Silica: an essential nutrient in wetland biogeochemistry

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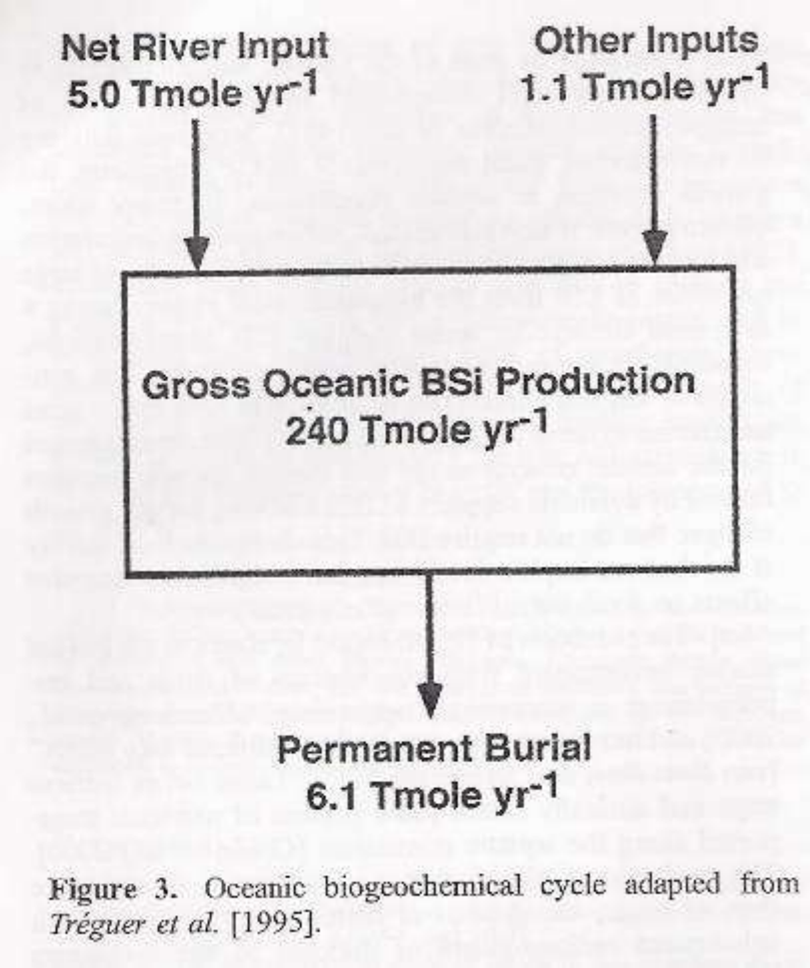
Why study the Si cycle?

Ocean Si pump



Net River Input
5.0 Tmole yr^{-1}

Other Inputs
1.1 Tmole yr^{-1}

Gross Oceanic BSi Production
240 Tmole yr^{-1}

Permanent Burial
6.1 Tmole yr^{-1}

Figure 3. Oceanic biogeochemical cycle adapted from *Tréguer et al.* [1995].

Biological C pump
~ Biological Si pump

Balanced by input from terrestrial environment

Diatoms need Si

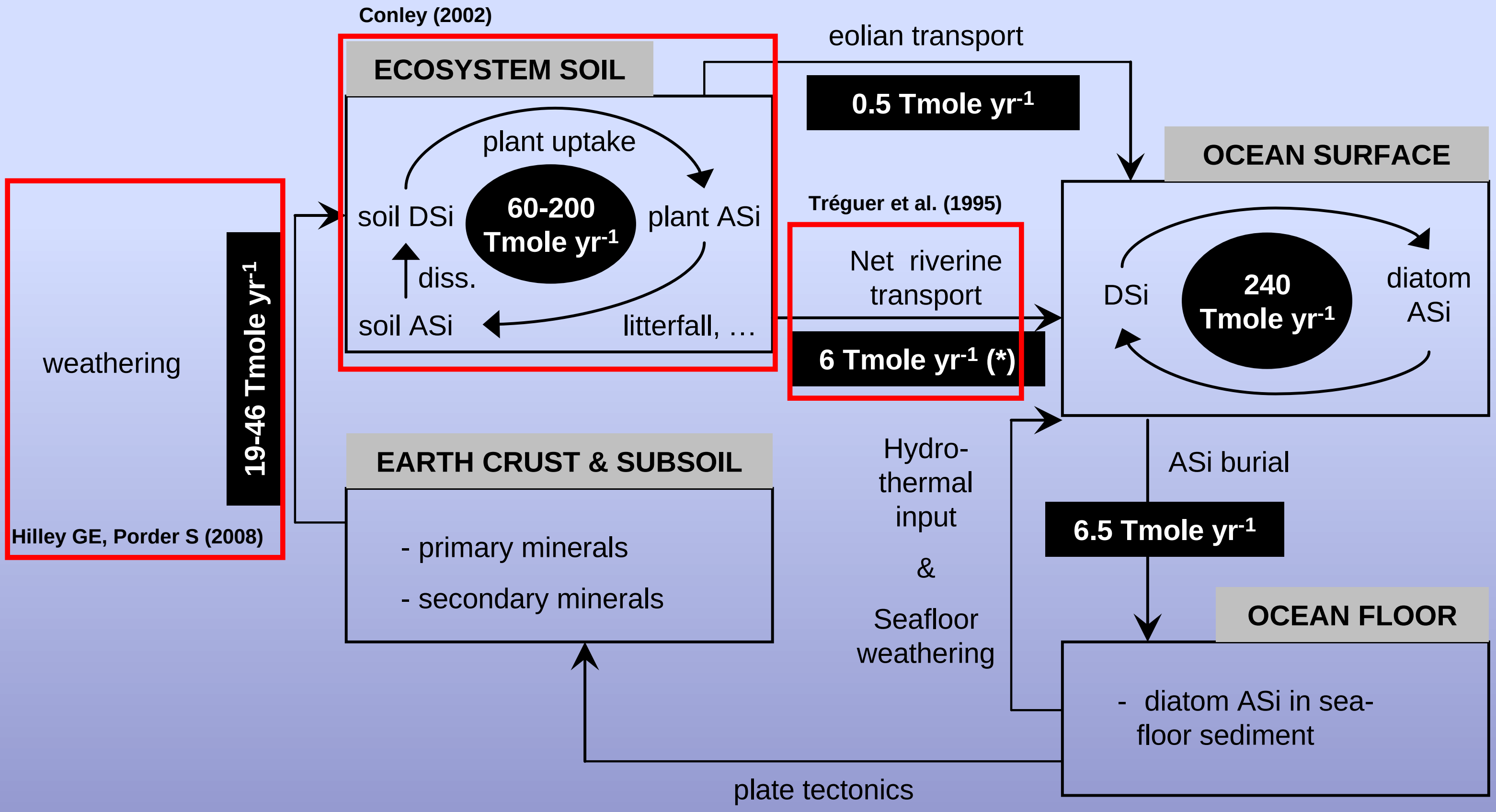
N/P/Si nutrient ratio determines coastal phytoplankton community composition

N and P input strongly enhanced

Shifts in phytoplankton communities

The biological Si buffer

Most weathered Si is taken up by biota/ecosystems (ASi)



Conley (2002)

ECOSYSTEM SOIL

plant uptake

soil DSi

60-200 Tmole yr^{-1}

plant ASi

diss.

soil ASi

litterfall, …

eolian transport

0.5 Tmole yr^{-1}

OCEAN SURFACE

DSi

240 Tmole yr^{-1}

diatom ASi

Tréguer et al. (1995)

Net riverine transport

6 Tmole yr^{-1} (*)

weathering

19-46 Tmole yr^{-1}

Hilley GE, Porder S (2008)

EARTH CRUST & SUBSOIL

- primary minerals
- secondary minerals

Hydro-thermal input

&

Seafloor weathering

ASi burial

6.5 Tmole yr^{-1}

OCEAN FLOOR

- diatom ASi in sea-floor sediment

plate tectonics

Struyf et al., Silicon, 2010 (in press)

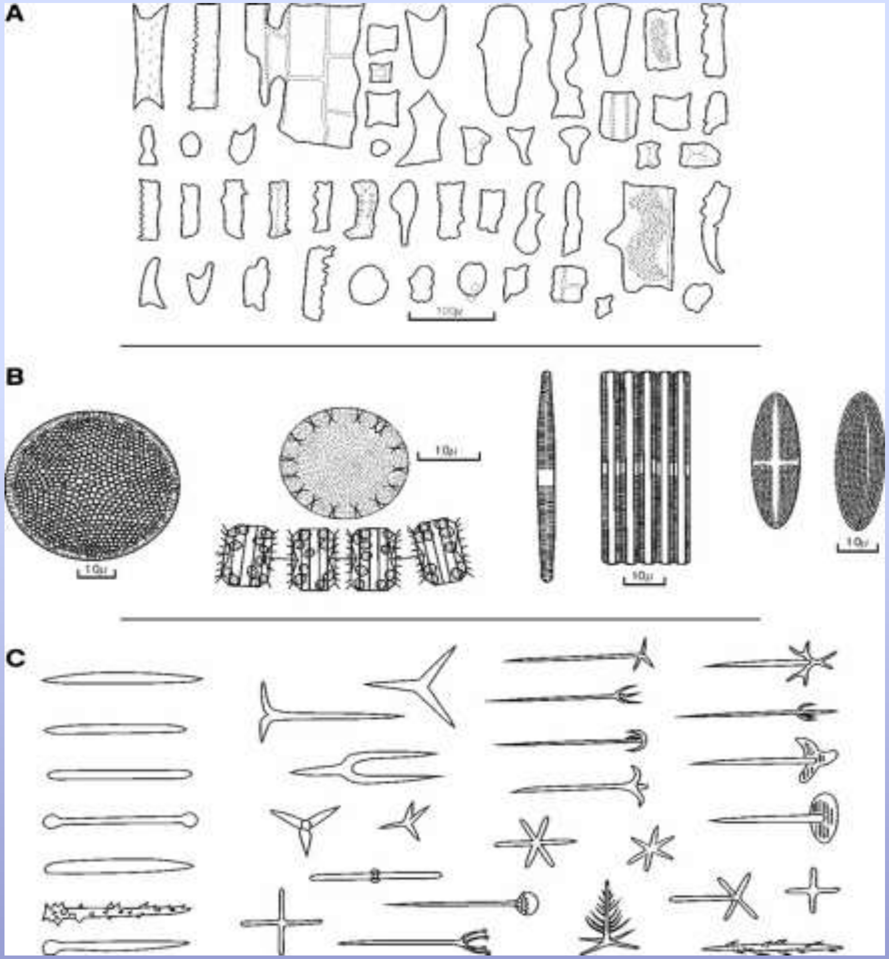
New paradigm

Actual Si export of terrestrial environment is leakage from biological cycle (Conley 2002)

Bio-Si buffer needs to be included in “weathering controlled” models for terrestrial-aquatic Si-links

Silica in wetlands?

All the biological amorphous Si is there



Phytoliths

Diatoms

Sponges

Clarke, Earth-Science Reviews, 2003

Large eco-economical value

Zedler JB, Frontiers Ecol Environ, 2003

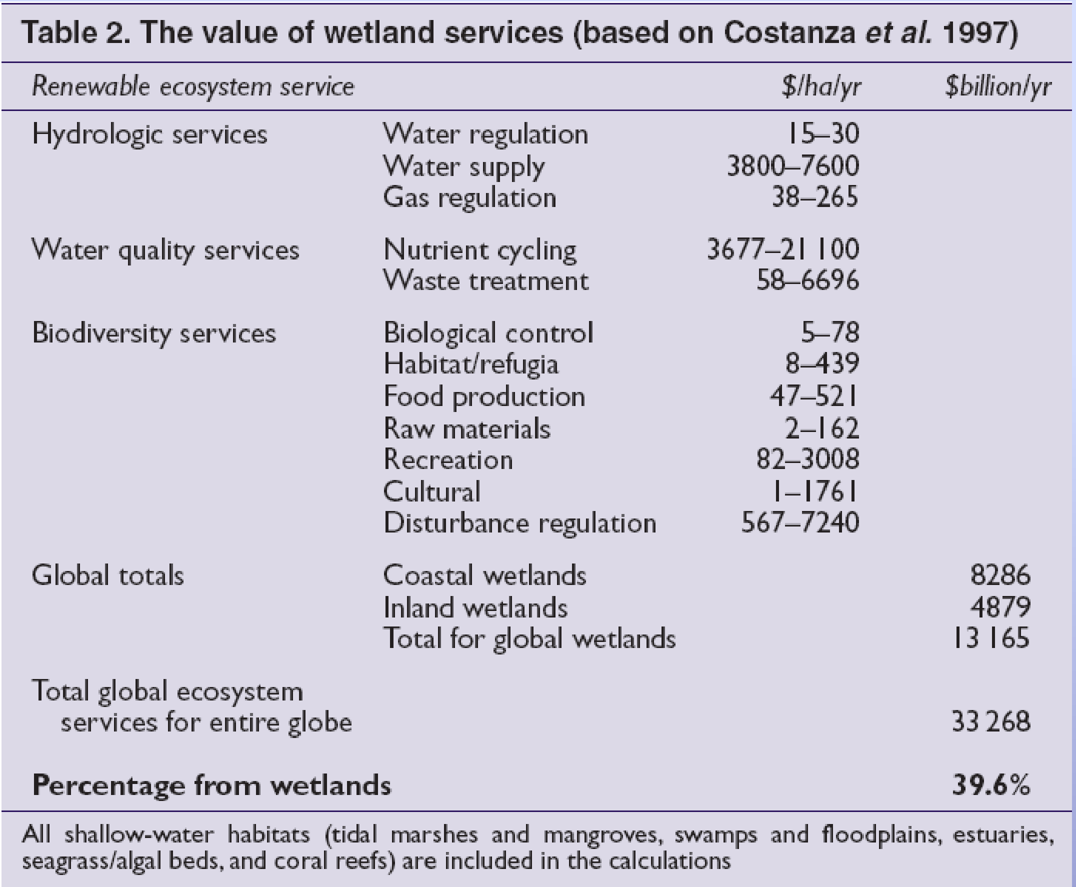


Table 2. The value of wetland services (based on Costanza *et al.* 1997)

Renewable ecosystem service		*$/ha/yr*	*$billion/yr*
Hydrologic services	Water regulation	15–30	
	Water supply	3800–7600	
	Gas regulation	38–265	
Water quality services	Nutrient cycling	3677–21 100	
	Waste treatment	58–6696	
Biodiversity services	Biological control	5–78	
	Habitat/refugia	8–439	
	Food production	47–521	
	Raw materials	2–162	
	Recreation	82–3008	
	Cultural	1–1761	
	Disturbance regulation	567–7240	
Global totals	Coastal wetlands		8286
	Inland wetlands		4879
	Total for global wetlands		13 165
Total global ecosystem services for entire globe			33 268
Percentage from wetlands			**39.6%**

All shallow-water habitats (tidal marshes and mangroves, swamps and floodplains, estuaries, seagrass/algal beds, and coral reefs) are included in the calculations

Wetlands control N and P fluxes:

the most important ecosystem function

Literature

In our review: (Frontiers in Ecology and Environment, 2009)

Journal Wetlands,1981-2007 abstract hits for:

N: ***92***, P: ***88***

Silicon, silica, silicate: ***3***

A virtually unstudied role!

Most data now exist for tidal marshes

→ **Close connection to coastal zone and diatom productivity: importance in eutrophication, food webs**

In this presentation

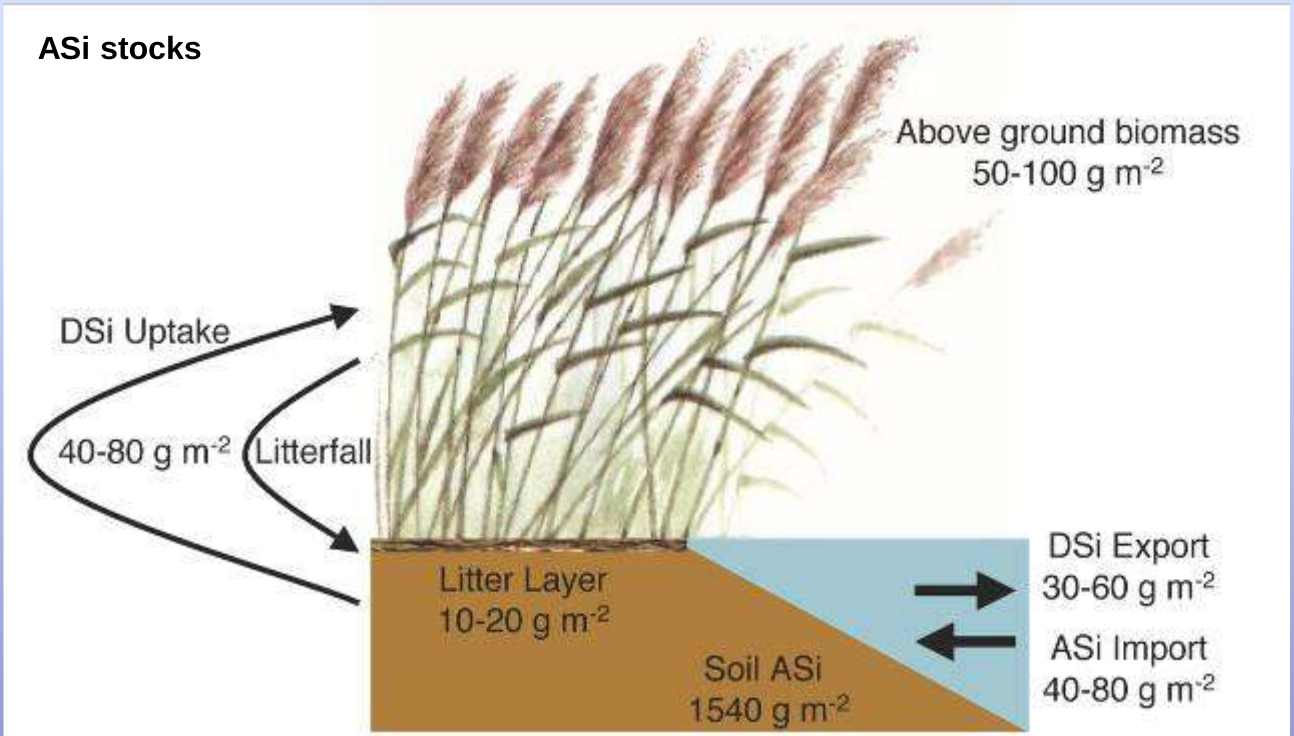

Scheldt tidal marshes


Bierbza NP (Poland)


Boreal wetlands (Sweden)

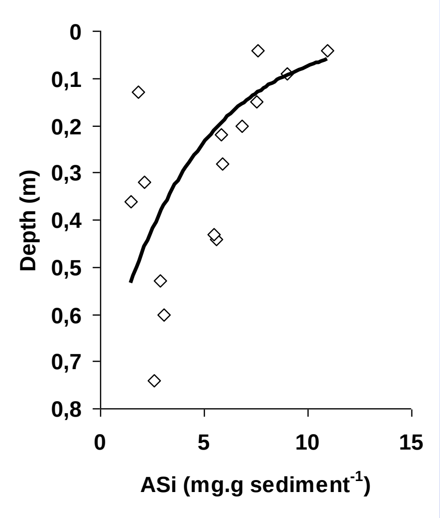
Tidal marshes: Si sinks and fluxes

Silica cycle was studied in detail in *Phragmites australis* dominated freshwater tidal marsh (Belgium): 2002-2006

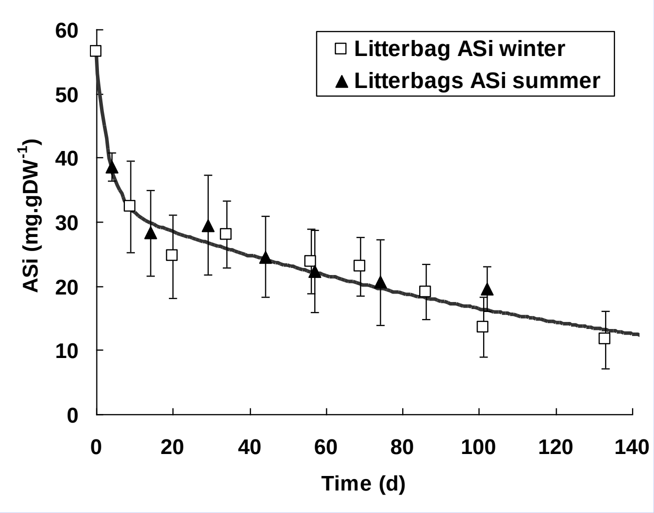


Struyf & Conley, Front. Ecol. Environ., 2009

Biologically controlled cycle



Struyf et al., Biogeochemistry, 2007



Struyf et al., Aquatic Botany, 2007

Sediment
Storage: +/- 1500 g ASi m^{-2}
Recycling: 30 – 60 g DSi y^{-1} m^{-2}

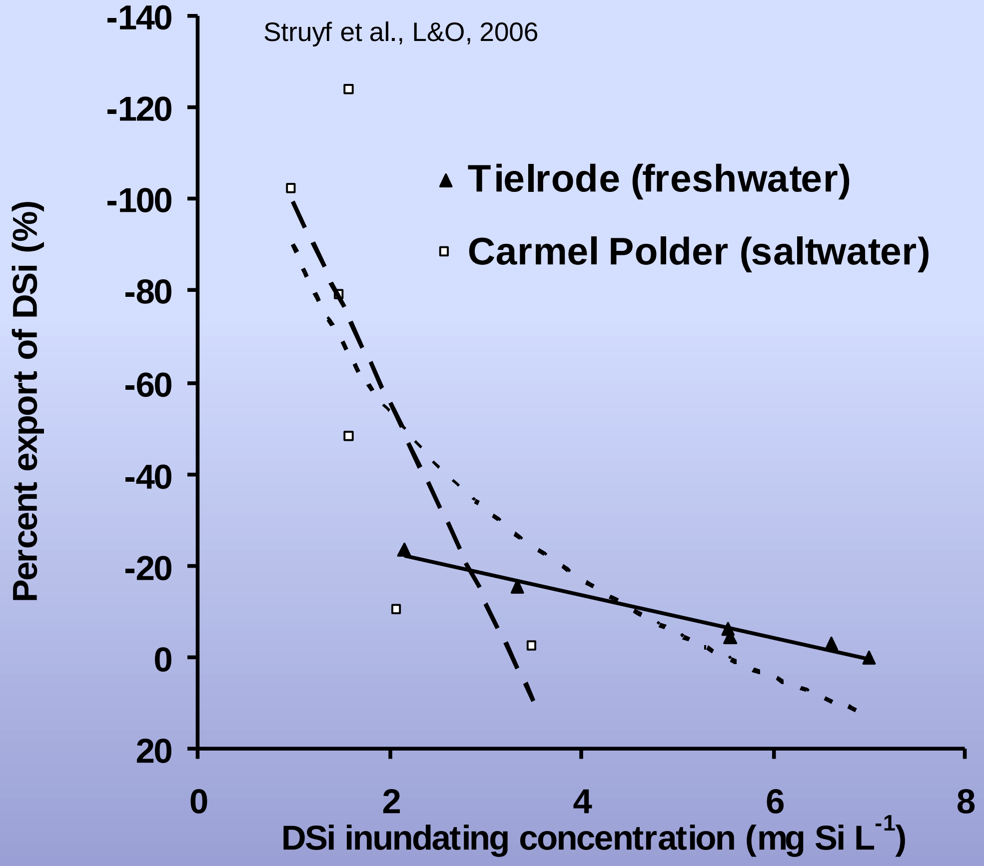
Slow recycling
40% permanently buried

Vegetation
Storage: 40 - 80 g ASi m^{-2}
Recycling: 40 – 80 g DSi y^{-1} m^{-2}

Quick and complete recycling

mineral weathering < 0.1 g m^{-2}
Complete biological control of the silica export from the wetland and cycling within marsh

Tidal marshes as silica buffers



Marshes export DSi

Export highest when DSi depleted

Buffer systems in estuarine Si cycling

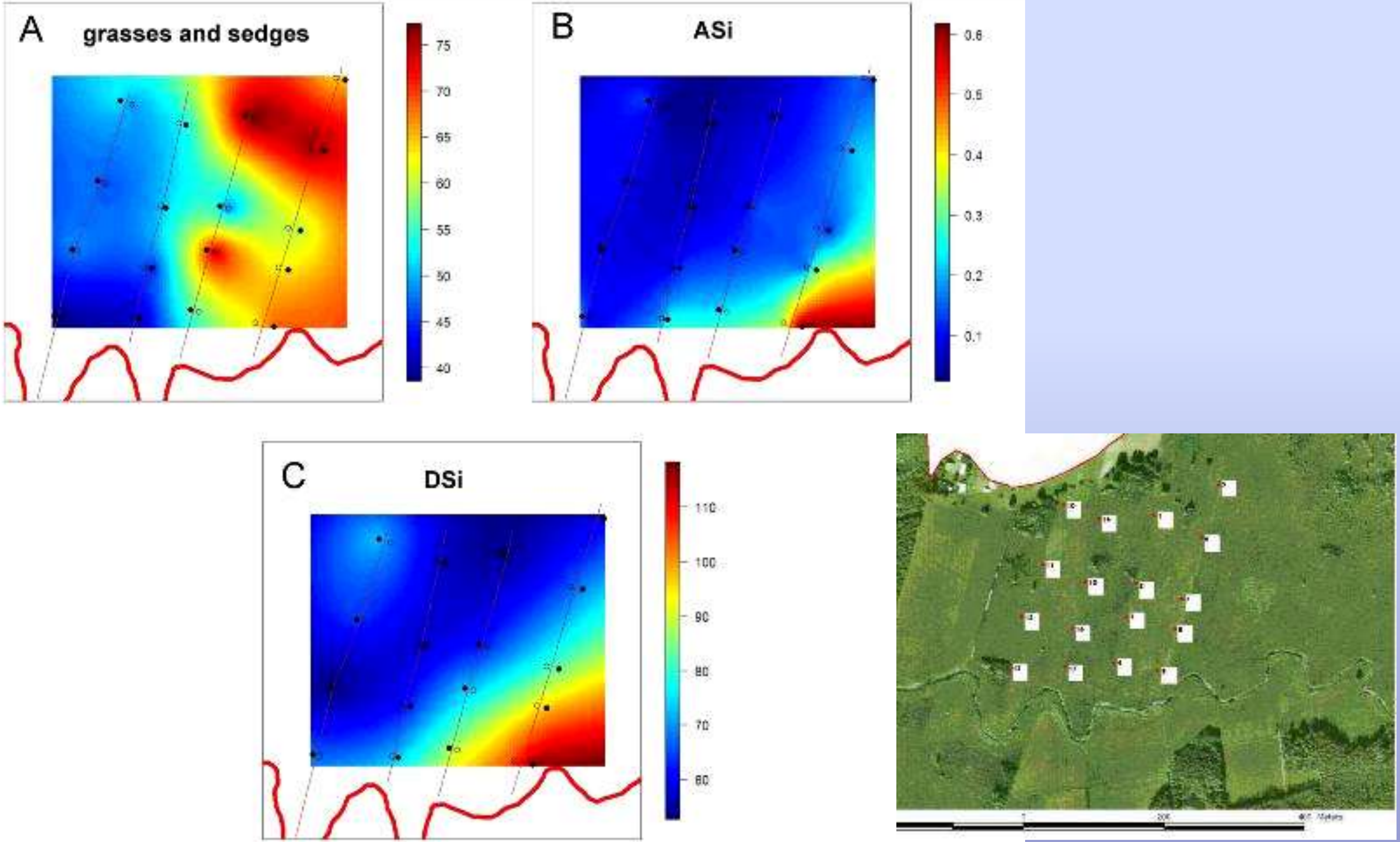
A biologically controlled mechanism

Biebrza National Park

One of the last pristine wetland areas in Central-Europe

All agriculture is traditional and extensive, both “virgin” and “influenced” areas

Biological controlling mechanisms



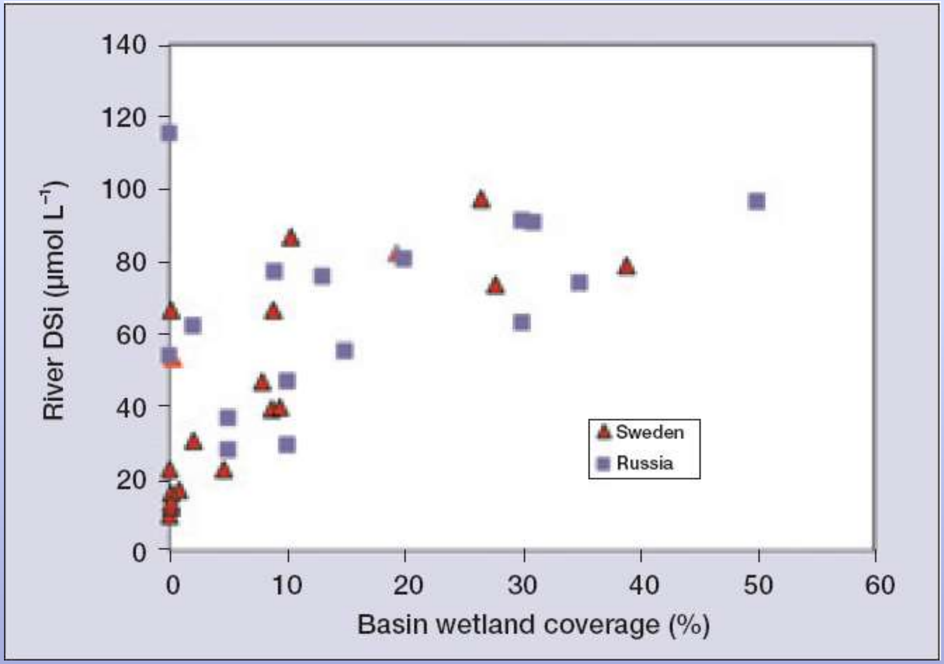
Struyf et al., Biogeosciences, 2009

Subarctic wetlands

Stordalen, Abisko, Sweden

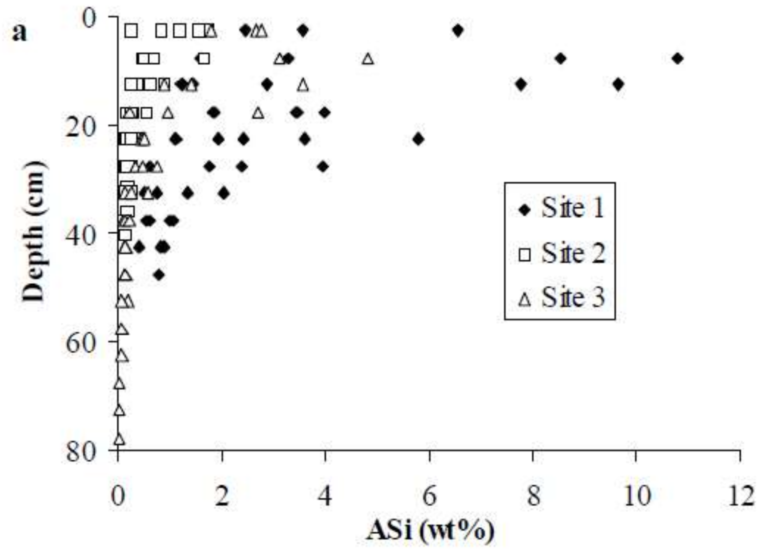
Muddus National Park, Sweden

Russia and Sweden



Struyf & Conley, Front. Ecol. Environ., 2009

The boreal wetland ASi stockpile



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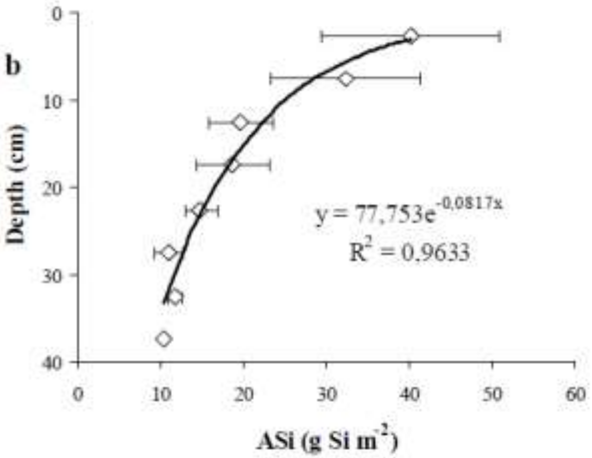


The lithology model

Lithology based model PhREEQCI
Inverse model based on weathering product ratios
30 years of monthly DSi flux data

*Uptake of DSi into bio-Si net accounts for **~ 37%** of weathering produced DSi at base-flow*

But: *automatically assigns biologically recycled DSi to lithological phase*

Actual control: >> 50 % of DSi fluxes?

Biological **uptake** increases **export** ??

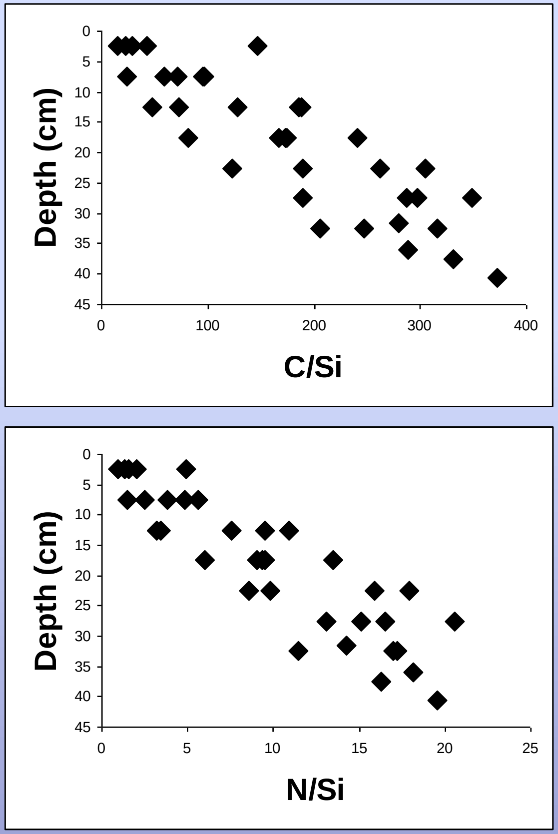
- Net release from a historically build-up buffer

OR

- **Stimulation silicate mineral weathering** by sedge vegetation (ligands, bio-acids)

Subsequent **quick cycling** and release from the ASi rich peat

Ratio with other nutrients indicates "leaky reservoir"



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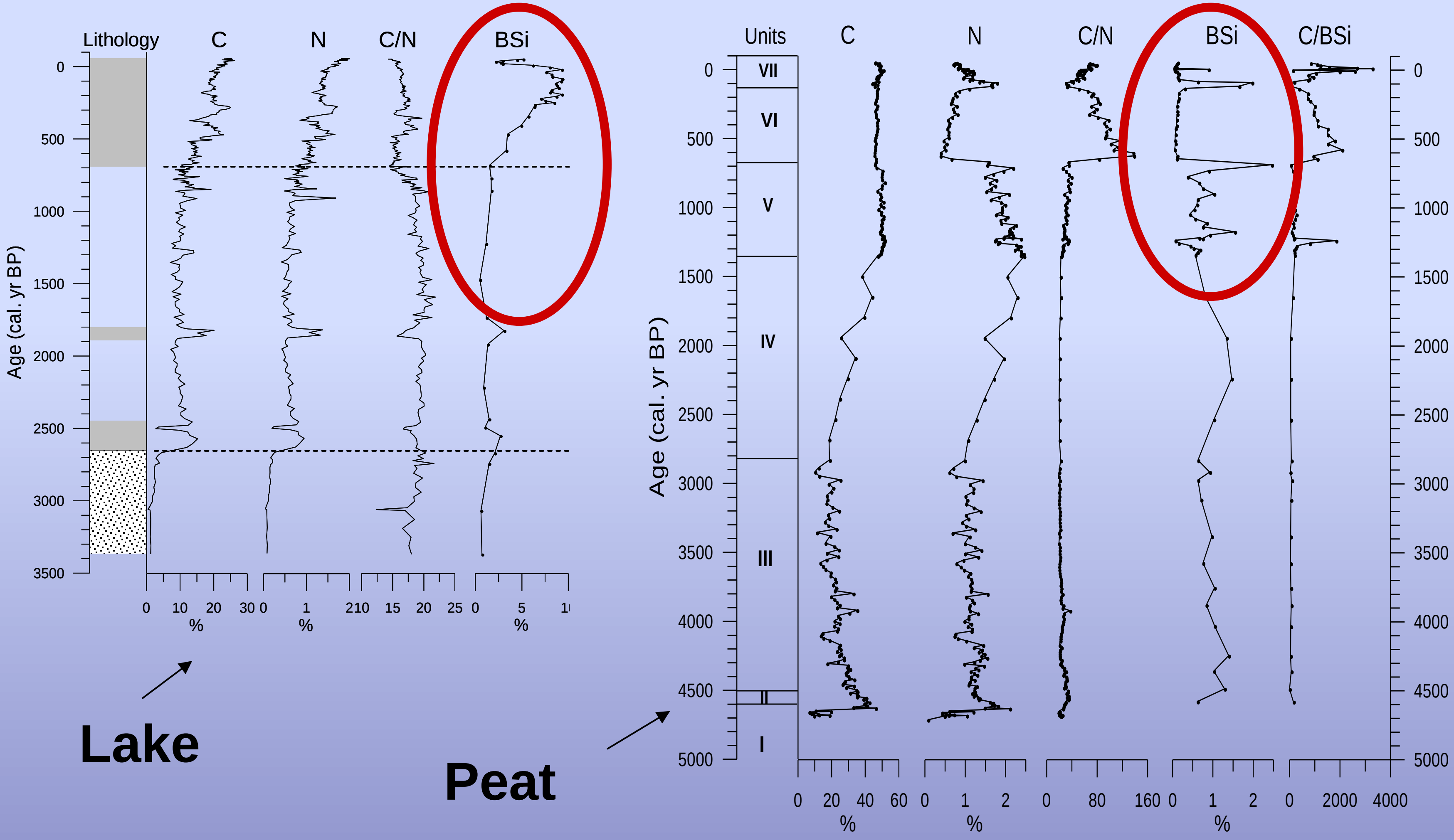
Lake – peatland connection



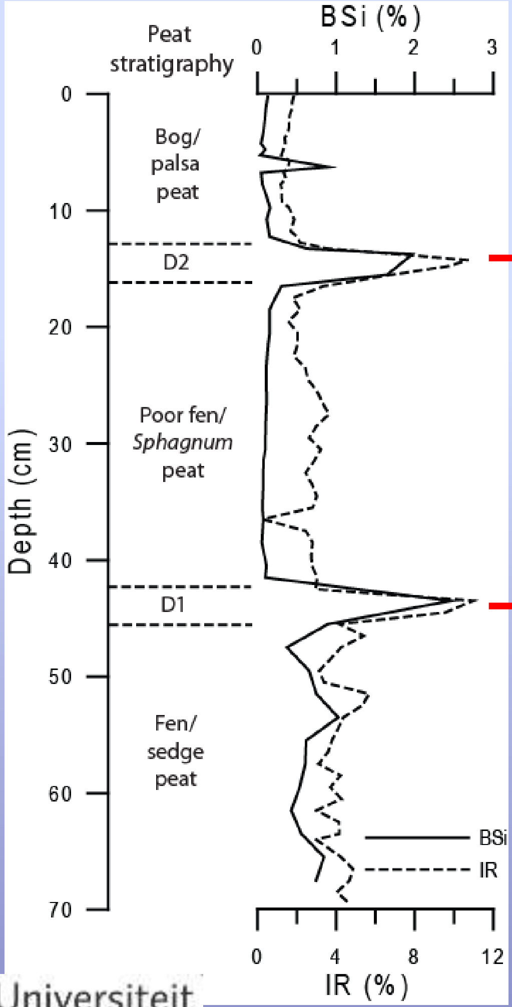
Lake

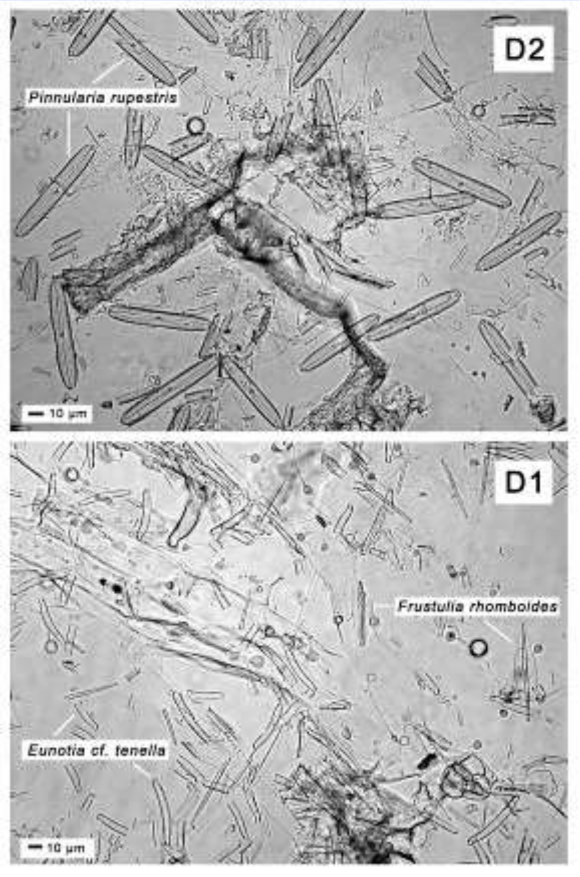
Peat

Kokfelt et al, Journal of Paleolimnology, in press

Diatoms rule in times of change

Kokfelt et al, Soil Biology and Biochemistry, 2009





Interbedded assemblages
contain up to 70% of one species

Conclusions

- Biology (diatoms and vegetation) controls Si cyling in wetlands
- The control is important on the watershed scale
- The buffer is dependent on climate and human management
- Interacts with the carbon cycle, both through controlling DSi export to rivers/oceans, and by sequestering carbon in ASi rich layers

Still poorly studied, in only few systems
Mechanisms need to be constrained
Global importance quantified

Review

Silica: an essential nutrient in wetland biogeochemistry

Eric Struyf[1,2*] and Daniel J Conley[1]

Recent research has emphasized the importance of terrestrial ecosystems in the global biogeochemical cycle of silica (Si). The production, retention, and dissolution of amorphous silica of biological origin in soils and vegetation effectively control terrestrial Si fluxes. However, surprisingly little is known about the role of wetlands in these processes. Wetlands are known hotspots for both nitrogen and phosphorus cycling, and there have been countless studies and numerous reviews on these nutrients worldwide. By bringing together previously scattered results, we show that wetland ecosystems may be as important for Si transport and processing as they are for other important biogeochemical cycles. Yet, the range of studied systems is small and incomplete. This constitutes a serious gap in our understanding of both coastal eutrophication and climate change, issues that are strongly linked to Si biogeochemistry. Ecosystem scientists and wetland biogeochemists around the world need to begin addressing these issues.

Front Ecol Environ 2009; 7(2): 88–94, doi:10.1890/070126 (published online 13 Feb 2008)

On geological time scales, mineral weathering and volcanic hydrothermal emissions are the ultimate source for all dissolved and biogenically fixed silica (Si) on Earth. However, on biological time scales, this "geo-aspect" of silica biogeochemistry is only one part of the story. The " 'bio' in silica biogeochemistry" (eg Markewitz and Richter 1998) has been studied less intensively, though recent research has shown that processing of Si within ecosystems greatly influences its transport and retention (Conley 2002; Derry *et al.* 2005; Blecker et al. 2006). This challenges our ability to predict rates of mineral Si weathering, as the biological contribution is poorly quantified. Assessing weathering rates is important: mineral Si weathering is an important sink for atmospheric CO_2. Furthermore, relative to the well-studied elements nitrogen (N) and phosphorous (P; eg Tiessen 1995; Boyer and Howarth 2002), the export of silica from land is a crucial factor in the occurrence of coastal eutrophication (Ittekot et al. 2000). Yet research on wetland Si cycling has been scattered and incomplete, and has never been summarized. This review will emphasize the role of biota (ie vegetation, diatoms, sponges) in Si cycling and show that, based on available data, Si should be included in wetland nutrient budgets.

The most evident biological sink for Si is diatoms (Bacillariophyceae), single-celled organisms abundant in aquatic phytoplankton communities worldwide. Diatoms take up dissolved silicate (DSi = ortho-silicic acid) and deposit it as amorphous silica (ASi), often referred to as biogenic silica (BSi), within the protective coating of the diatom frustule (the cell wall of a diatomic silicate cell). The ocean cycle of diatom ASi is characterized by rapid recycling, with only 3% of yearly diatom ASi production permanently buried in the ocean floor (Van Cappellen 2003). The "biological Si pump" is an important mechanism by which C is transferred from the atmosphere to the deep ocean (Dugdale et al. 1995). Ocean food webs would collapse if buried ASi were not replenished by inputs from land, via rivers. Many important global fisheries are dependent on diatom-based food webs (Officer and Ryther 1980).

Another major biological factor in Si cycling is vegetation. Plants take up DSi from soil solution, and deposit it as ASi, mainly in siliceous bodies known as phytoliths (Piperno 1988). Phytoliths are more resistant to decomposition than other plant tissues. They remain buried in large quantities in soil (Clarke 2003), and are often used as paleo-indicators in the reconstruction of past vegetation communities (Blinnikov 2005). Their solubility is still several orders of magnitude greater than that of mineral silicates (Van Cappellen 2003). Conley (2002) has estimated that the global annual fixation of phytolith silica (60–180 Tmol yr^{-1}) is on the same order of magnitude as the amount annually fixed in ocean diatom communi-

In a nutshell:

- Wetlands are rich in biologically fixed, amorphous silica, and may exert biological control over the silica cycle
- Hydrology and vegetation control processing of silica in wetlands; human interference has impacts on interactions between wetland Si biogeochemistry on the one hand, and climate change and eutrophication on the other
- Currently, the silica biogeochemistry of several types of wetland, including mangroves, Arctic peatlands, and riparian wetlands, is poorly understood

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Struyf E., Conley DJ. (2009)
Silica: an essential nutrient in wetland biogeochemistry.
Frontiers in Ecology and Environment,7(2), 88-94.

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