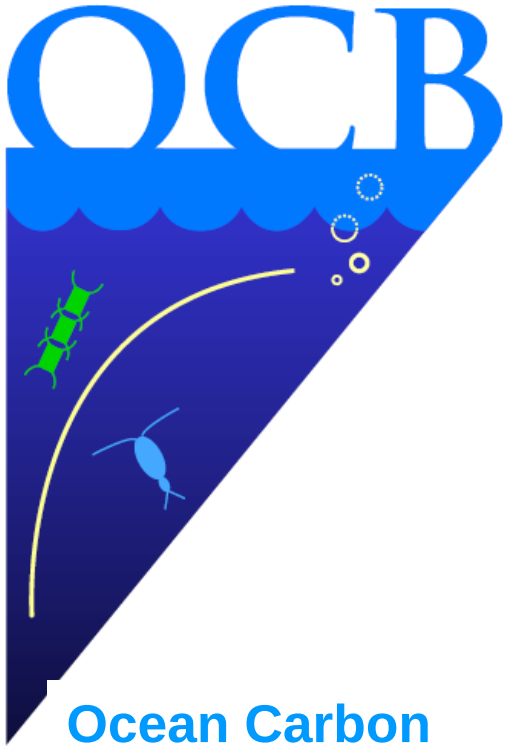
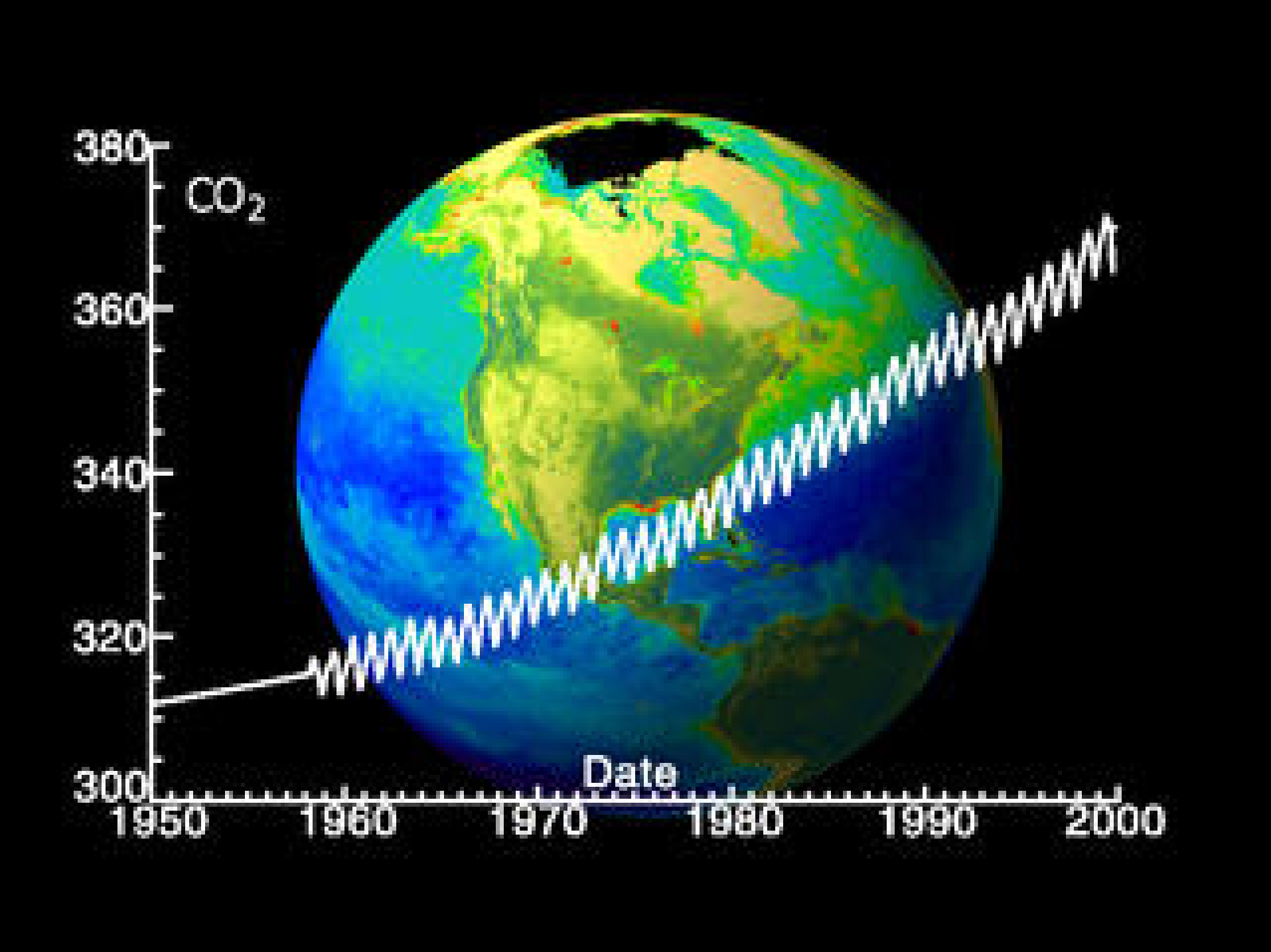


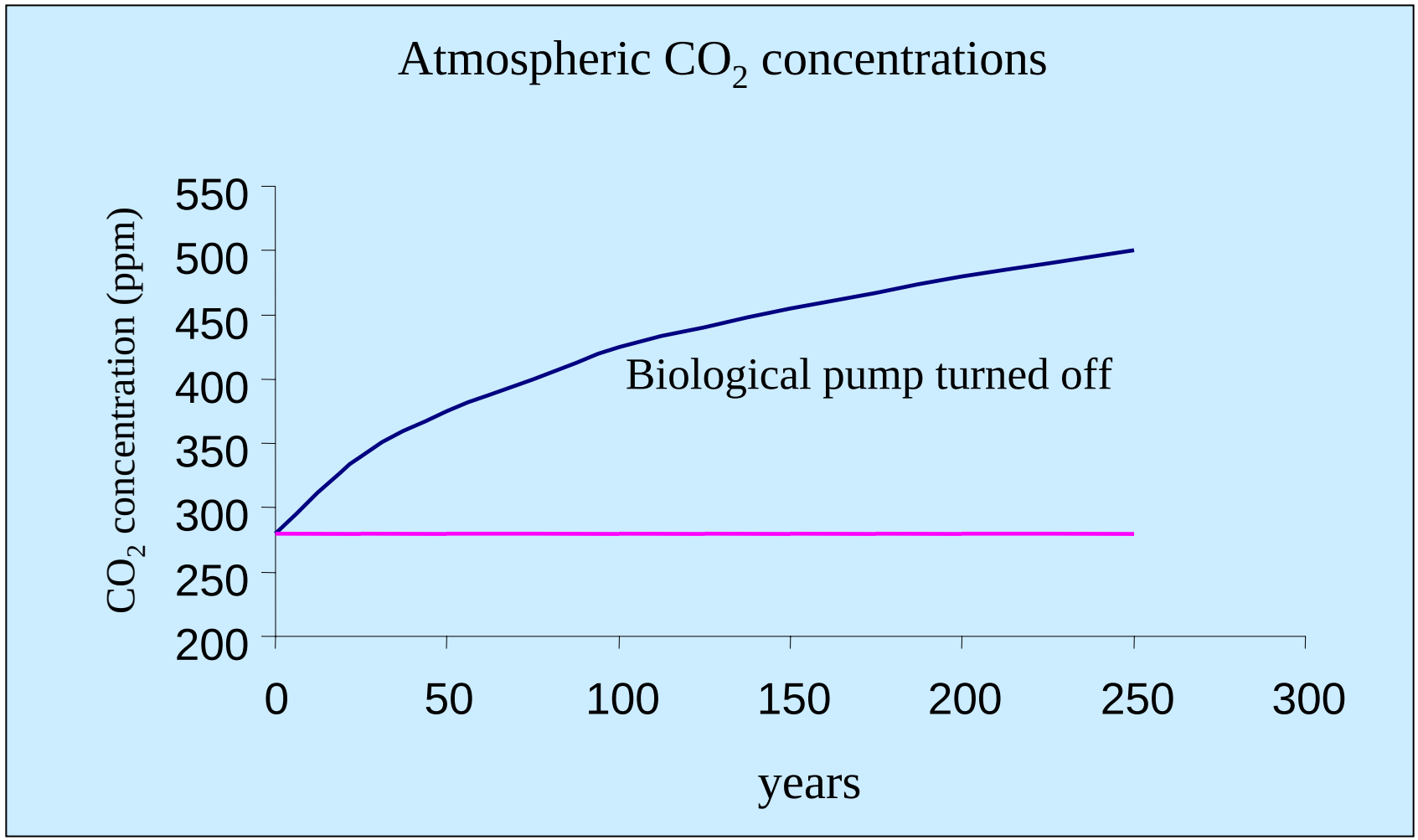
Ocean Carbon
& Ballasting

Respiration, decomposition and export

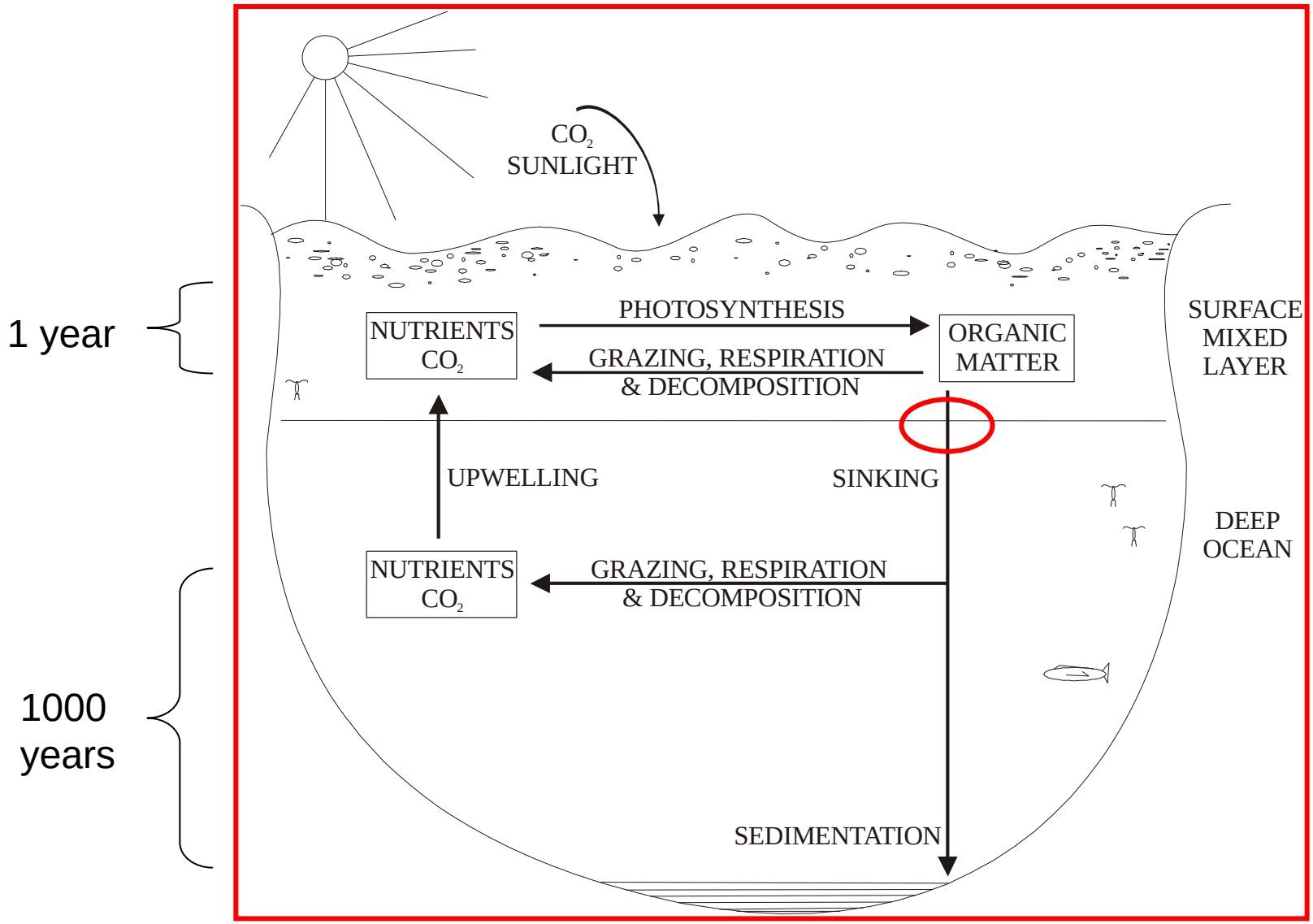
Uta Passow
(AWI, Bremerhaven
and MSI, UC Santa Barbara)

Does Ocean acidification change the C-flux to depth, or the strength or the efficiency of the biological pump?


380
CO_2
360
340
320
300
Date
1950
1960
1970
1980
1990
2000


Atmospheric CO_2 concentrations
CO_2 concentration (ppm)
550
500
450
400
350
300
250
200
0
50
100
150
200
250
300
years
Biological pump turned off

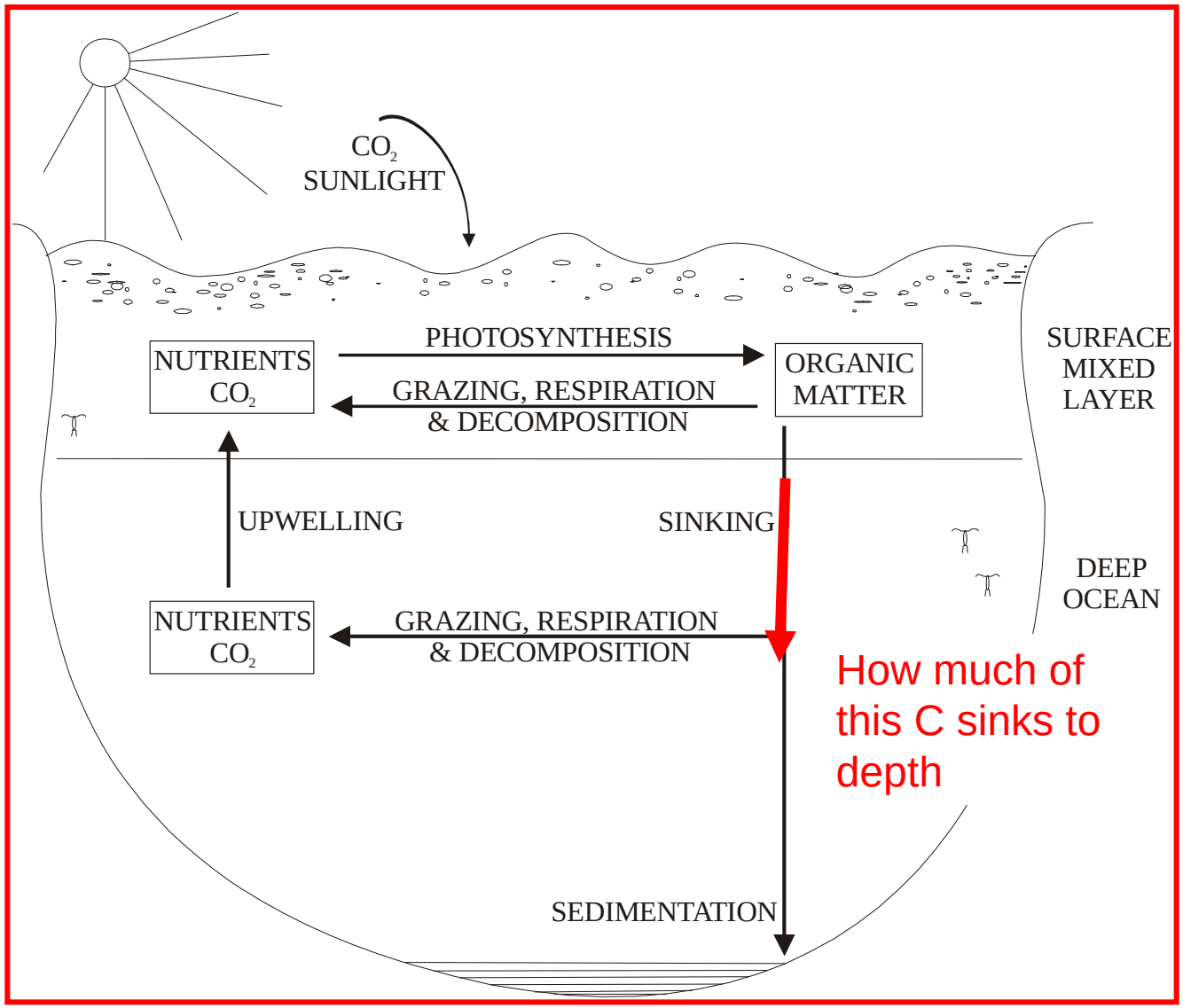
A Simplified View of the Biological Pump



POC-transport out of the euphotic zone depends on process in the euphotic zone

- POC production (primary productivity)
- POC type (species composition, TEP etc)
  - aggregation - sinking behavior,
  - bio-mineral production - sinking behavior,
  - C: N ratio
- POC loss (food web structure)

A Simplified View of the Biological Pump



1 year

1000 years

Sinking Fluxes of POC below the euphotic zone...

represent a balance between

sinking velocity (W, in units of m d^{-1})

and the

rate of loss (degradation = D,

in units of mass $mass^{-1}$ d^{-1})

$$\frac{dC_z}{dz} = -\frac{D}{W}C_z$$

Rate of loss during C-flux to depth

Bacterial degradation

A.Antia:
No or little effect of higher CO_2 on zooplankton in 2005 mesocosm experiment

Impact of acidification on C-transport to depth

1. Zooplankton activity

2. Microbial degradation

3. Sinking velocity: Aggregates
    1. TEP = Transparent Exopolymer Particles
    2. Minerals

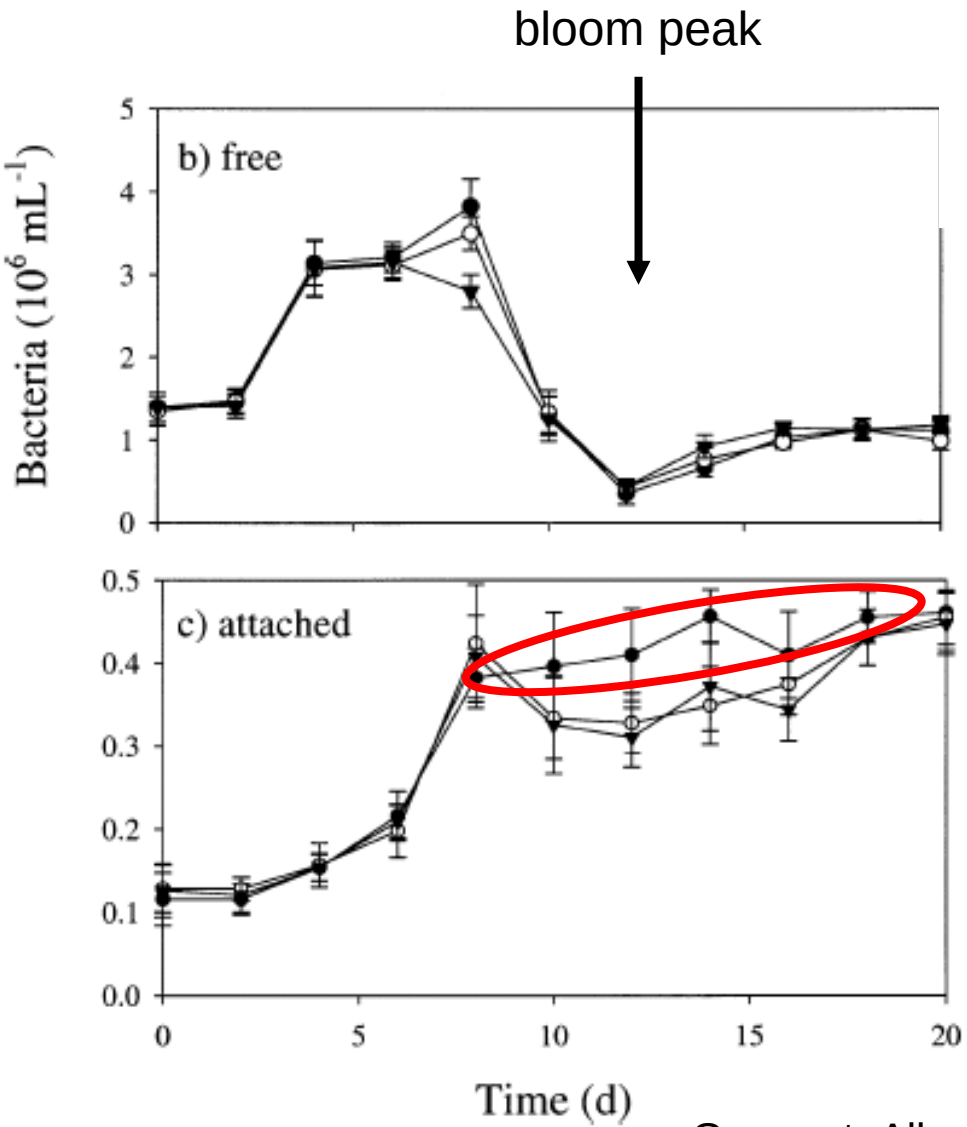
Work that needs doing

2003 Bergen experiment

3 mesocosms each: future, present, pre-industrial $CO_{2,}$, initiate phytoplankton bloom

Grossart, Allgaier, Passow, Riebesell 2006

Bacteria numbers in mesocosms with past, present and future CO_2

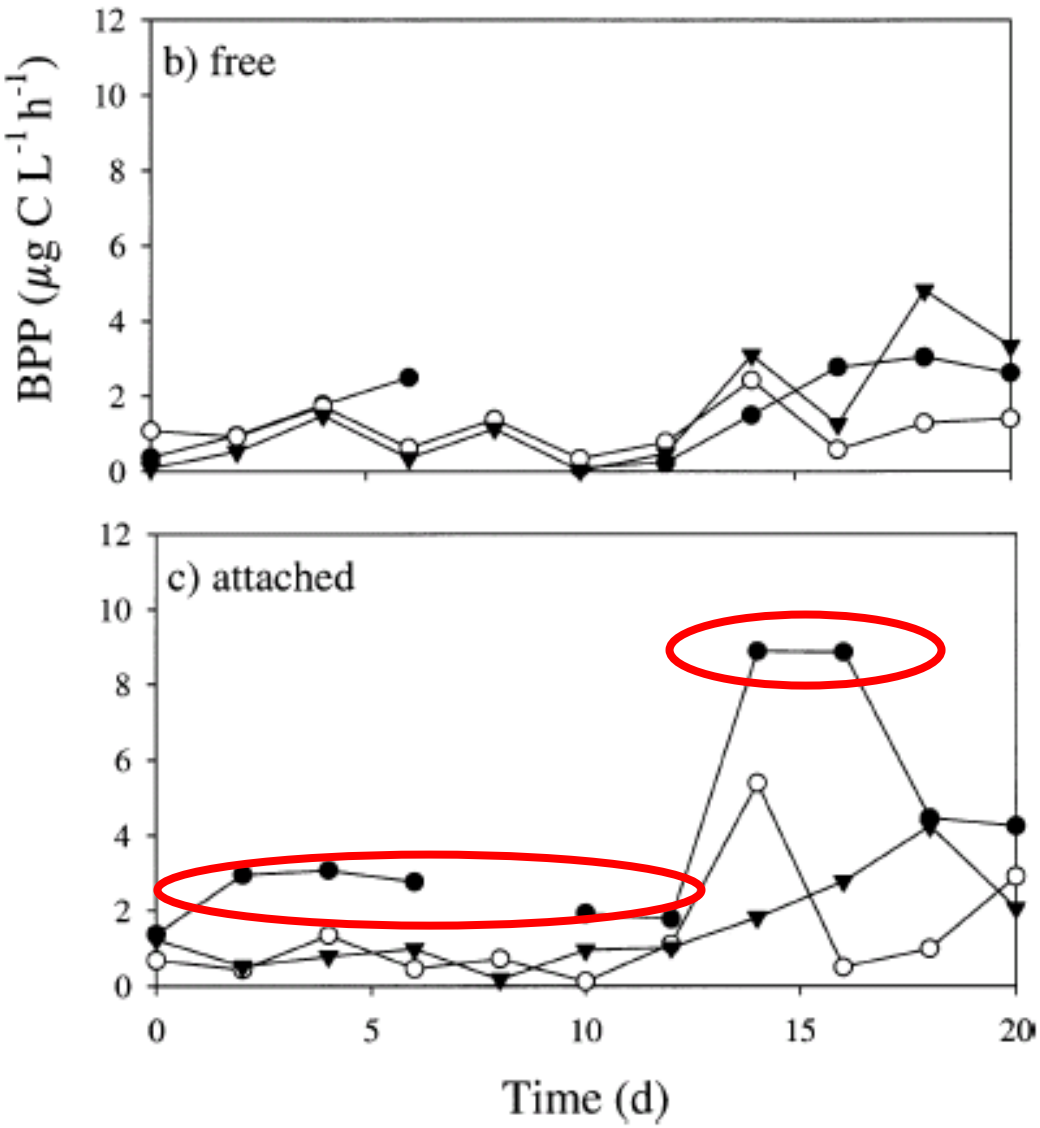


future 700 ppm
present 370 ppm
past 190 ppm

Future: more attached bacteria after bloom, indirect effect

Grossart, Allgaier, Passow, Riebesell 2006

Bacteria protein production in mesocosms with past, present and future CO_2

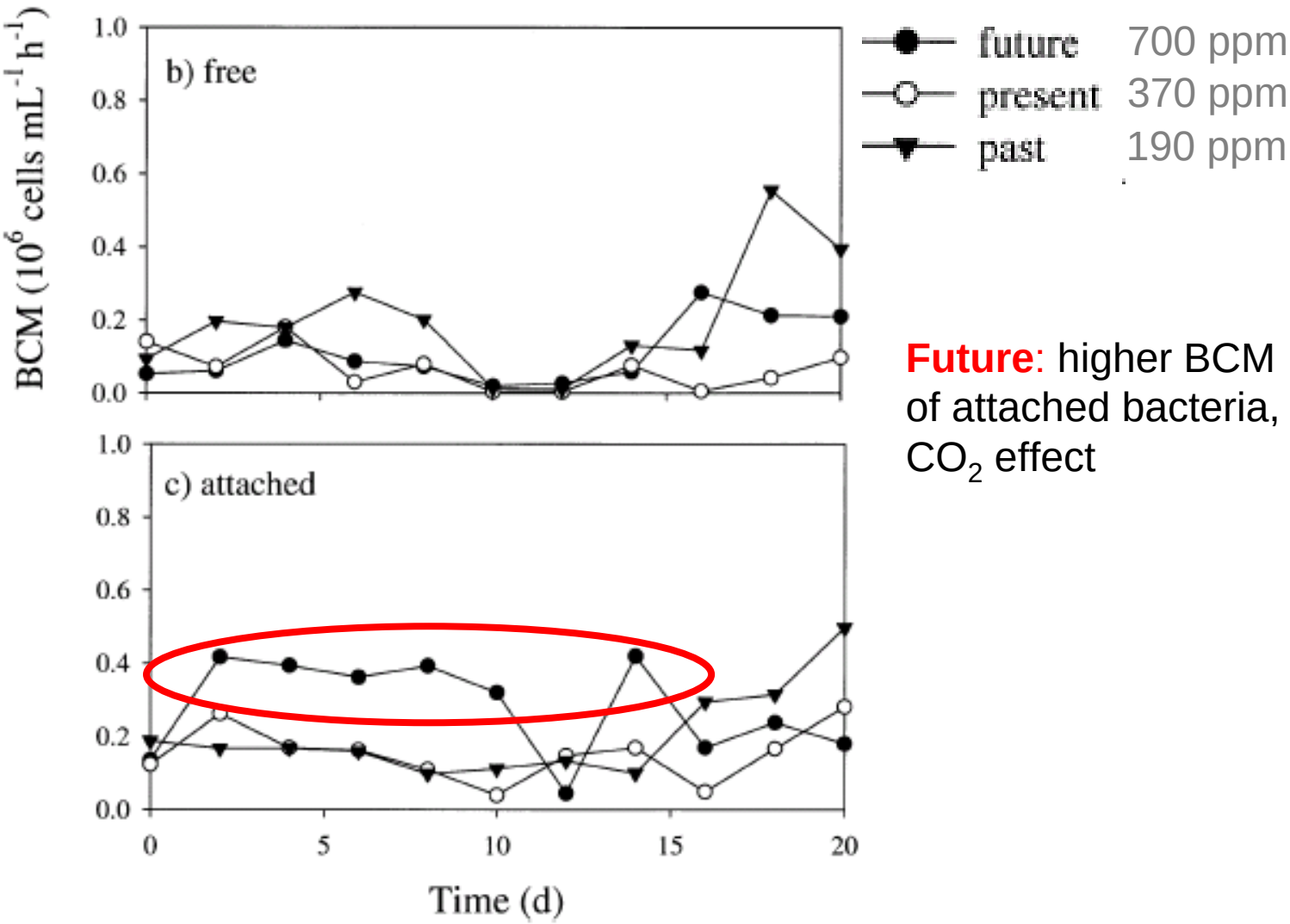


future 700 ppm
present 370 ppm
past 190 ppm

Future: higher BPP of attached bacteria, CO_2 effect

Grossart, Allgaier, Passow, Riebesell 2006

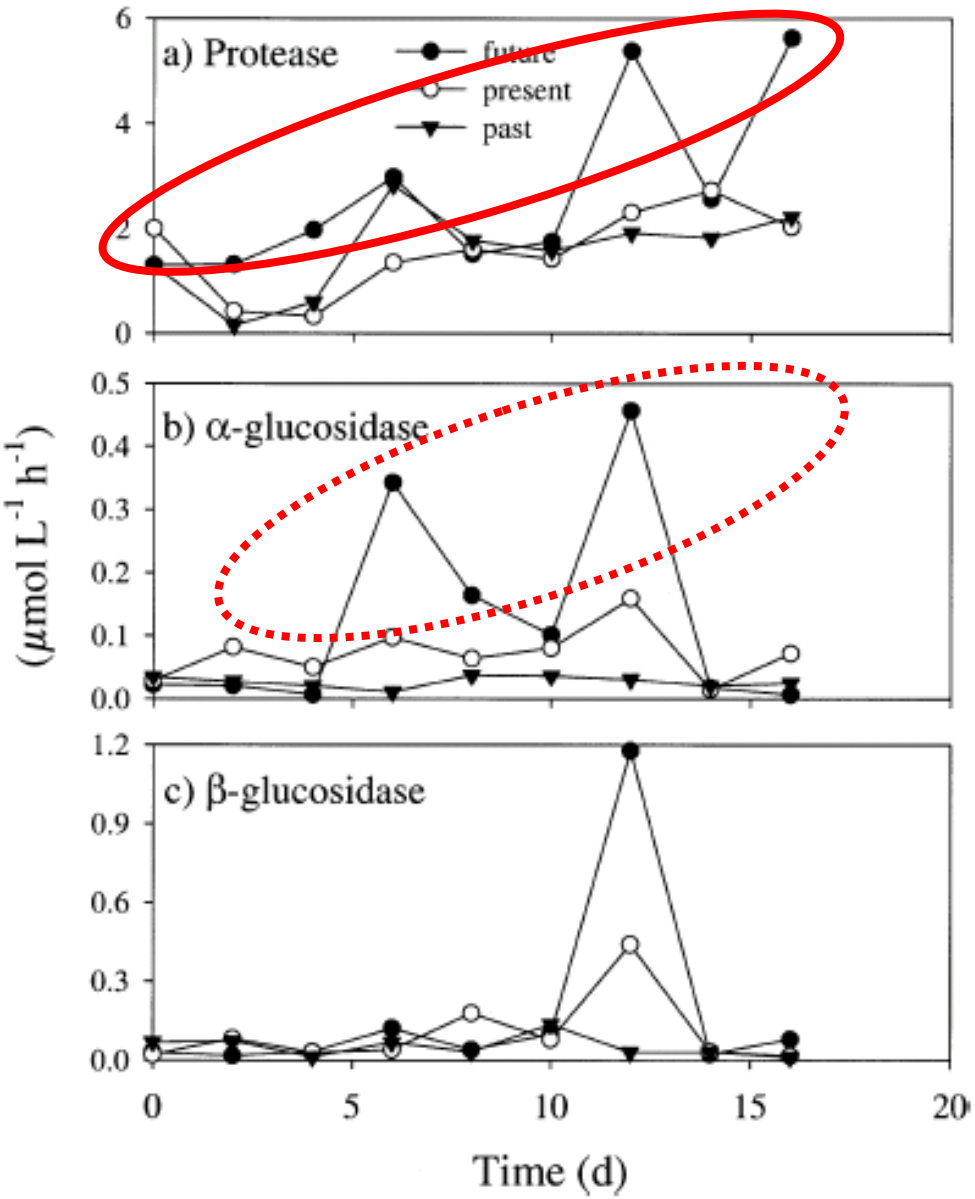
Bacteria cell multiplication in mesocosms with past, present and future CO_2



Future: higher BCM of attached bacteria, CO_2 effect

Grossart, Allgaier, Passow, Riebesell 2006

Exo-enzyme activity in mesocosms with past, present and future CO_2

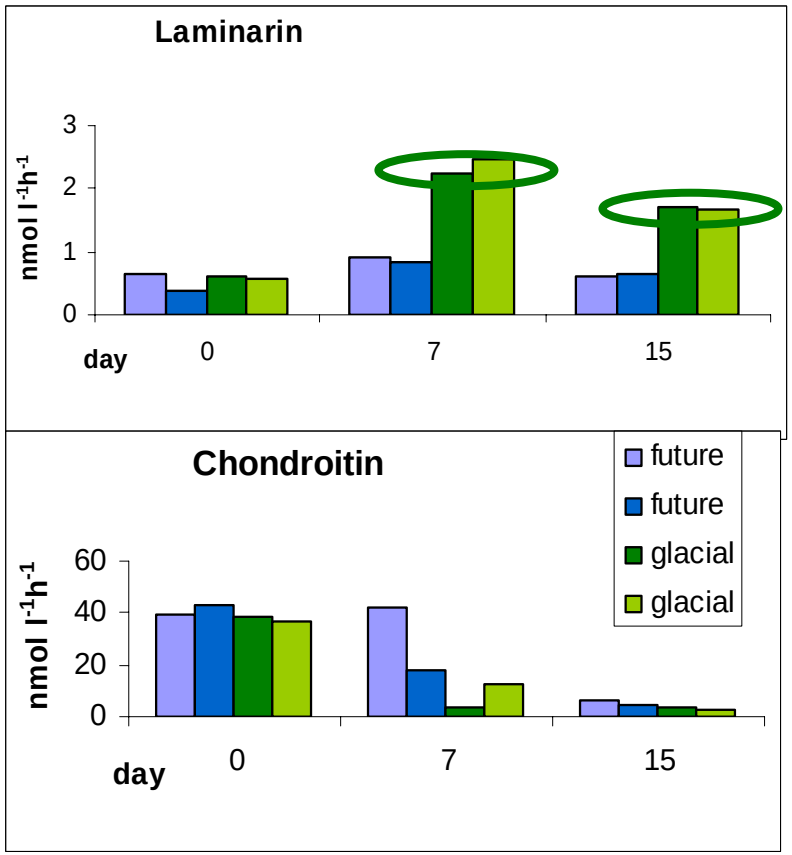


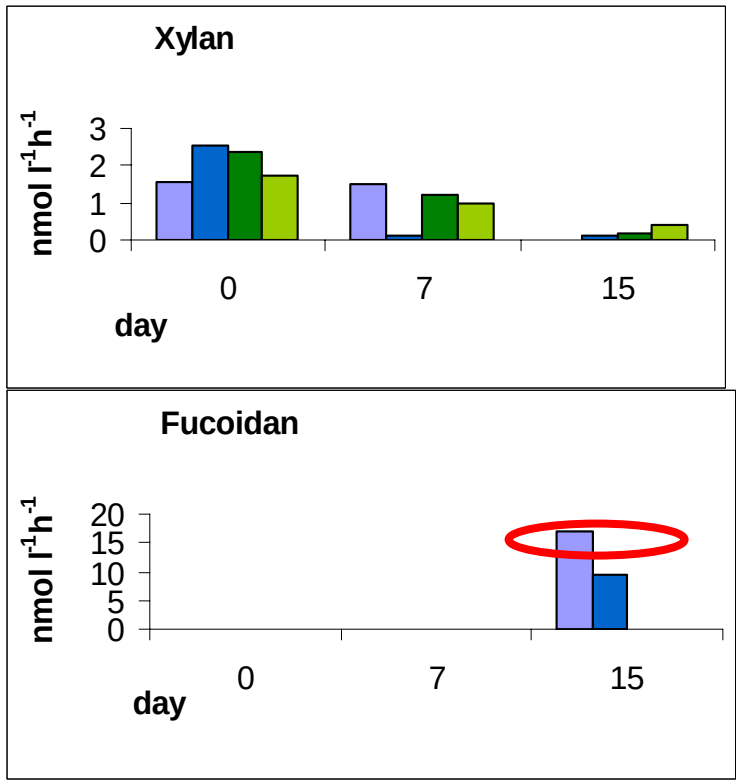
Future: higher protease activity, CO_2 effect

Grossart, Allgaier, Passow, Riebesell 2006

Exo-enzyme activity of specific complex polysaccarides

Differences in the degradation capability of specific polysaccharides, without favoring one mesocosm overall.





M.Muehling: DGGE – some bands differ between future, past and present mesocosm

Passow & Arnosti unpubl.

Summary: Microbial degradation

no CO_2 effect,
but effect of phytoplankton (indirect effect)

possibly CO_2 effect on activity

What is and has been going on?

Mesocosm experiments

Rochelle-Newall et al. 2004: 2001 Bergen no CO_2 effect on total bacterial numbers

M Allgaier, HP Grossart in prep.: 2005 Bergen: no CO_2 effect on bacterial number or productivity, but reflected in community structure of free-living bacteria. Activity and dynamics of heterotrophic bacteria, especially attached bacteria, were tightly linked to phytoplankton development.

I Joint: In 2006 microbiological mesocosm experiment studying the effect of a high CO_2 world on pelagic microbes, comparing high CO_2 and present day conditions.

Lab. experiment

Coffin et al. 2004:
experiments in the dark, deep water (no phytoplankton)

pH 6.95: enhance bacterial production
pH 5.6: suppressed bacterial production

Pretty extreme values, our future mesocosm; pH > 7.7

Impact of acidification on C-transport to depth

1. Zooplankton activity

2. Microbial degradation

3. Sinking velocity: Aggregates
    1. TEP = Transparent Exopolymer Particles
    2. Minerals

Work that needs doing

Key Controls of Sinking Velocity

$$W = (1 - P)\frac{2}{9}\frac{gr^2(\Delta\rho)}{\mu}$$

According to Stokes' Law, the sinking velocity (W) of spherical particles at low Reynold's numbers

The Terms to Watch...

$$(1-P)r^2(\Delta\rho)$$

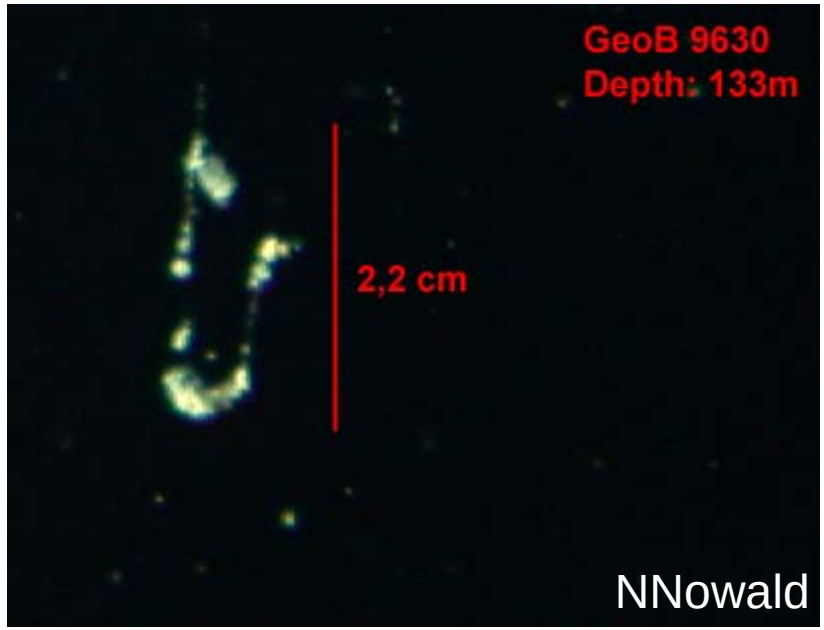
Porosity

Size

Excess density

Aggregates, [redacted]

Impact of acidification on C-transport to depth



1. Loss by Zooplankton activity

2. Microbial degradation

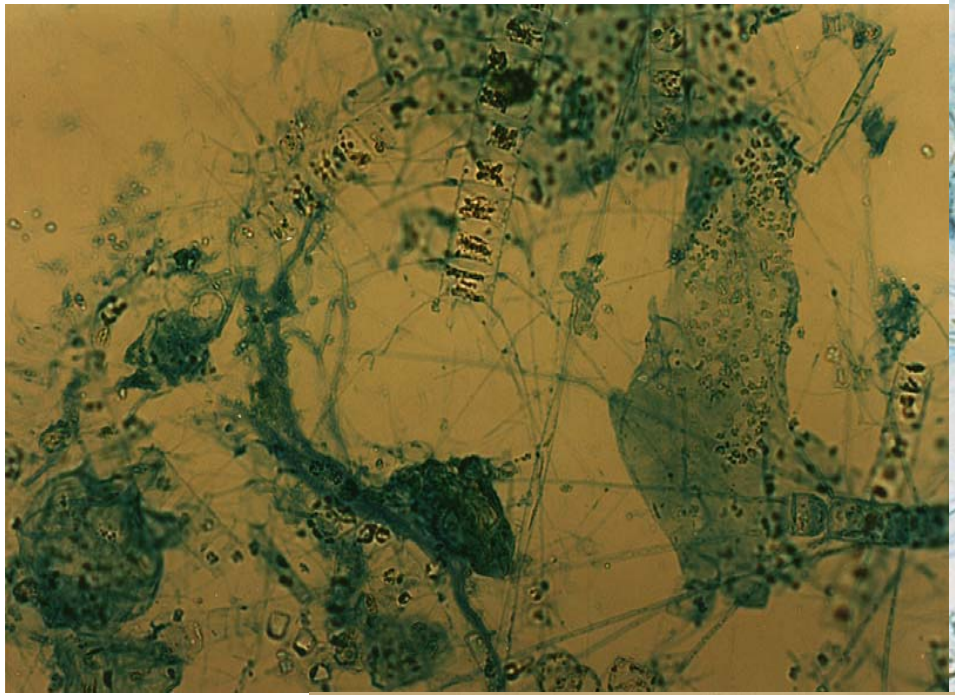
3. Sinking velocity: Aggregates (0.5mm - ..)

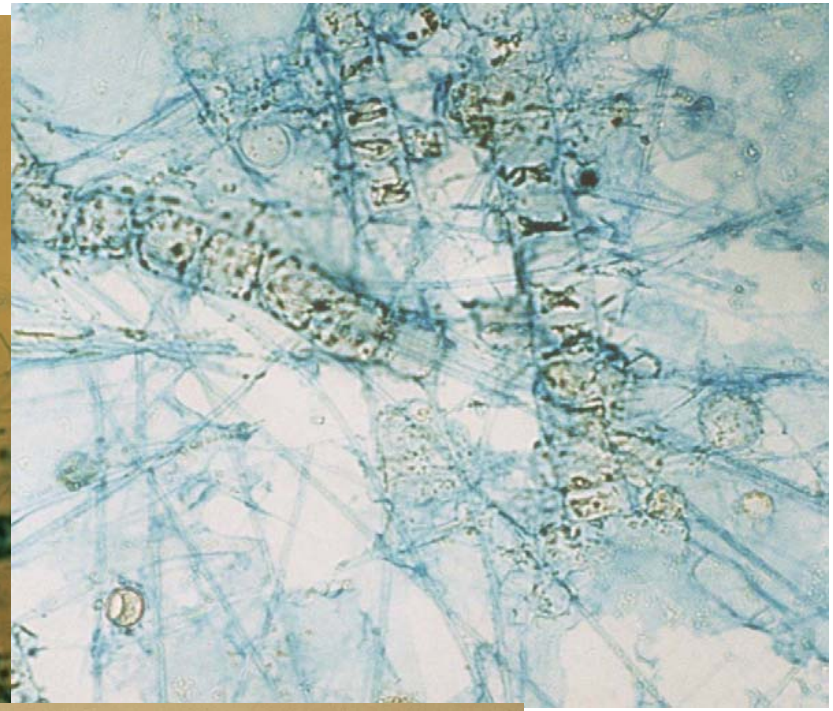
1. TEP = Transparent Exopolymer Particles

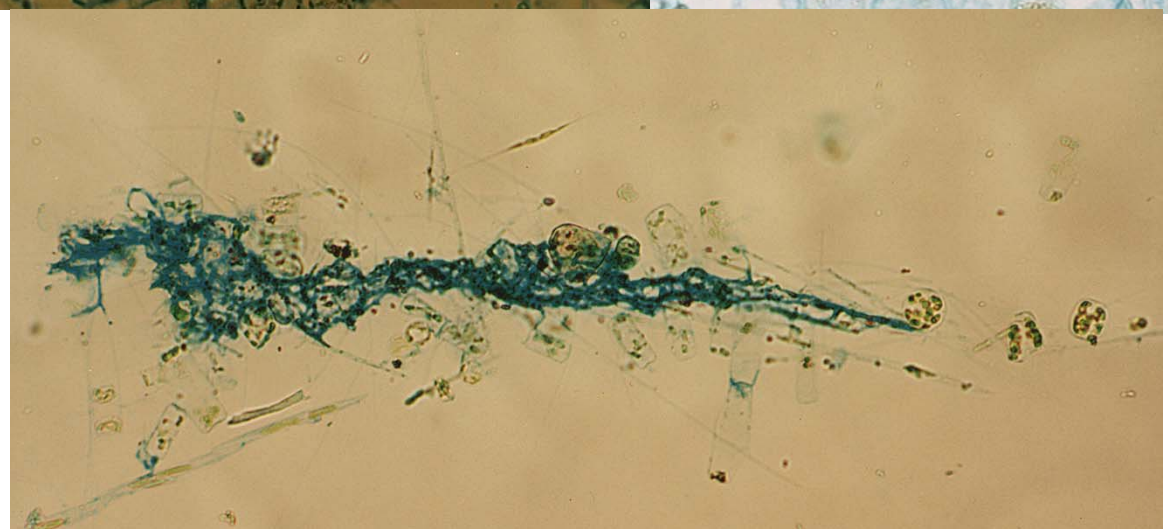
2. Minerals

Work that needs doing

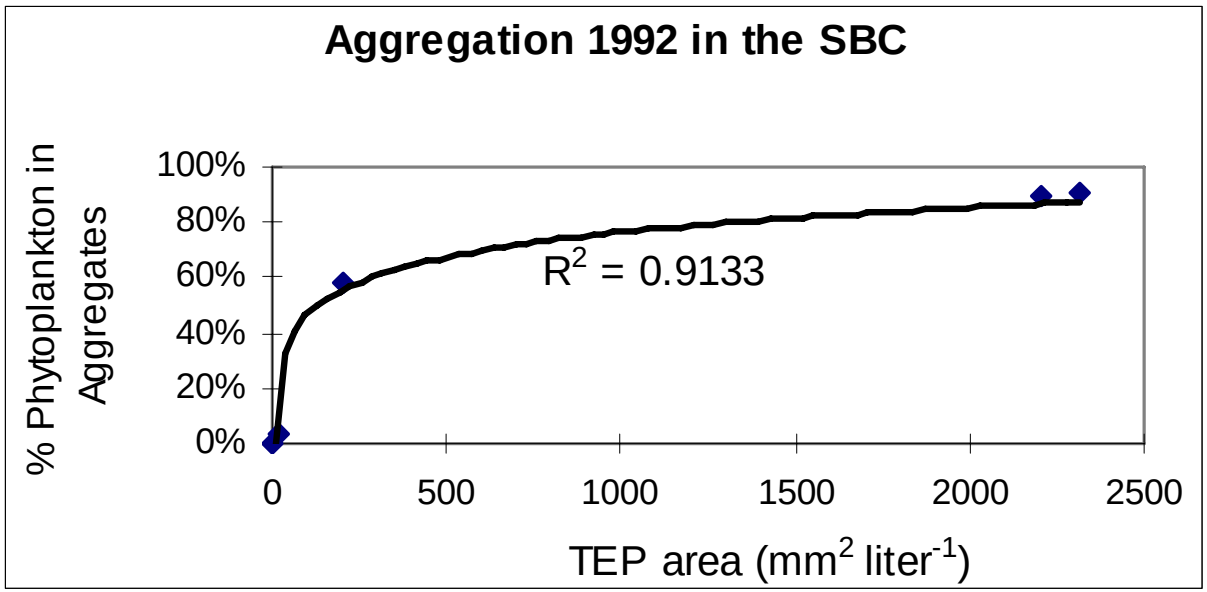
Transparent **E**xopolymer **P**articles







Aggregation and TEP



TEP are very sticky.

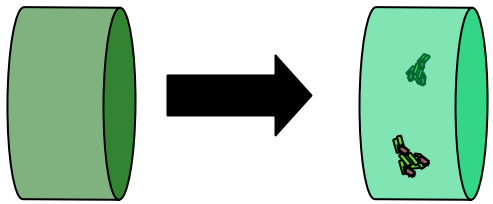
TEP provide the glue of the ocean and are essential for aggregation!

Passow et al. 94

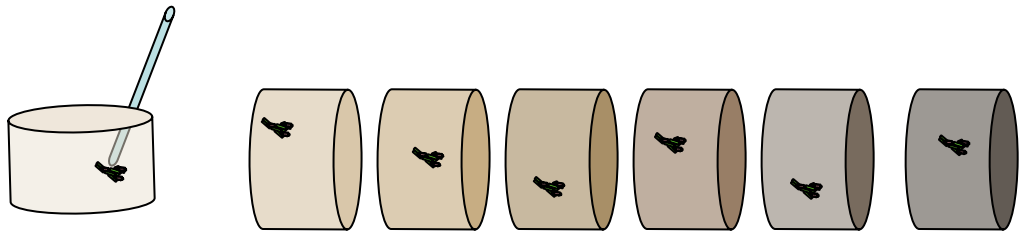
Do aggregates scavenge minerals, increasing their density, e.g. their sinking velocity?

Experimental set up

1) Make aggregates from diatoms, feces and detritus

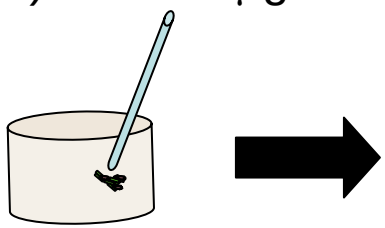


2) Transfer into ballast solutions and incubate for 48 hrs



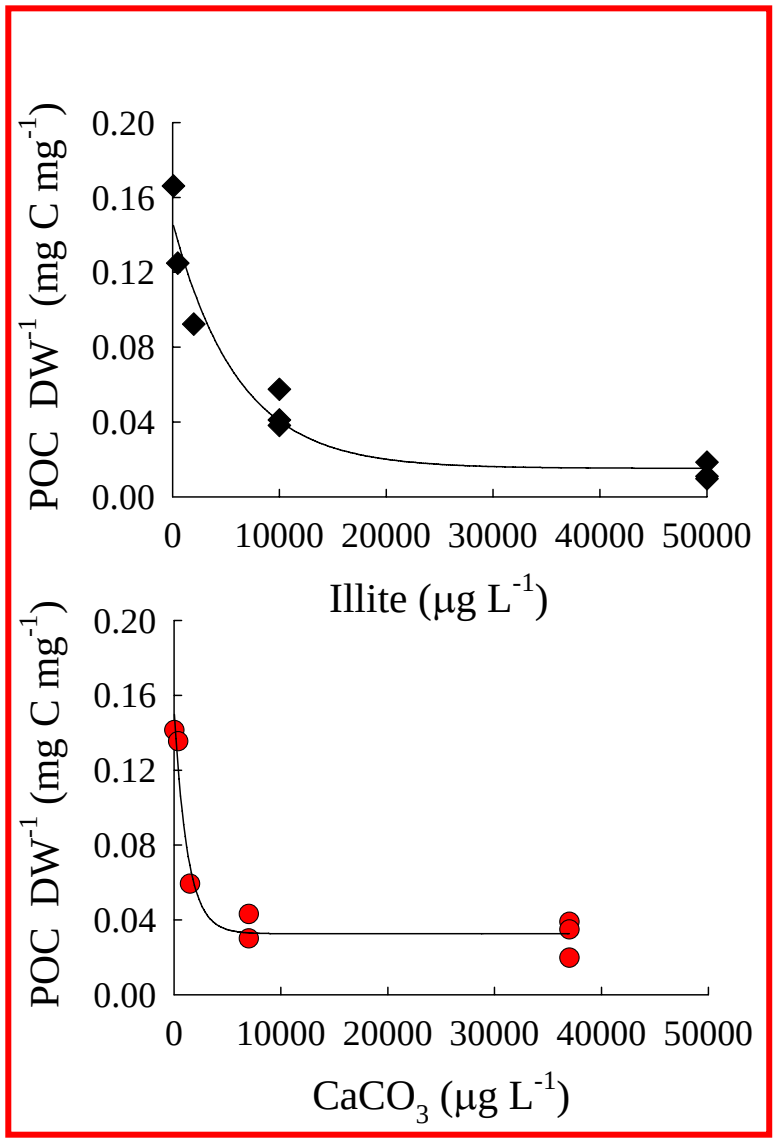
7 different mineral concentrations (illite, $CaCO_3$, opal) from 10 μg to 50 mg l^{-1}; 5 aggregates each

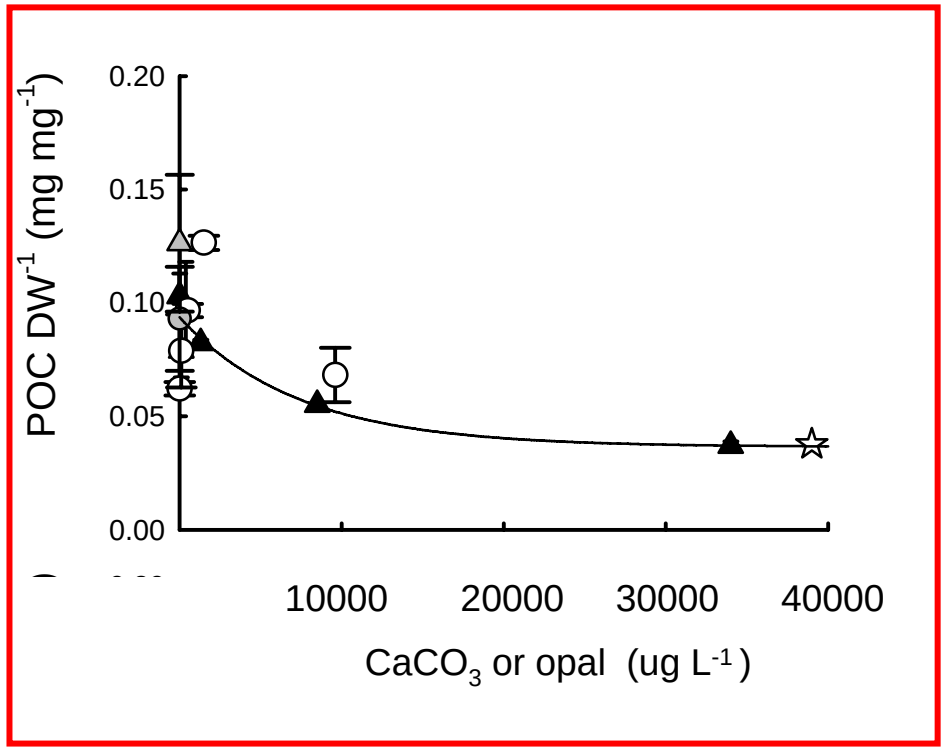
3) After 48 hrs collect aggregates, size and determine POC and DW



analysis

Saturation of Organic Aggregates With Minerals





POC: DW of ~ 5% confirms trap data

Passow & De la Rocha 2006 and unpubl.

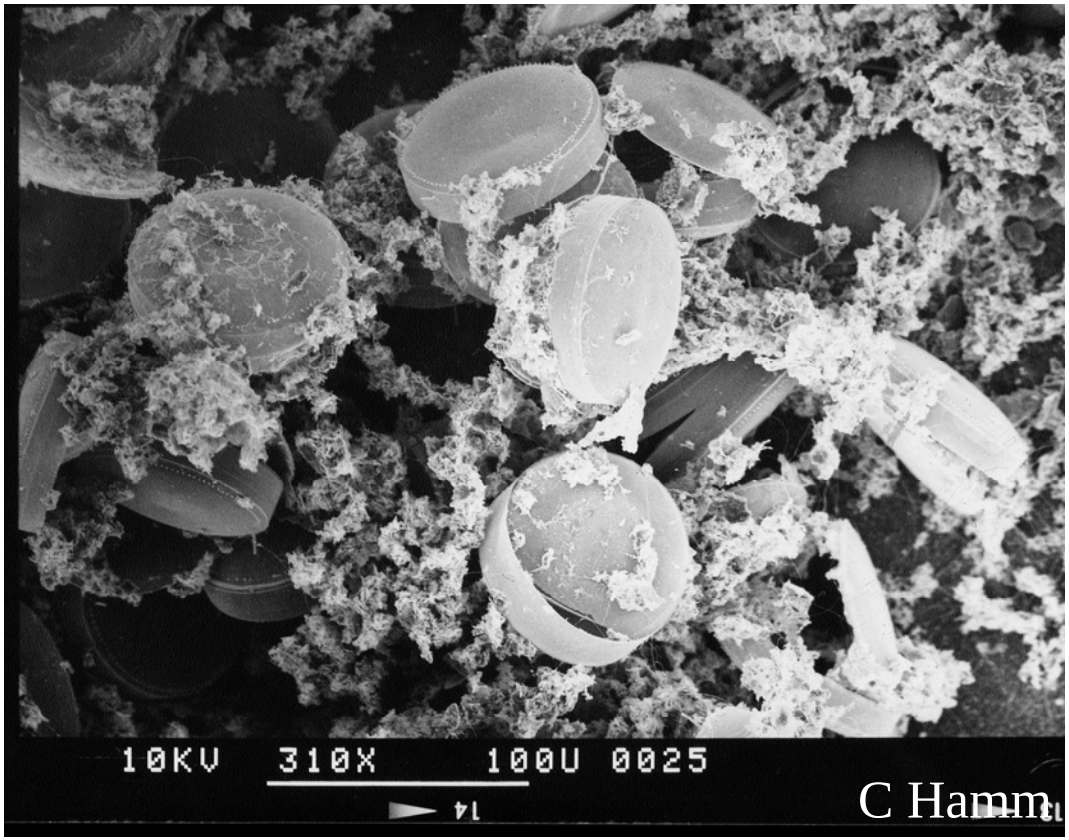
Implications

Aggs with high mineral loads should sink hundreds of times faster than those with low loads

Contribution to sinking velocity difference of

- r^2 factor of 0.1
- $\Delta\rho$ factor of 130
- (1-P) factor of 40

“Ballasting” of POC



**TEP (glue) and minerals (ballast)
are essential for the rapid sinking of aggregates,
e.g. high POC flux!**

How will ocean acidification affect this?

The sticky fraction of POC consists largely of TEP,
which are rich in acidic polysaccharides
(Mopper et al. 1995, Zhou et al. 1998).

Ocean acidification
should result in a
decrease of free acidic groups,
lowering the carrying capacity
or stickiness
of each unit of POC.

What Ocean Acidification Mean for the Deep POC Transport of the Future!

- Availability of biominerals will change (*reduced*)
- Availabity of lithogenic minerals will change (*locally increased*, *open ocean?*)
- Species composition will shift and that will impact aggregation potential (*negatively*)
- **Binding of minerals might change, changing ballasting (*negatively*)**

Collapse of biological pump?

Impact of acidification on C-transport to depth

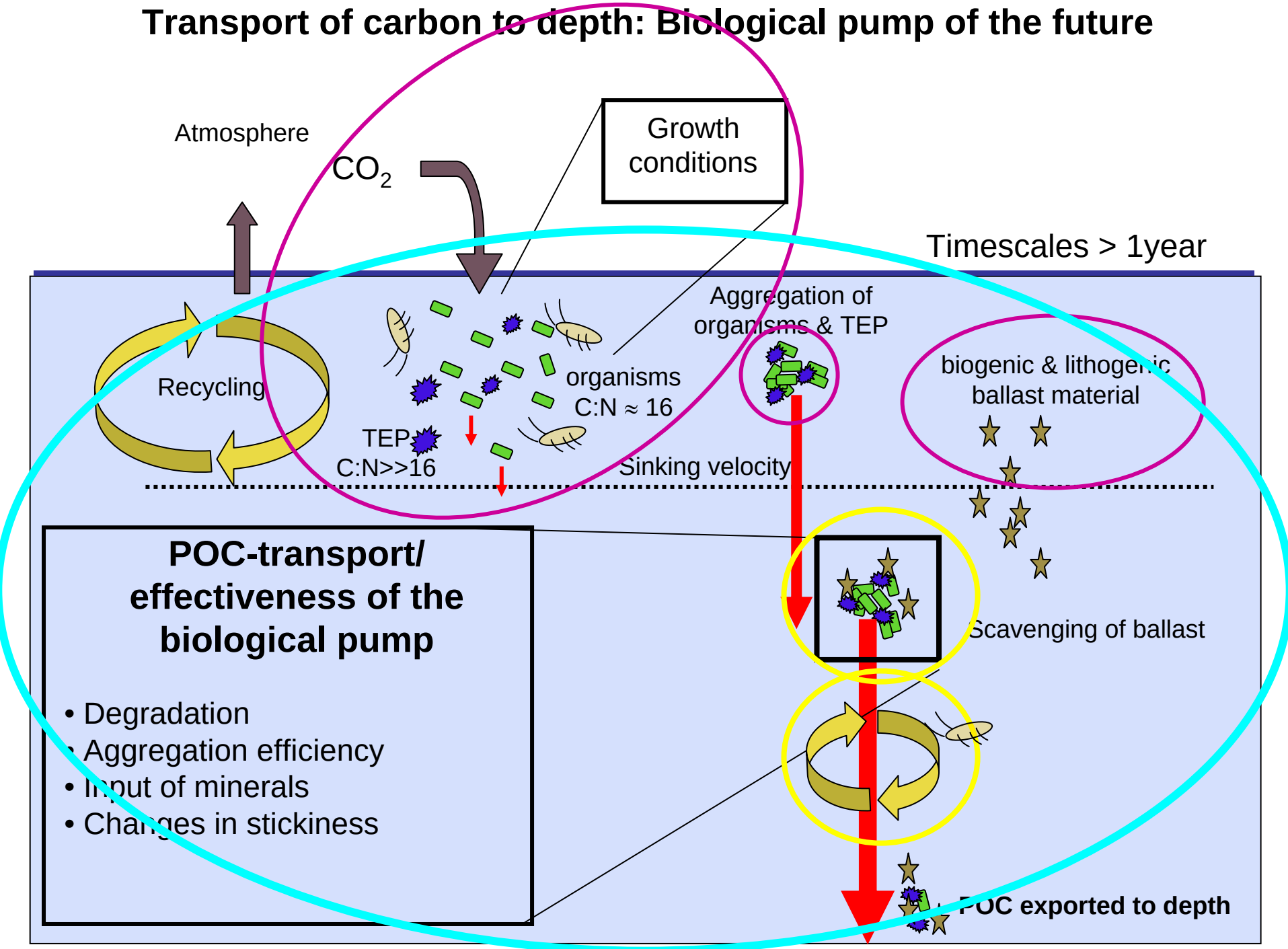
1. Zooplankton activity

2. Microbial degradation

3. Sinking velocity: Aggregates
    1. TEP = Transparent Exopolymer Particles
    2. Minerals

Work that needs doing

Transport of carbon to depth: Biological pump of the future



Proposals: Effect of ocean acidification on the efficiency of biological pump

Topic: surface ocean processes and what they means for carbon flux.
Effect on 1 production, species composition, TEP production, bio-mineral production, food web structure….

Topic: flux below the mixed layer
Change in binding capacity and consequences
Change in degradation rate
?? Zooplankton

Topic: Synthesis: modeling of interacting effects
1 D process model or spatially explicit…

Open for discussion