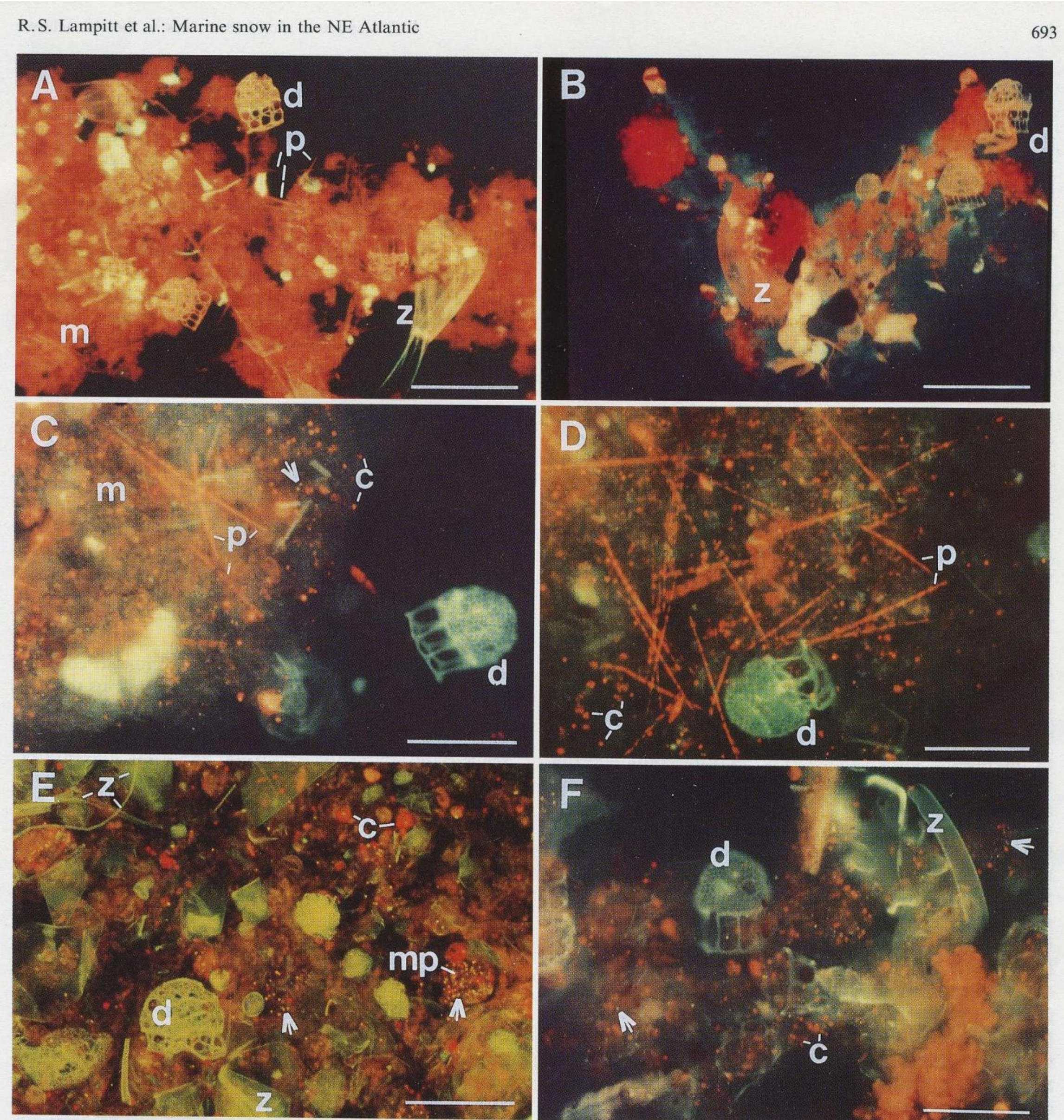
Buesseler & Boyd 2009

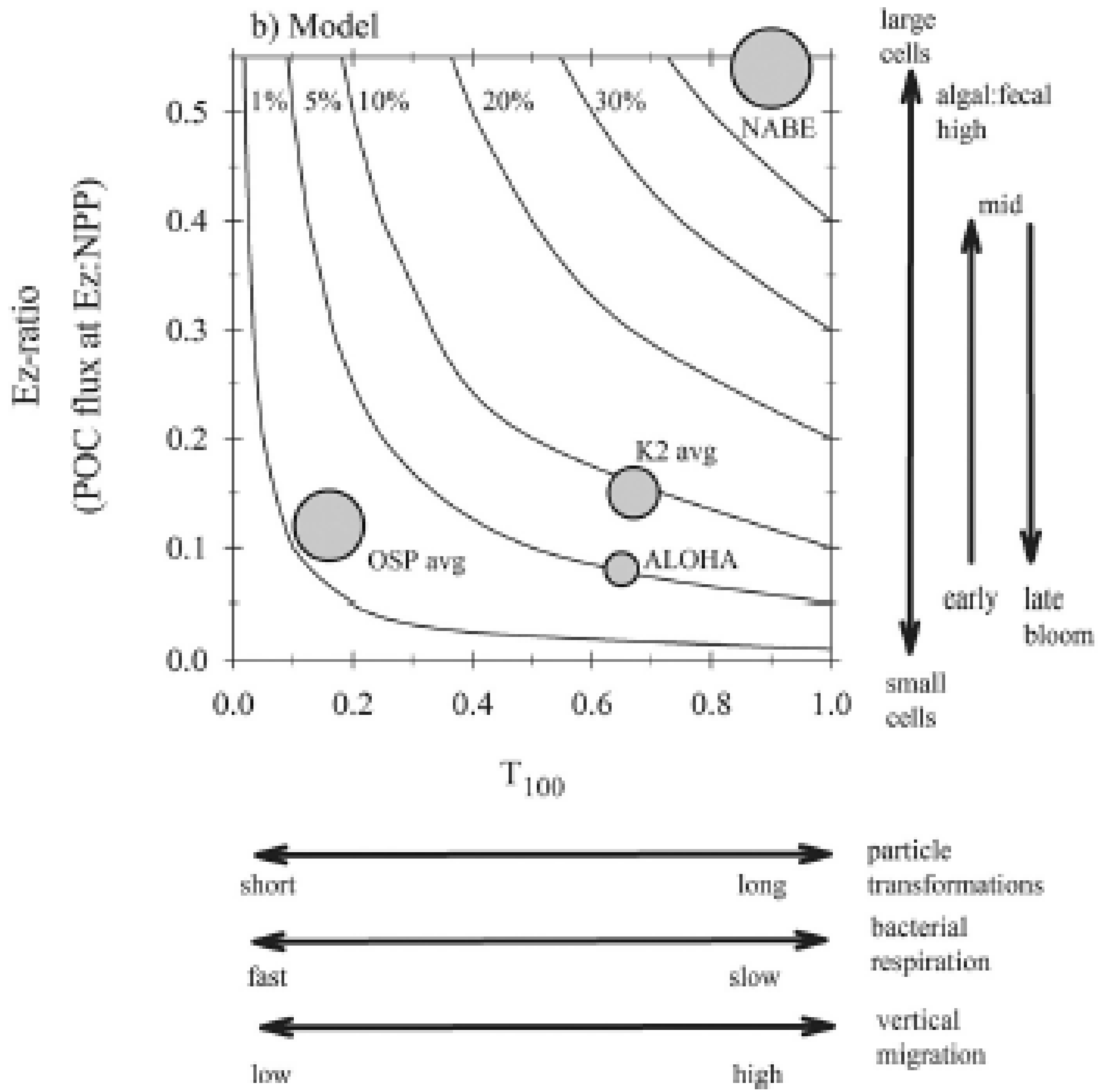
End-member – Direct algal sinking



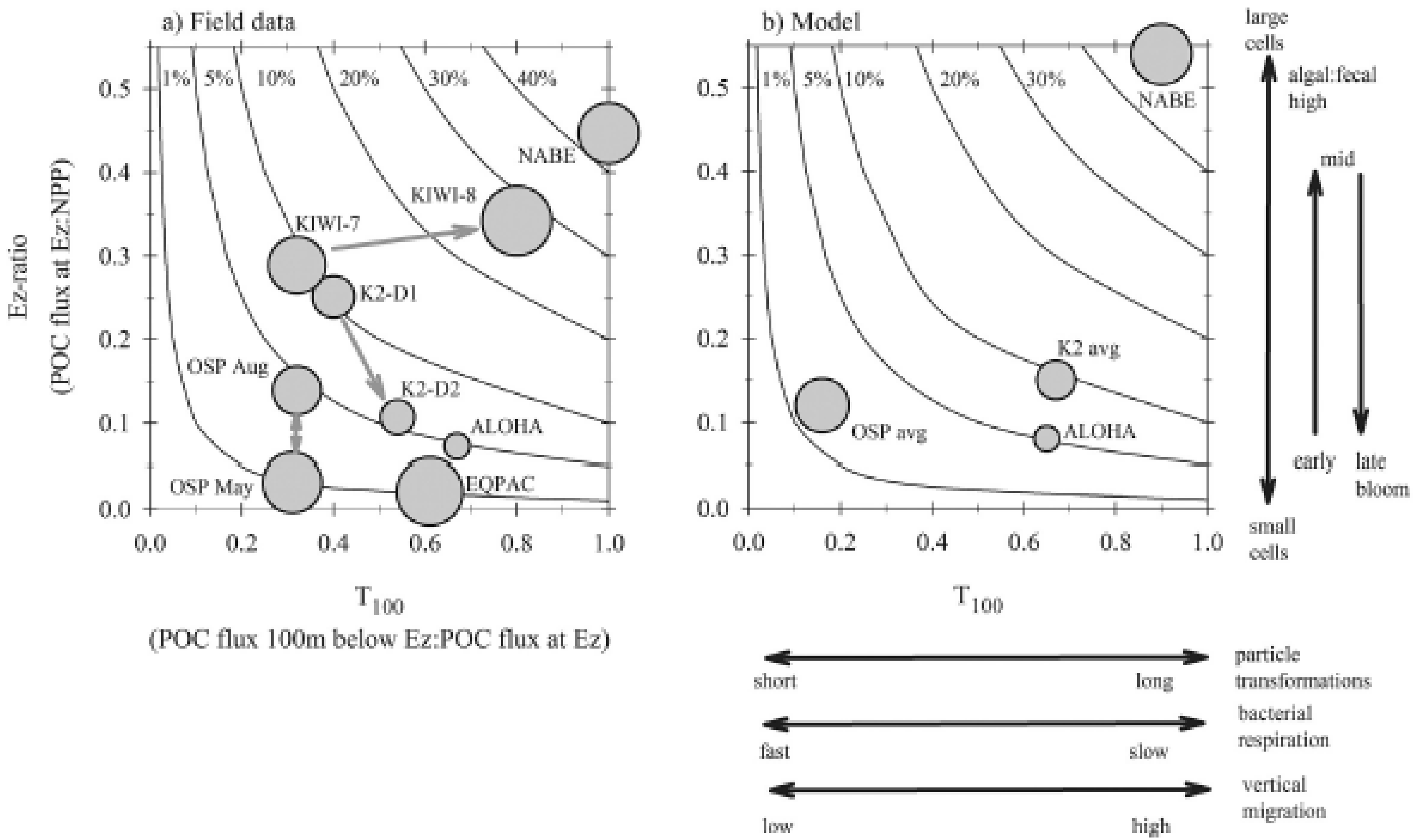


End-member – heavily transformed particles



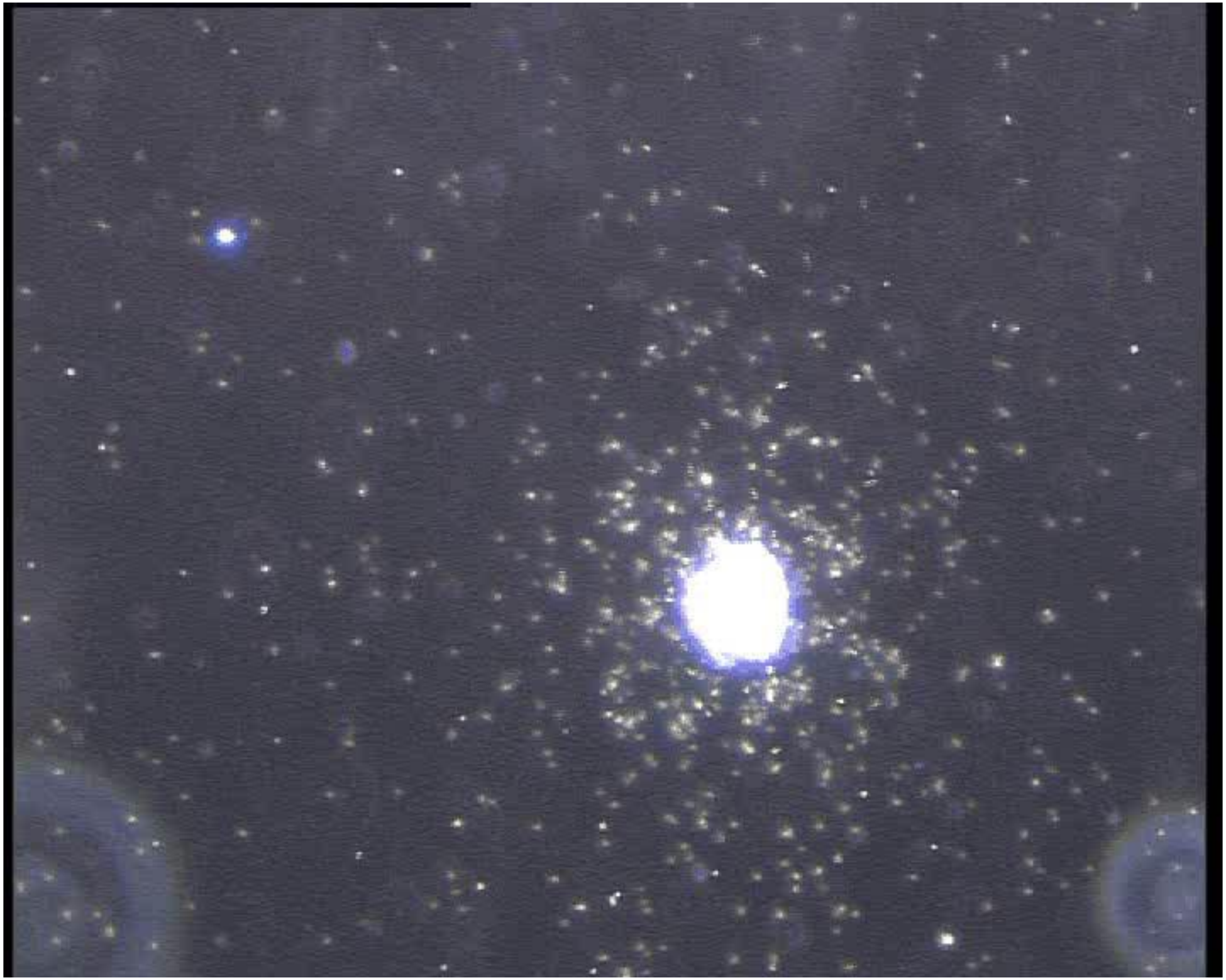


Buesseler & Boyd 2009



Buesseler & Boyd 2009

Biological pump – at a cellular level

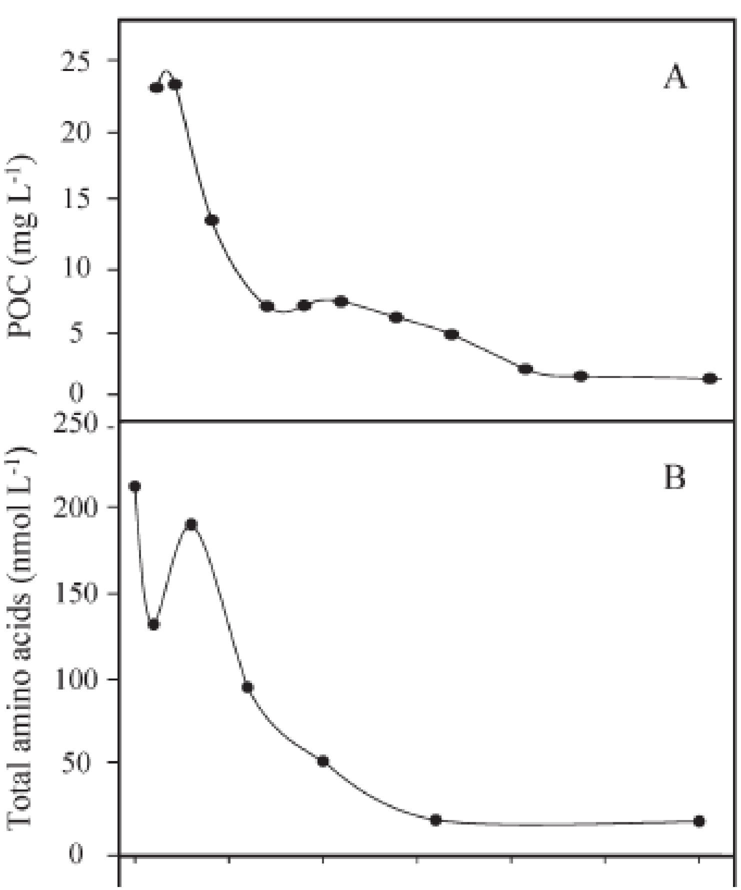


Courtesy Thomas Kiorboe Denmark

Limnol. Oceanogr., 55(4), 2010, 1790–1804

doi:10.4319/lo.2010.55.4.1790

The path to preservation: Using proteomics to decipher the fate of diatom proteins during microbial degradation



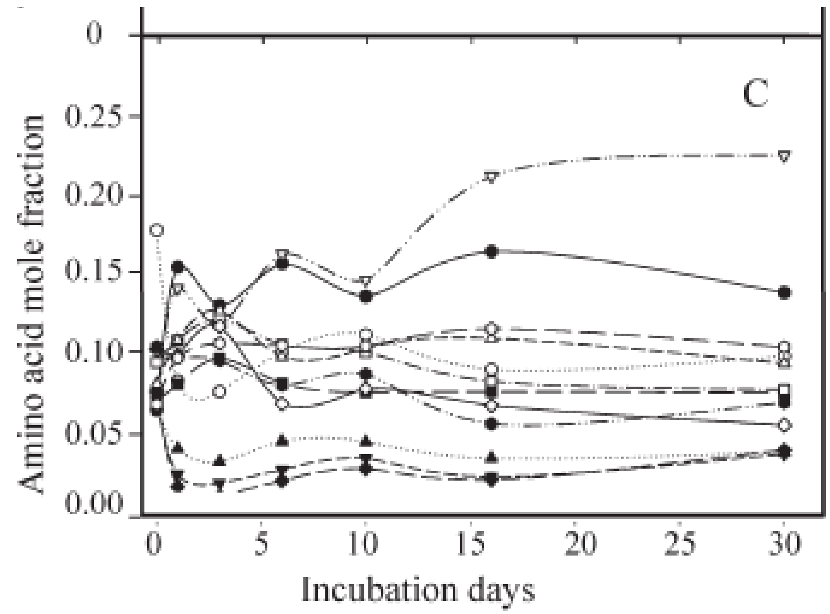


Fig. 1. Concentrations of (A) particulate organic carbon POC) and (B) total amino acids, and (C) relative distributions of ımino acids collected over the 30-d incubation of *T. pseudonana* as legradation proceeded. Solid circle, solid line: Ala; open circle,

Nunn et al. 2010

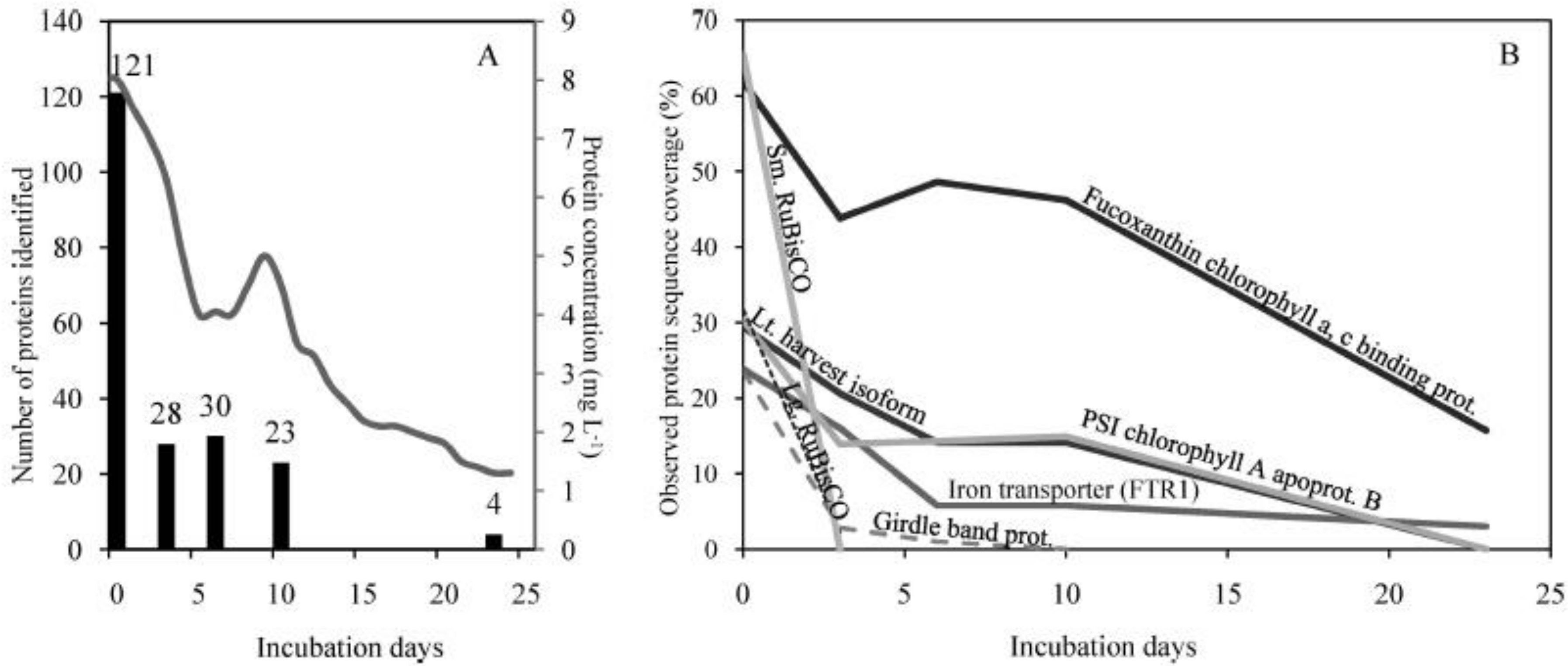


Fig. 2. (A) The time course of total particulate protein present during diatom degradation. Histogram: total number of proteins identified using LC-MS/MS; solid gray line: concentration of protein as measured by the Bradford assay. (B) Line graph tracking the percent of protein sequence detected using LC-MS/MS of seven different proteins through the degradation experiment.

Nunn et al. 2010

Limnol. Oceanogr., 59(3), 2014, 689–704

doi:10.4319/lo.2014.59.3.0689

Differential remineralization of major and trace elements in sinking diatoms

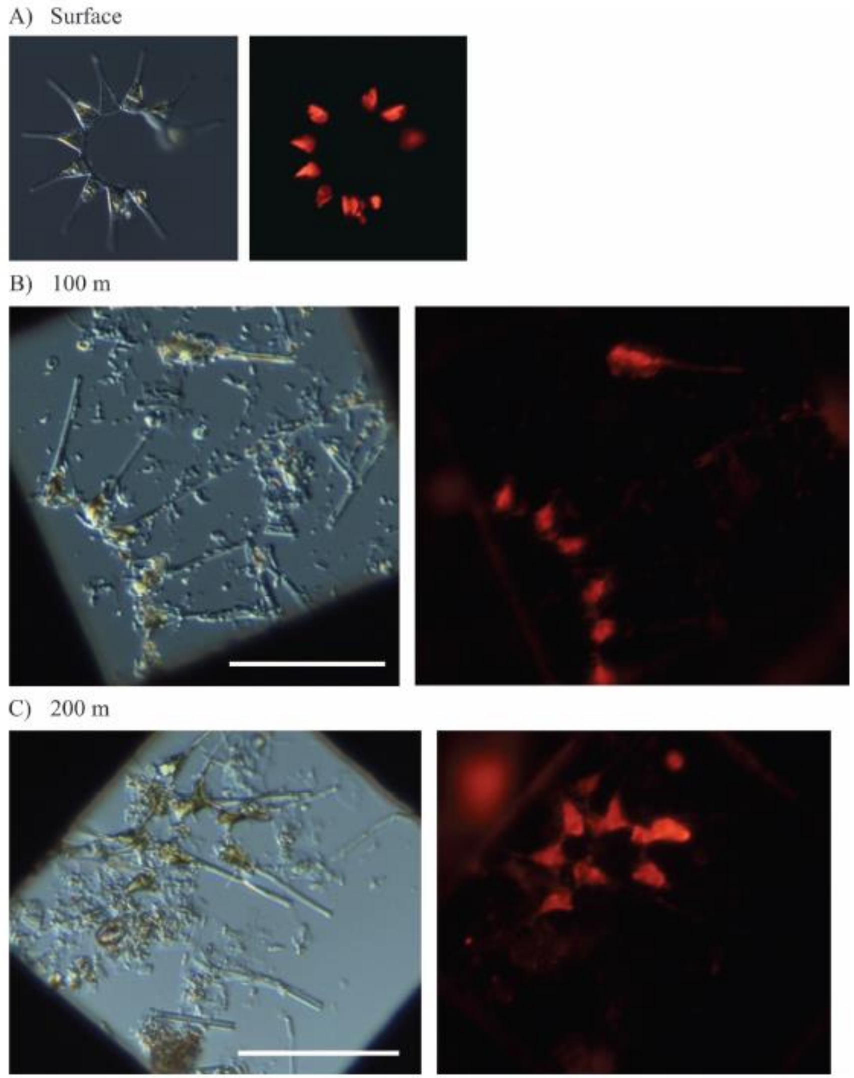


Fig. 3. Light (differential interference contrast) and epifluorescence (480 nm excitation)

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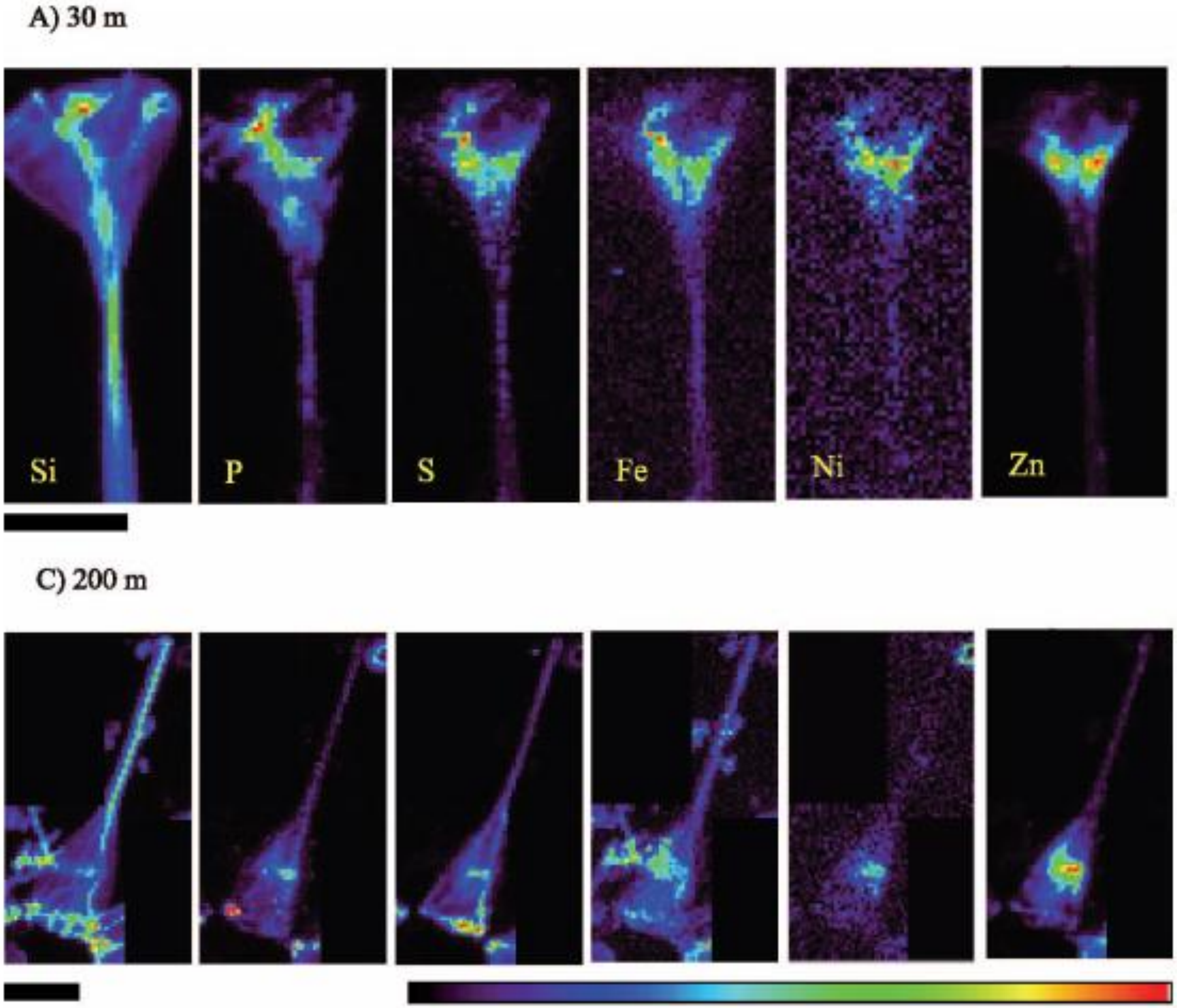
2014



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2014

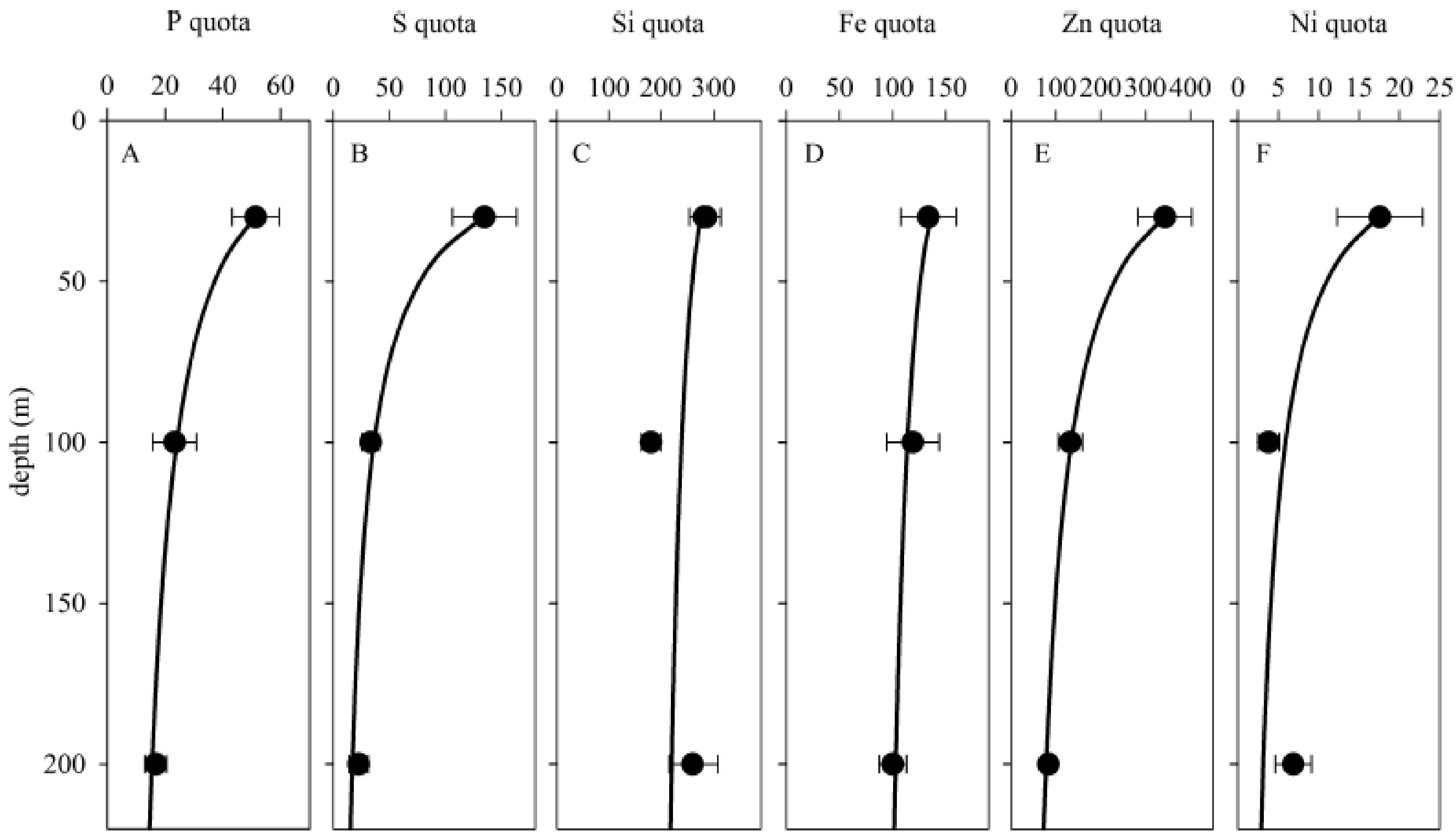

Fig. 4. Depth profiles of *Asterionellopsis glacialis* cellular element quotas for (A) P, (B) S, (C) Si, (D) Fe, (E) Zn, and (F) Ni. The quotas are means ± SE (n = 5–14). A power-law function (Flux = a(depth)$^{-b}$) has been fitted to each data set and the resulting attenuation coefficients (b) for the cells are shown in Table 1. P, S, and Si quotas are presented as fmol cell^{-1}, while Fe, Zn, and Ni quotas are presented as amol cell^{-1}.

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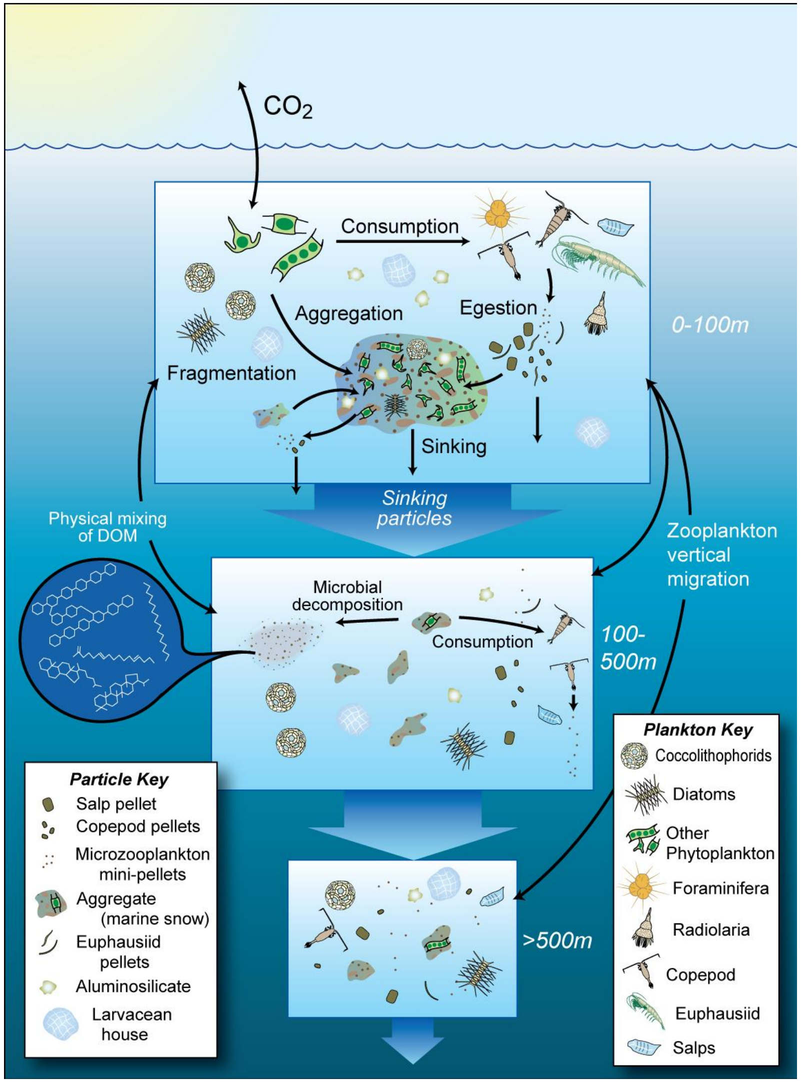
The Future

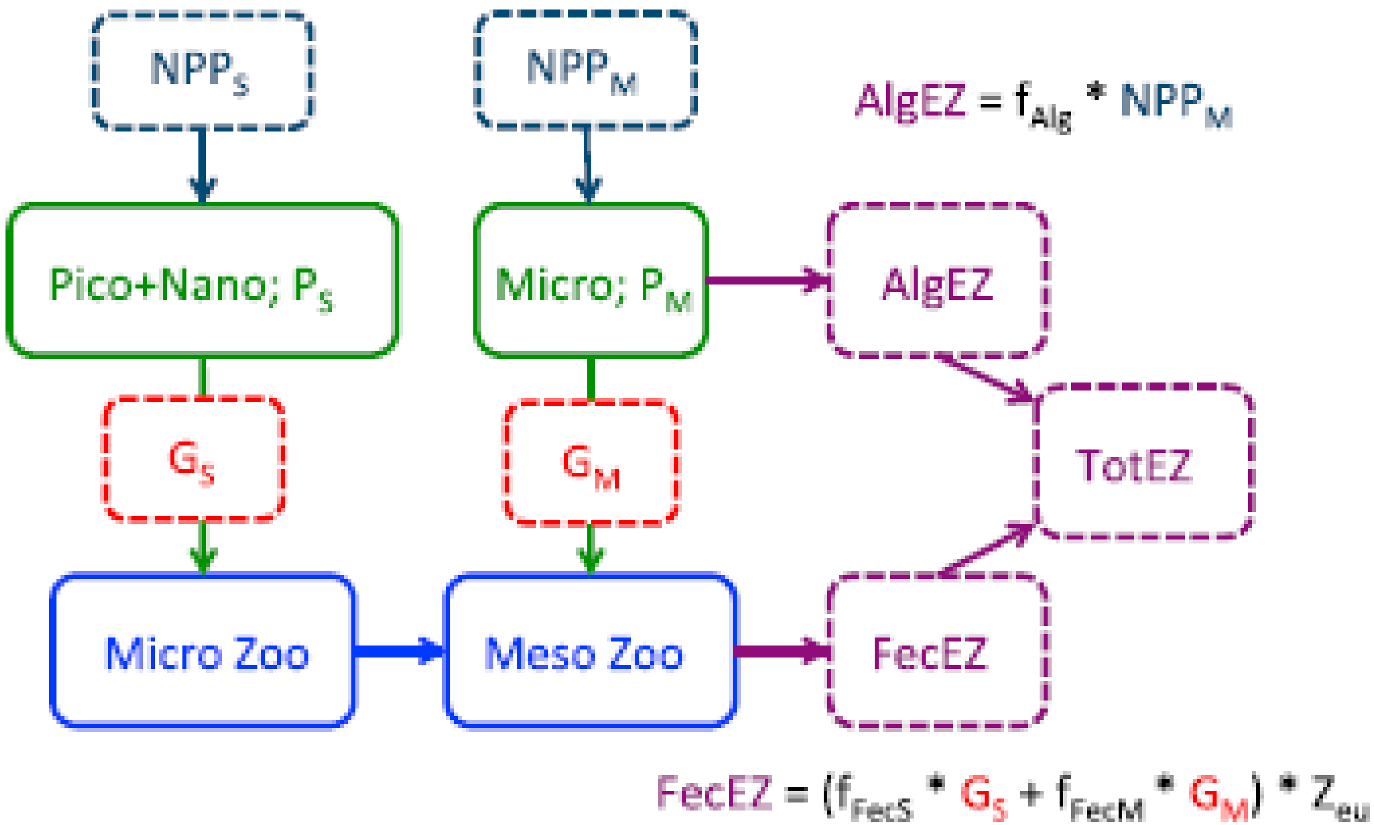
Detection and attribution of change in export



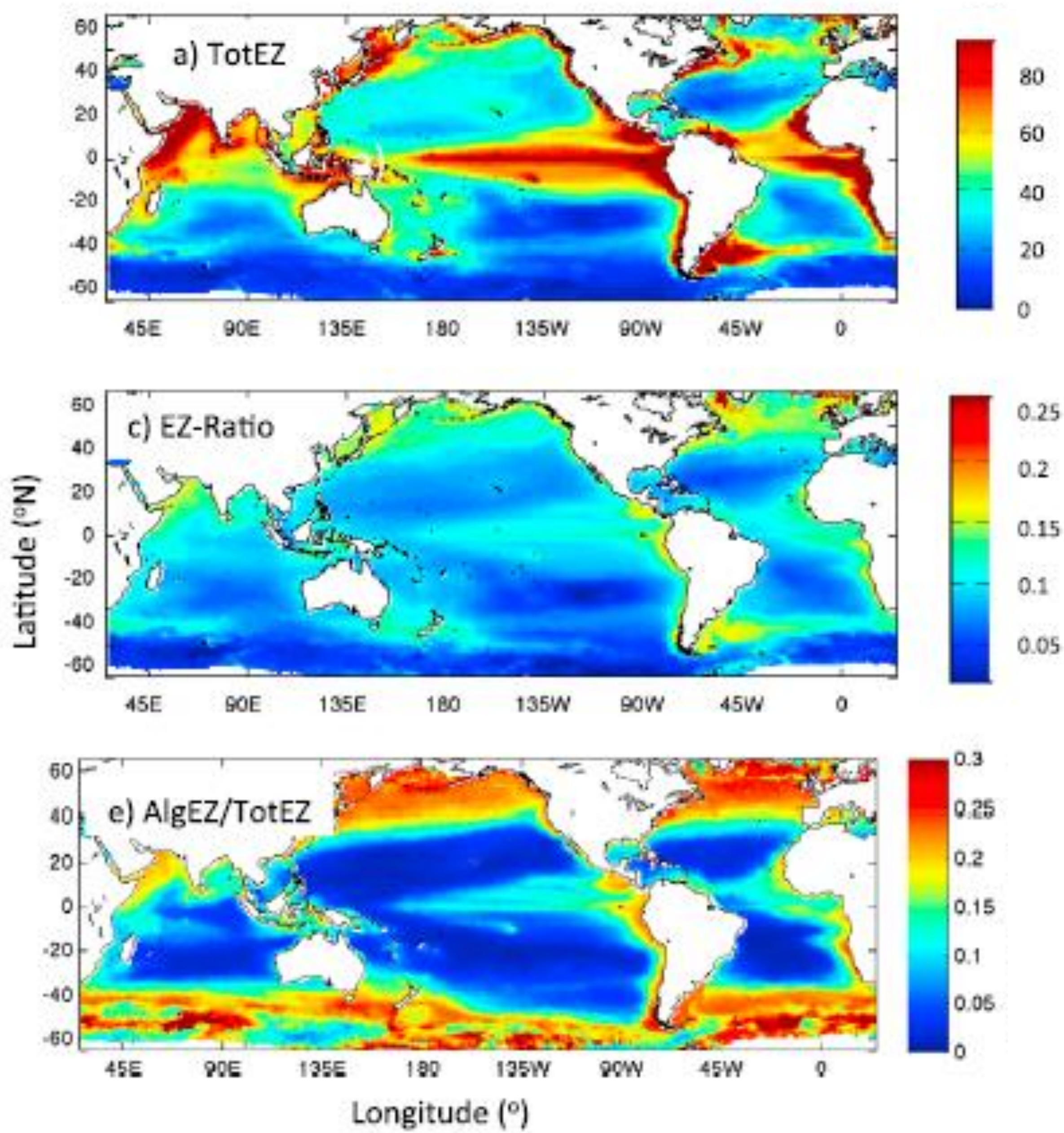
IPCC 2014

Global assessment of ocean carbon export by combining satellite observations and food-web models

D. A. Siegel[1], K. O. Buesseler[2], S. C. Doney[2], S. F. Sailley[3], M. J. Behrenfeld[4], and P. W. Boyd[5]



Siegel et al. GBC 2014



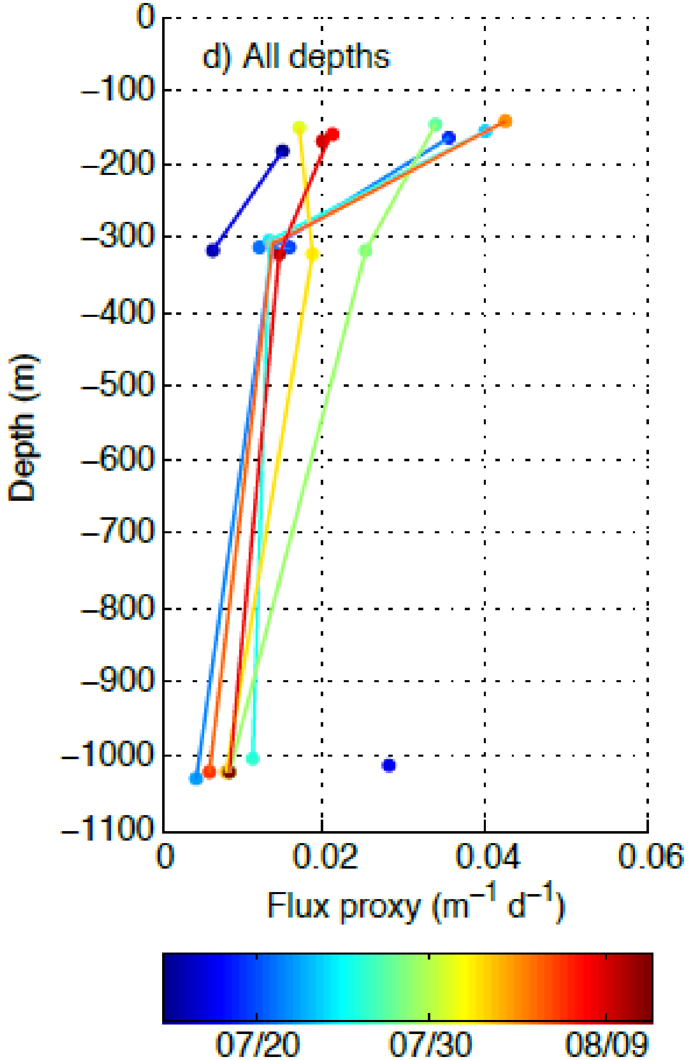
Log 10
mg C m^{-2} d^{-1}

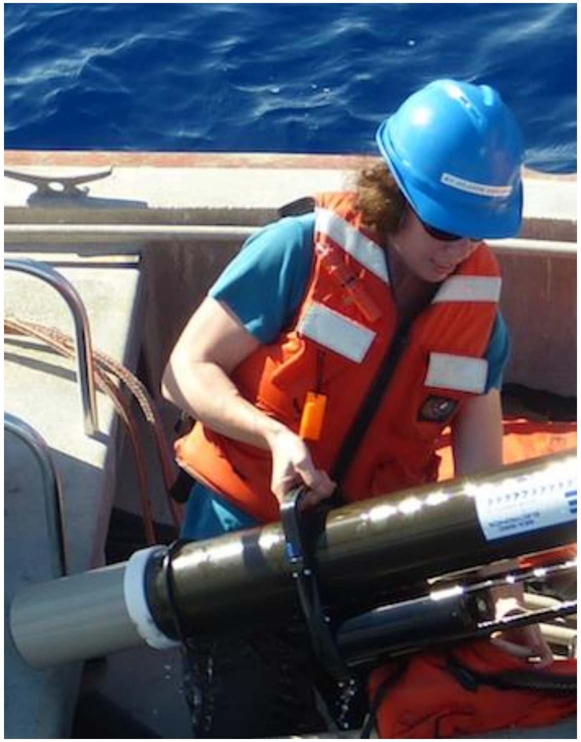
Siegel et al. GBC 2014

Autonomous, high-resolution observations of particle flux in the oligotrophic ocean

M. L. Estapa[1], K. Buesseler[1], E. Boss[2], and G. Gerbi[3]

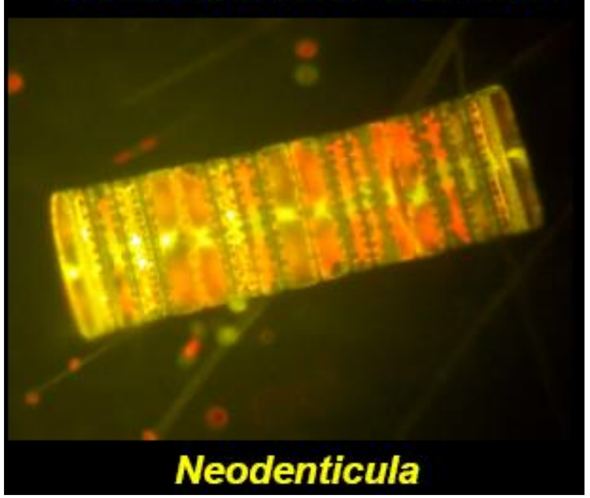
2014





APEX float
With BOSS bio-optics

The biological pump and planktonic community structure



Conclusions

The pump drives multiple processes – C sequestration, nutrient regeneration, particle scavenging, nutrition of the deep ocean

The export of carbon from the surface is driven by foodweb transformations – from aggregation to faecal pellets

Carbon export in the subsurface ocean is controlled by both animal and microbial activity on particles

Export efficiency varies regionally and seasonally

Models are now providing the means to obtain global estimates of export from the surface ocean