Increasing Biodeposition: implications for the biogeochemical cycling of Si and phytoplankton dynamics


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The importance of the element Si

Many examples:
- North Sea,
- Adriatic Sea
- Chesapeake Bay
- Mississippi river mouth
- Danube river mouth
- etc...
The Bay of Brest

Decreasing Si:N ratios

Proliferation of Crepidula fornicata

Decreasing Si:N ratios

Proliferation of Crepidula fornicata

1950

1979

1995

1976

1978

1980

1982

1984

1986

1988

1990

1992

1994

1996

1998

2000

1975

1977

1979

1981

1983

1985

1987

1989

1991

1993

1995

1997

1999

2001

Summer Si:N

NO₂ + NO₃ (µM)

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The *Crepidula* paradox in the Bay of Brest

*Crepidula* endangers the fisheries of the Great scallop

*But ...*

*Crepidula* might play an important role in the resilience of the ecosystem (few shift towards non-diatom species)

Implications, at the ecosystem level, of managing *Crepidula* ????
Nutrient inputs (N, Si, P)

The working hypothesis

Crepidula introduction

Benthos

Suspension feeders (Crepidula)

Spreading

Biodeposition

Dissolution

Nutrient inputs (N, Si, P)

Sediment

BSi storage

Differential mortality

Grazing ?

Summer: Flagellates

Si limitation

Advection: BSi exportation out of the Bay

Dissolution

Spring: Diatoms

Summer: Diatoms

Grazing

«Normal»

Perturbation
Annual cycle of DSi benthic fluxes at 2 sites with contrasted densities of *C. fornicata*

DSi fluxes are much higher at the site with *C. fornicata* than at the site without *C. fornicata*

- Facteur 2-4, spring & early summer
- Facteur 10-20, summer/fall

Evidence for temporary Si retention

Maxima occur earlier at the site without *C. fornicata*

(Ragueneau et al., 2002, L&O)
Seasonal budgets of Si fluxes in the Bay of Brest

During summer, the diatom demand depends almost exclusively on benthic DSi recycling
Now, imagine there is no more *Crepidula*...

The eradication of this invasive species is associated with a big risk of harmful algal blooms development during summer, following DSI limitation.
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The eradication of this invasive species is associated with a big risk of harmful algal blooms development during summer, following DSI limitation.
Hydrodynamical model

- 2D vertically averaged model.
- Model resolution: 150m x 150m
- Model parameters: bed friction coefficient and eddy viscosity
Biogeochemical model

- Diatoms consuming DIN and DSi
- Dinoflagellates consuming DIN
- Copepods consuming both diatoms and dinoflagellates
- Benthic suspension feeders feeding on pelagic diatoms and dinoflagellates as well as on benthic diatoms

Data: L. Guérin, G. Thouzeau
Comparison with measured data at Station R3

DIN

DSi

Chlorophylle

data from A. Lorrain, A. Leynaert
Measured and modeled benthic DSi fluxes
Measured and modeled benthic DSi fluxes
Measured and modeled benthic DSi fluxes

- With C. fornicata
- Without C. fornicata

Si(OH)₄ benthic flux (mmol m⁻² d⁻¹)

May, June, July, September, November

Time:
- Jan-04
- Avr-04
- Juil-04
- Oct-04
Importance of biodeposition in the annual Si cycle in the Bay of Brest

Biodeposition represents 84% of annual DSi delivery by rivers
27% of BSiO$_2$ biodeposited accumulates annually
Importance of biodeposition in the annual Si cycle in the Bay of Brest

Biodeposition represents 84% of annual DSi delivery by rivers. 27% of BSiO$_2$ biodeposited accumulates annually.
Perspectives in the Bay of Brest

Evidence from process studies, biogeochemical budgeting and ecological modeling, that *Crepidula* plays a major role in the ecosystem.

Coupling of whatershed, river and Bay of Brest models in the MOITEM project, funded by the region Brittany.

Scenarios of changing agricultural practices and removing *Crepidula* from the ecosystem.
Evidence of *Crepidula* invasion in the sediments?

Because BSiO$_2$ preservation is so good in *Crepidula* mats …
Increasing biodeposition and silica depletion

Two routes in the « silica-depletion » hypothesis

Historical changes in DSi concentrations in Lake Michigan (redrawn from Schelske, 1988)

Testing the idea that increasing biodeposition might be a third route in the « silica depletion » hypothesis

Historical changes in DSi concentrations in the coastal Black Sea (redrawn from Humborg et al., 1997)
A question for you:

Do you know any ecosystem, where:

- Biodeposition is increasing, due to the proliferation of benthic suspension feeders (accidental or aquaculture purposes)
- The residence time of the ecosystem is long enough
- There exist a monitoring station seaward of the invasion, where we could look for long-term changes in DSi concentrations
Seasonal Si budgets in the Bay of Brest

Confirmation: summer benthic fluxes sustain most of diatom production
Seasonal Si budgets in the Bay of Brest

Confirmation: summer benthic fluxes sustain most of diatom production
Modification of the Si cycle with eutrophication and river manipulation

Historical changes in DSi concentrations in Lake Michigan (redrawn from Schelske, 1988)

Historical changes in DSi concentrations in the coastal Black Sea (redrawn from Humborg et al., 1997)

Two ways for the silica depletion hypothesis
Invasive species: their importance in the functioning of coastal ecosystems

Invasion of San Francisco Bay by the Asiatic clam, *Potamocorbula*. Colonization by this filter-feeding organism has led to depletions of phytoplankton in the North Bay.
Invasive species: their importance in the functioning of coastal ecosystems

Time series images of Saginaw Bay, Lake Huron, for the post-Dreissena (1992-1993) versus pre-Dreissena (1991) period. Seston concentrations were uniformly lower in the post-Dreissena years (from Budd et al., 2001)

Dreissena polymorpha
Invasive species: their importance in biogeochemical cycles

Bivalve mollusks strongly influence the cycling of several elements such as C (Doering et al., 1987), N (Dame et al., 1991), P (Asmus et al., 1995), S (Hansen et al., 1996) and inorganic C (Chauvaud et al., in press).

Quid of the element Si?
Outline of the presentation

1. Suspension feeders and the Si cycle: *evidence* for a seasonal effect of this interaction on phytoplankton dynamics

2. Suspension feeders and the Si cycle: *hypothesis* for a third route along this silica depletion hypothesis

3. Perspectives in the context of increasing biodeposition
Outline of the presentation

1. Suspension feeders and the Si cycle: evidence for a seasonal effect of this interaction on phytoplankton dynamics

2. Suspension feeders and the Si cycle: hypothesis for a third route along this silica depletion hypothesis

3. Perspectives in the context of increasing biodeposition
Si and C decoupling through *Crepidula*

1. Preliminary calculation

Net sedimentation (Jean, 1994):
- 9 mol C m$^{-2}$ yr$^{-1}$

Biodeposition by *C. fornicata*
(Chauvaud, 1998):
- 800,000 t of wet OM
- 11,000 t of dry OM
- 3.5 mol C m$^{-2}$ yr$^{-1}$

40% of C net sedimentation

<table>
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<th>C</th>
<th>Si</th>
<th>Si:C</th>
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<td>10</td>
<td>0.1</td>
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<tr>
<th>C</th>
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<tr>
<td>40</td>
<td>10</td>
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The Si:C molar ratio is increasing by a factor 2.5

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**Si and C decoupling through *Crepidula***

1. **Preliminary calculation**

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$40 \%$ of C net sedimentation

The Si:C molar ratio is increasing by a factor 2.5
Si and C decoupling through *Crepidula*

2. Experimental confirmation

- **Chaetoceros calcitrans**
  - $\text{Si:C} = 0.05$

- **Crepidula fornicata**
  - $\text{Si:C} = 0.12$

- **Faeces**
  - $\text{Si:C} = 0.05$
Annual Si budget in the Bay of Brest

- **Aulne and Elorn rivers**
  - Annual C sedimentation: 9 mol m\(^{-2}\) yr\(^{-1}\)
  - Si:C ratio in phytoplankton: 0.07
  - Si:C increasing factor through Crepidula: 2.5
  - Annual C biodeposition: 3.5 mol m\(^{-2}\) yr\(^{-1}\)

- **Bay of Brest**
  - BF (0.52)

- **Iroise Sea**
  - E (0.64-0.75)

- **Direct measurement**

- **Difference**
  - Annual C accumulation: 0.32 mol m\(^{-2}\) yr\(^{-1}\)
  - Si:C ratio in shelf sediments: 0.6
On the importance of biodeposition in Si accumulation in the Bay of Brest

1. Annual Si biodeposition represents 72% of annual river inputs
2. Annual Si accumulation represents 13-32% of Si biodeposition
3. Annual Si accumulation represents 10-23% of annual river inputs
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Invasive species: an increasing global concern

World aquaculture production: Mollusks

The aquaculture example
Invasive species: an increasing global concern

The example of increasing accidental proliferation
Conclusions

1. We have provided evidence for a strong influence of a benthic suspension feeder onto phytoplankton seasonal dynamics,

2. We have proposed a third route in the silica-depletion hypothesis, which does not require enhanced diatom production, but rather enhanced Si retention owing to increasing biodeposition with the proliferation of invasive species of suspension feeders,

3. We believe it is worth testing this hypothesis (e.g. by coring below suspension feeders mats to search for past changes in BSi accumulation), in the present context of increasing proliferation of invasive species.
Testing the hypothesis