Biogeochemistry of C and nutrients in peatlands: *Applied aspects*

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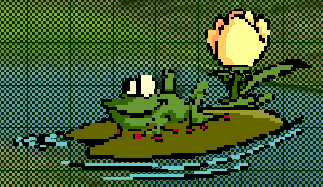

- Biogeochemical processes wet / dry
- Decomposition and eutrophication
- Role of water & sediment quality
- Applied ecological issues: desiccation / restoration / wetland creation / water storage


DC PHANTOM STRANGER
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THE PHANTOM STRANGER
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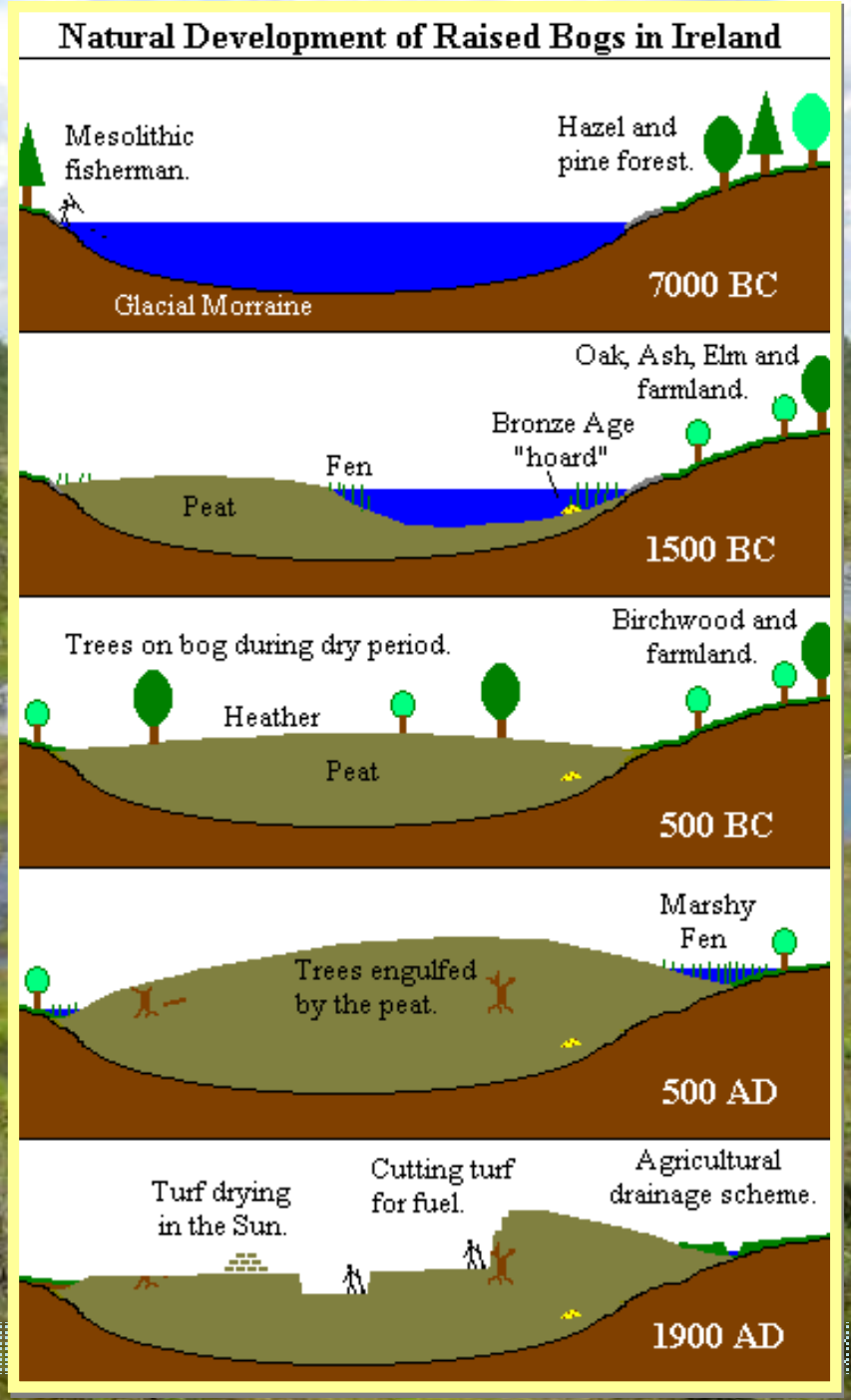
SPECTRE OF THE STALKING SWAMP!



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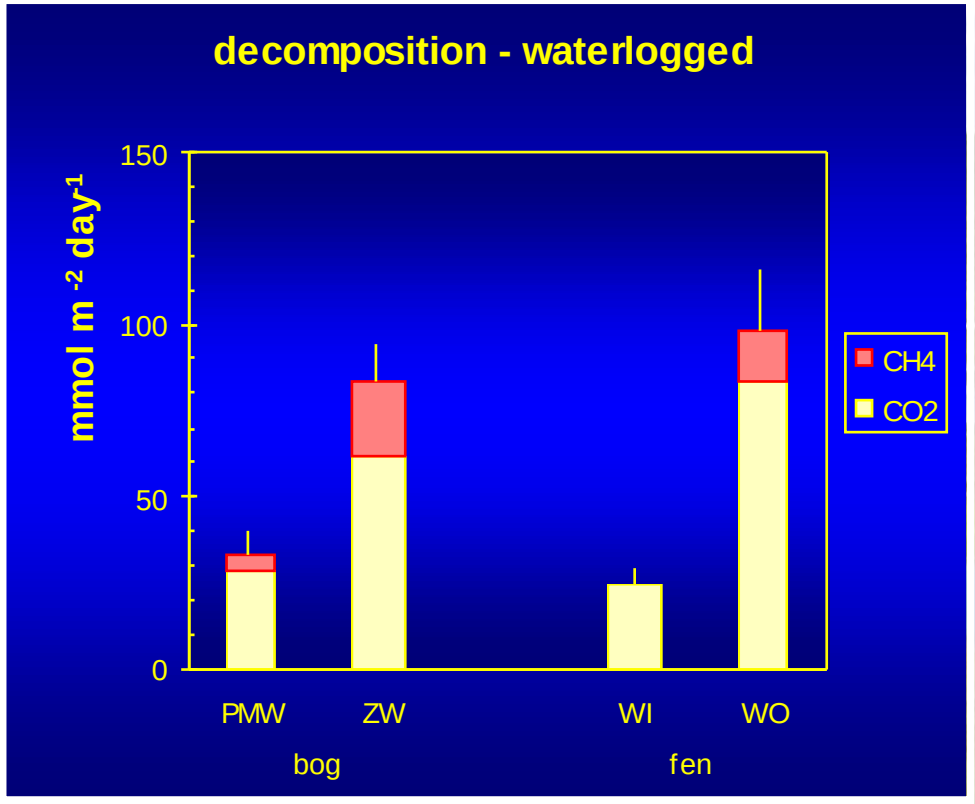
Peatlands

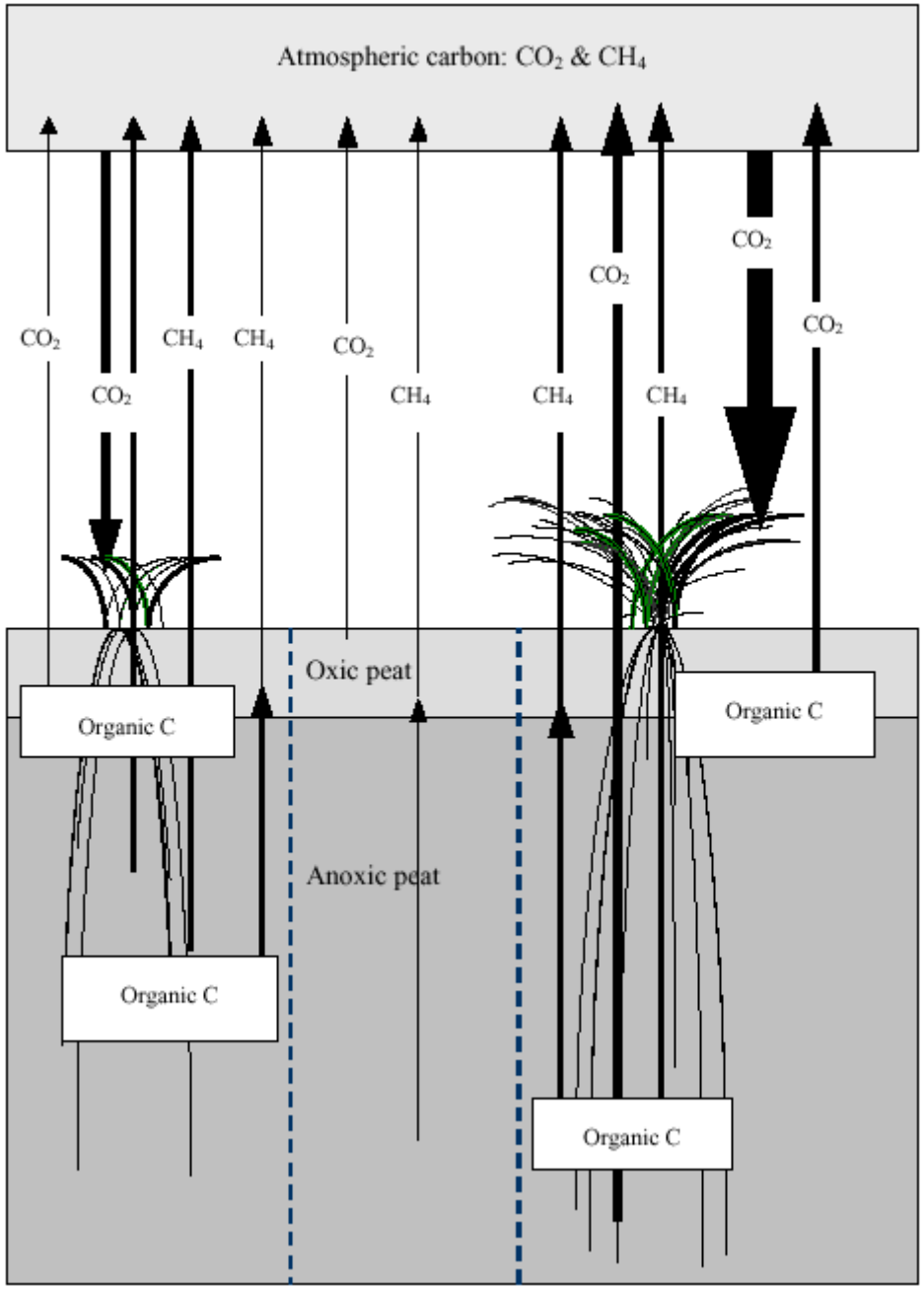
1. High efficiency for C storage: low pO_2 , low pH (bogs), recalcitrant organic matter (e.g. phenolic compounds), high C refixation potential.

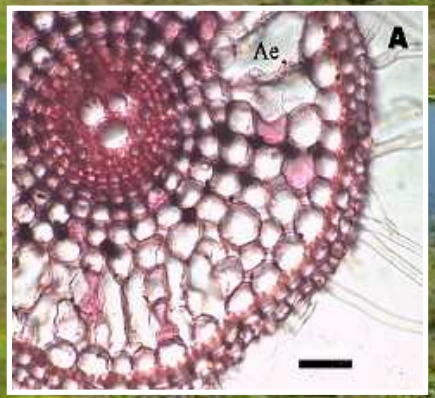
2. Drainage, combustion, eutrophication, and S-pollution; transition C sink to source.

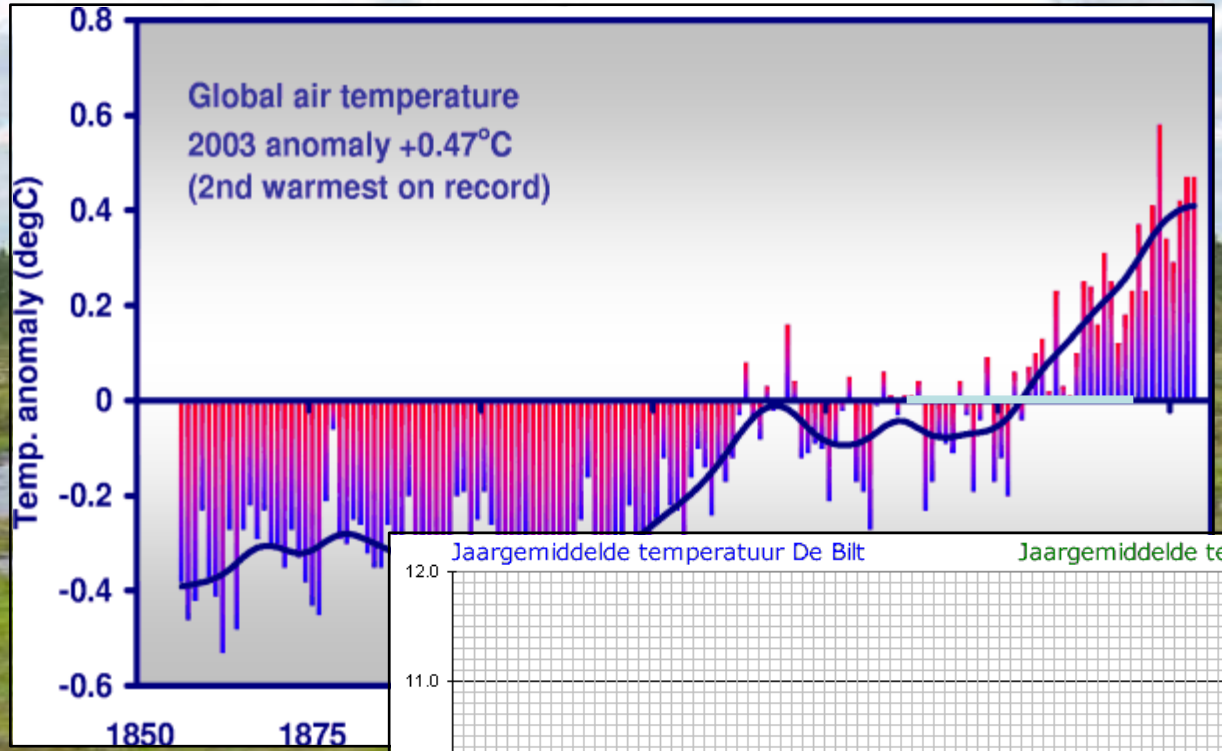
2. Biogeochem. key processes, ecosystem-microbial level;
   - global change (T, CO_2, CH_4, H_2O, N, S)
   - flooding risks (peat settlement)
   - reversal C sink-source transition (peatland restoration)

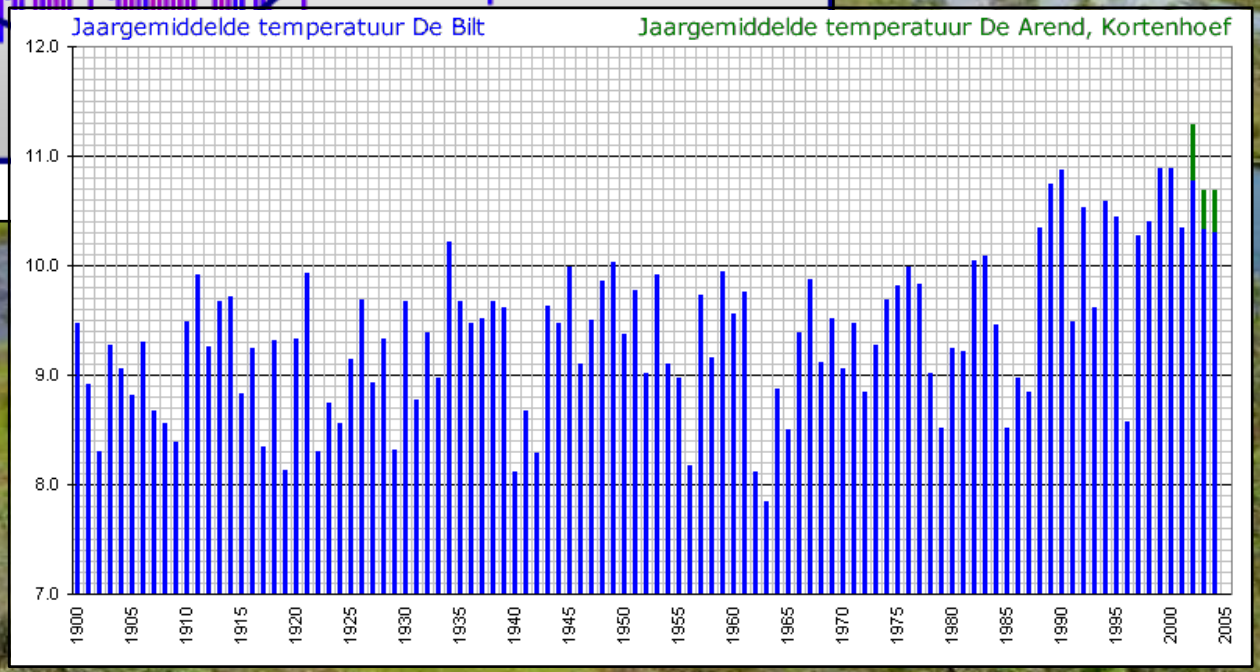


Lamers et al in prep


Atmospheric carbon: CO_2 & CH_4
CO_2
CO_2
CH_4
CH_4
CO_2
CH_4
CH_4
CO_2
CH_4
CO_2
CO_2
Oxic peat
Organic C
Organic C
Anoxic peat
Organic C
Organic C


A
Ae





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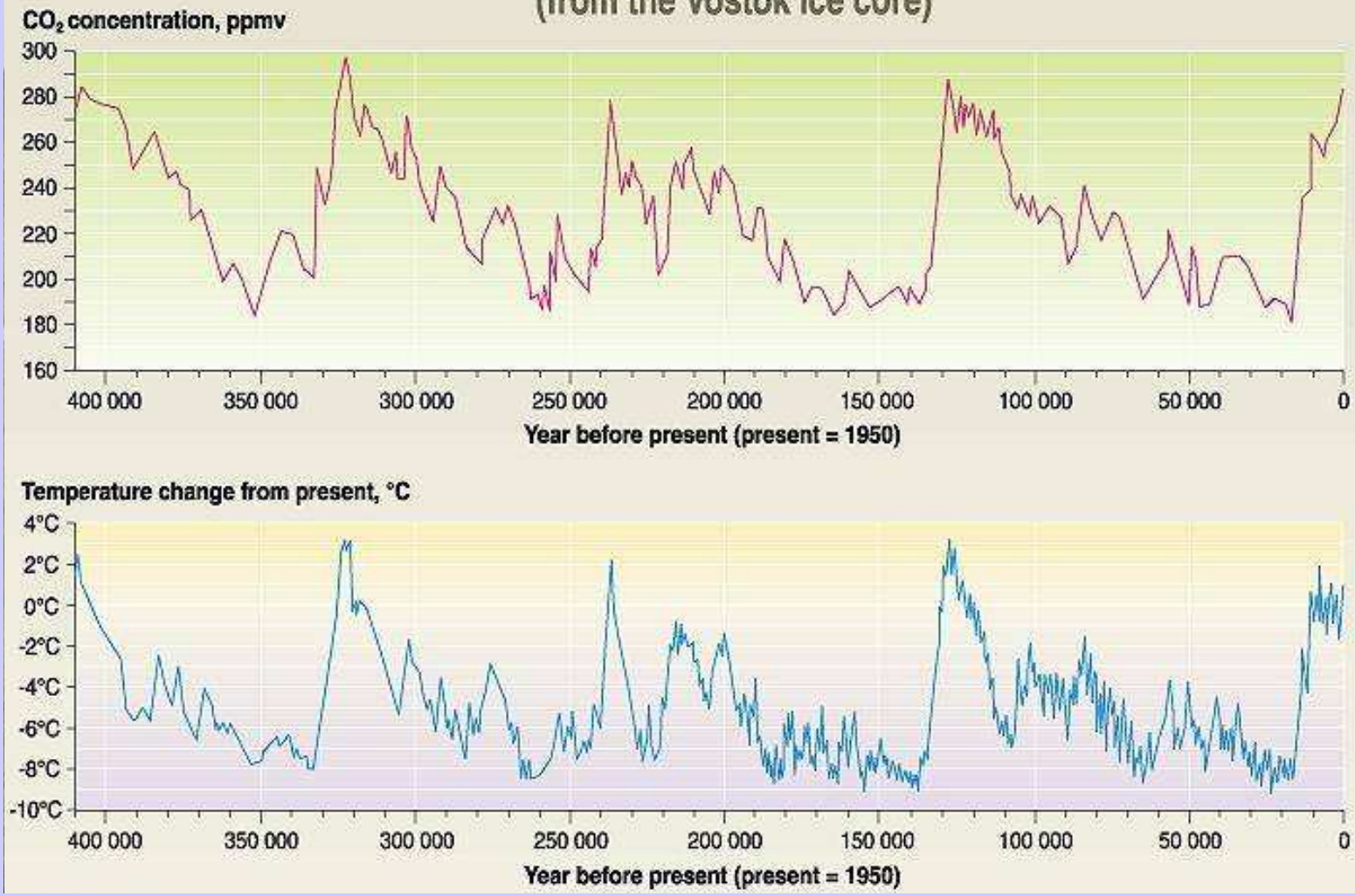
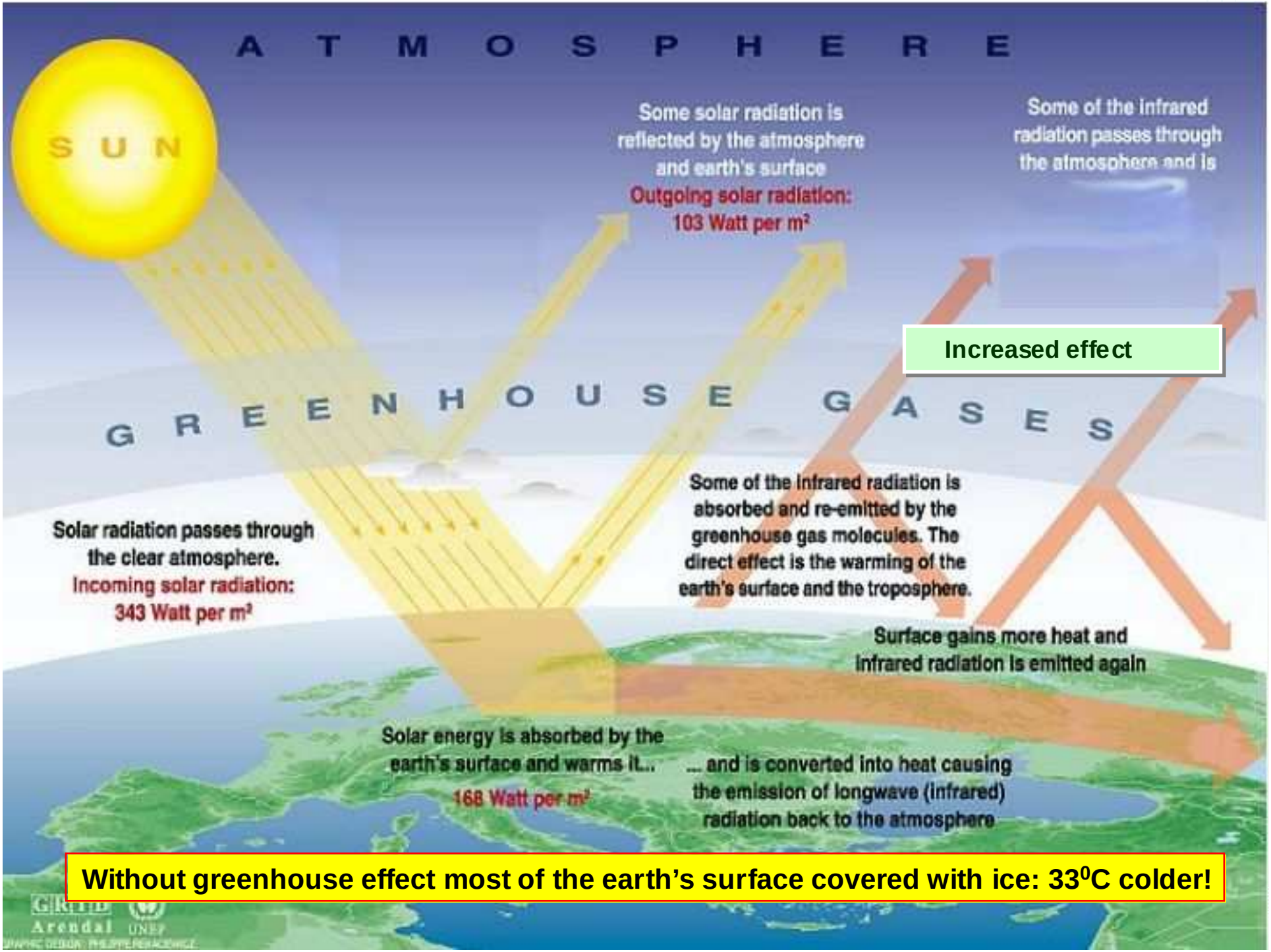
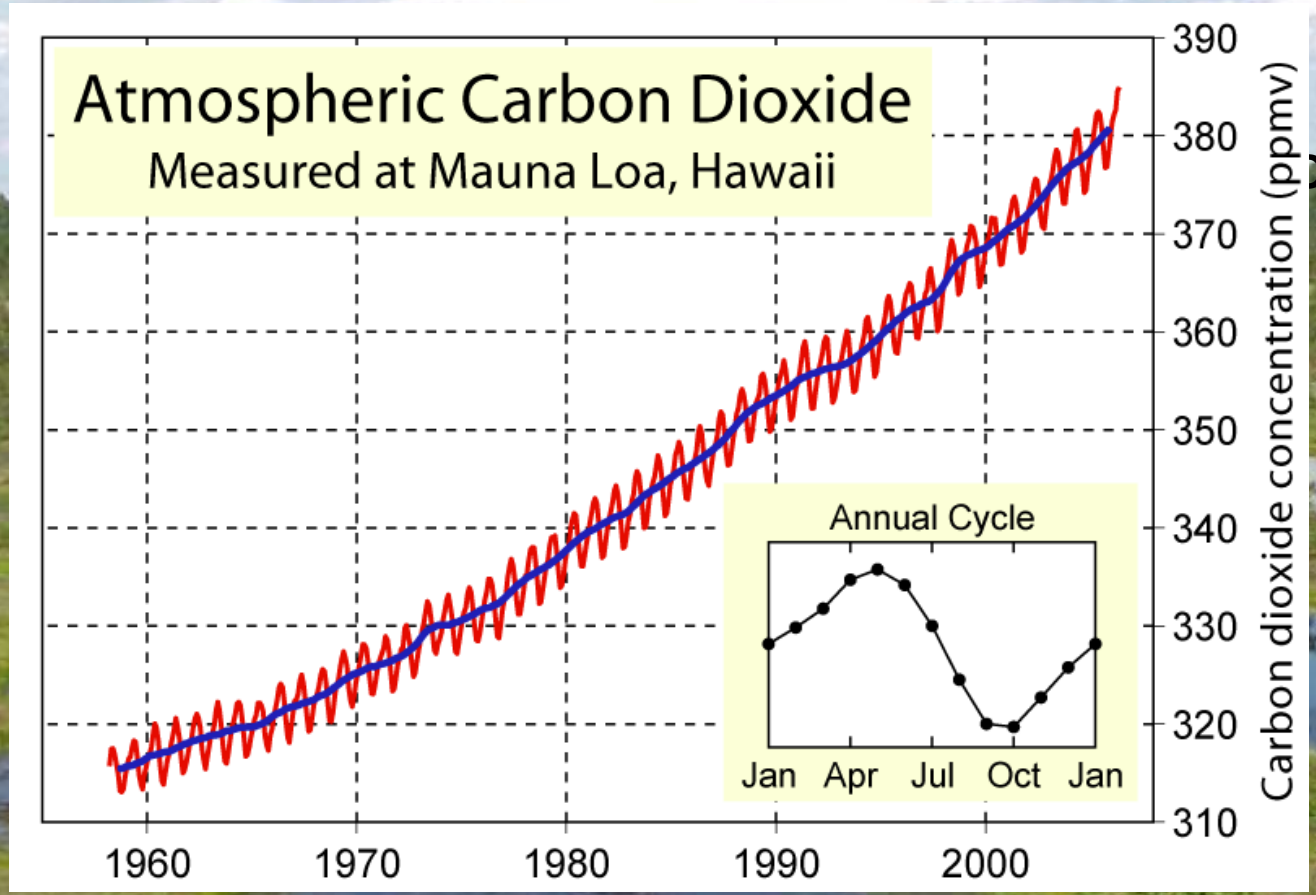
Temperature and CO_2 concentration in the atmosphere over the past 400 000 years (from the Vostok ice core)

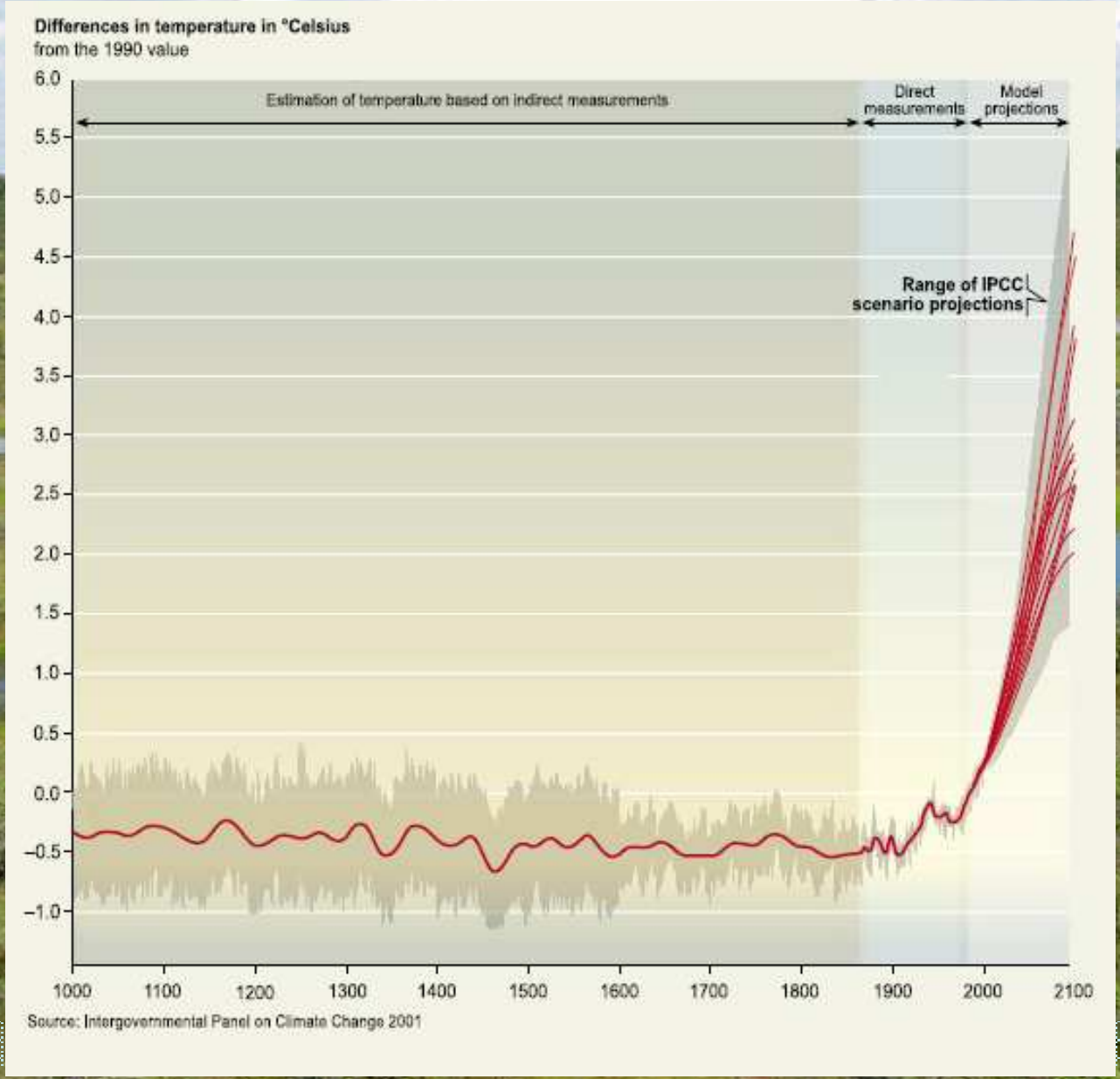



ATMOSPHERE
SUN
Some solar radiation is reflected by the atmosphere and earth's surface
Outgoing solar radiation: 103 Watt per m²
Some of the infrared radiation passes through the atmosphere and is
Increased effect
GREENHOUSE GASES
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth's surface and the troposphere.
Solar radiation passes through the clear atmosphere.
Incoming solar radiation: 343 Watt per m²
Surface gains more heat and infrared radiation is emitted again
Solar energy is absorbed by the earth's surface and warms it...
168 Watt per m²
... and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere
Without greenhouse effect most of the earth's surface covered with ice: 33⁰C colder!
GRID Arendal
UNEP


Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
1960
1970
1980
1990
2000
310
320
330
340
350
360
370
380
390
Carbon dioxide concentration (ppmv)

CO_2

temperatuurverhoging: voorspellingen



Global Carbon Cycling

Increased C sources (loss)

- Combustion fossil organic C
- Clearing of (rain)forests
- Drainage and increased T peatlands: decomposition
- Increased T permafrost
- Increased T decomposition other ecosystem types

Increased C sinks (sequestration)

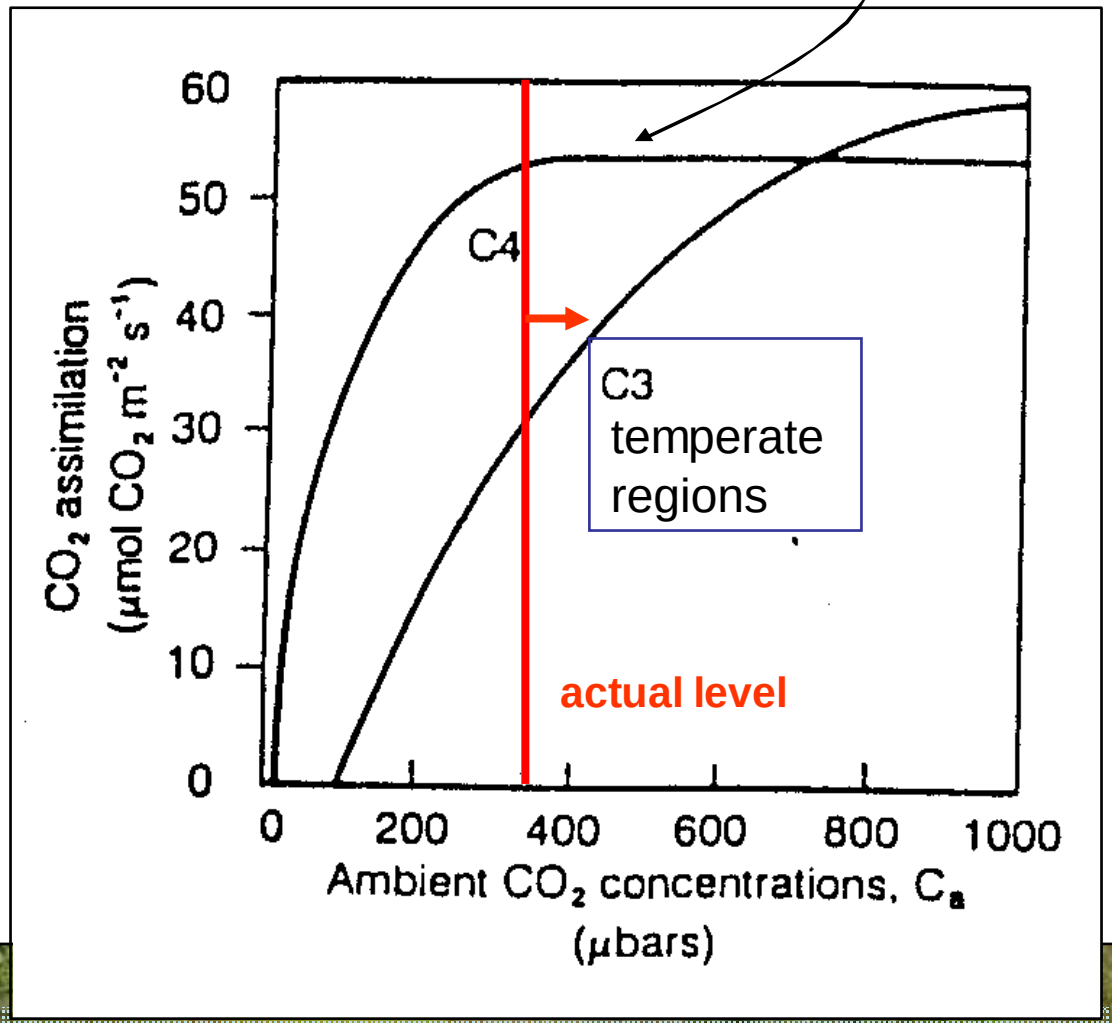
- Increased primary production terrestrial ecosystems
- Increased primary production oceans (?)

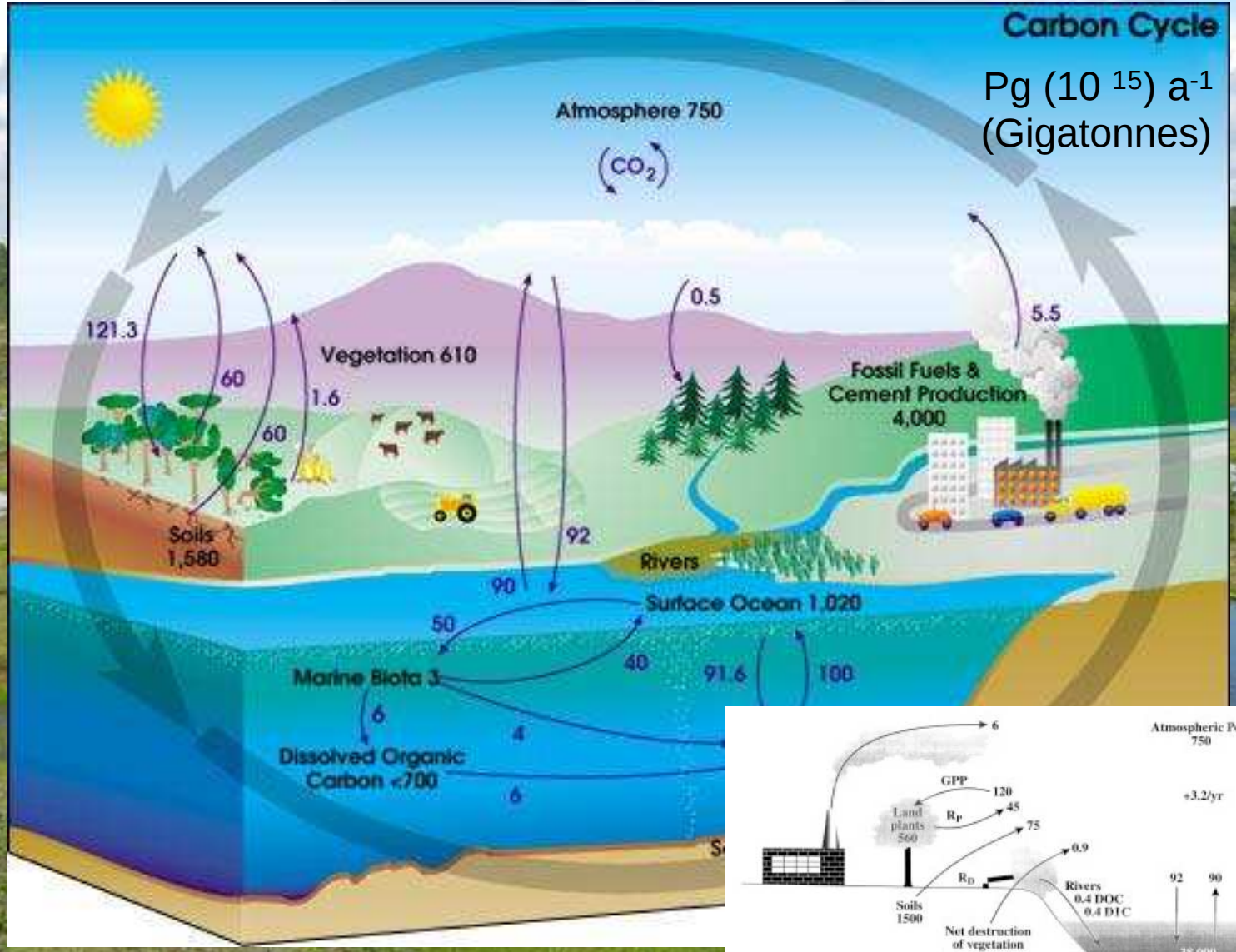
Additional effect increased CO_2

- Higher primary productivity leads to higher proportion of recently assimilated organic carbon
- Higher DOC losses *Freeman* et al. *Nature 2004*

- Changes in plant composition due to interspecific competition

- Increased primary production?





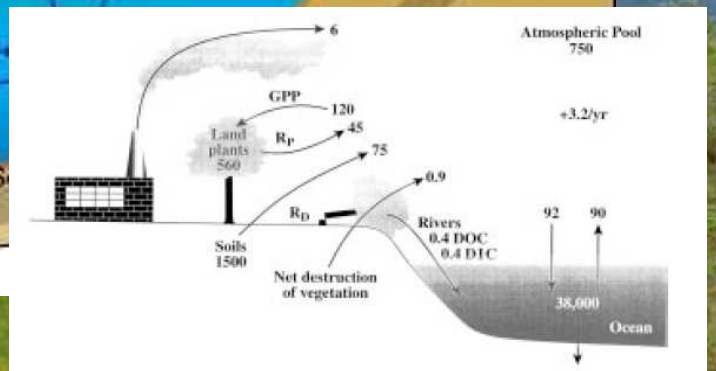
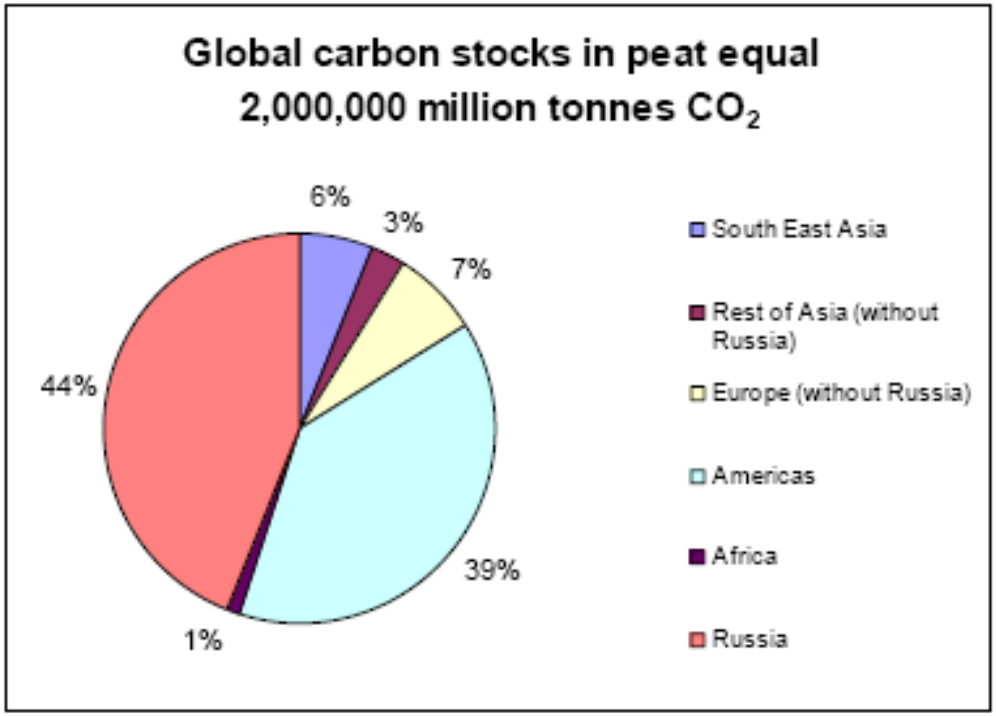
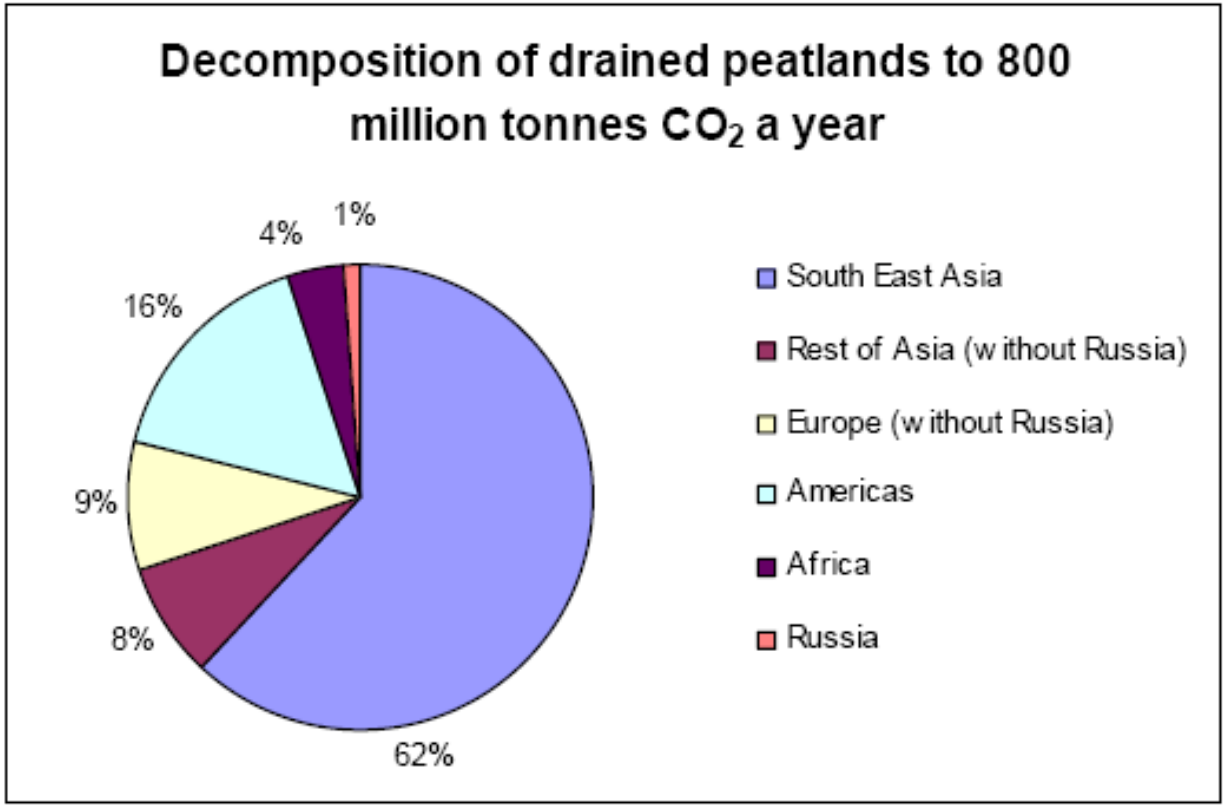


Figure 1. The global carbon cycle. All pools are expressed in units of 10^{15} gC and all fluxes in units of 10^{15} gC/yr, averaged for the 1980s. Modified from Schlesinger (1997).

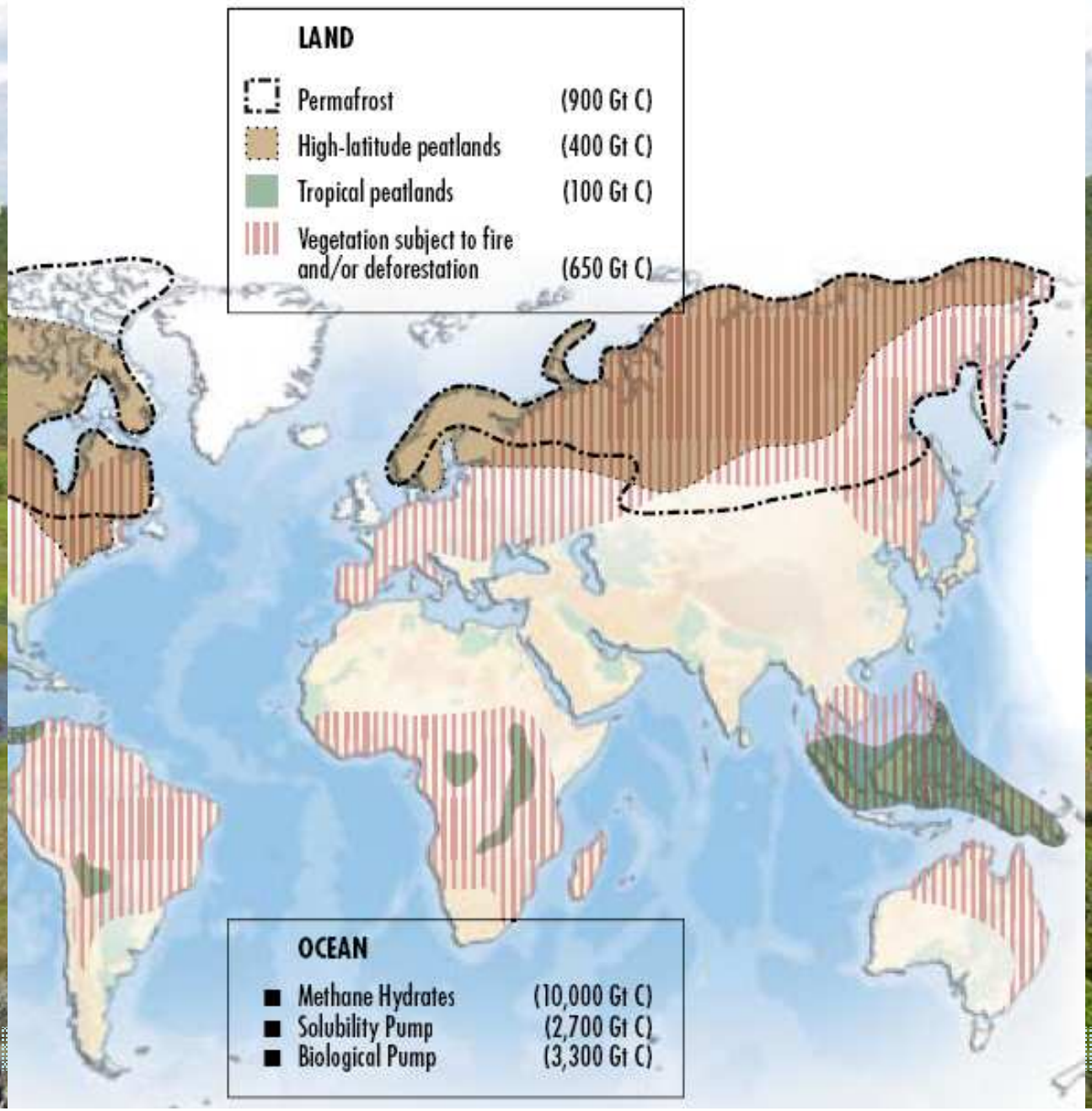


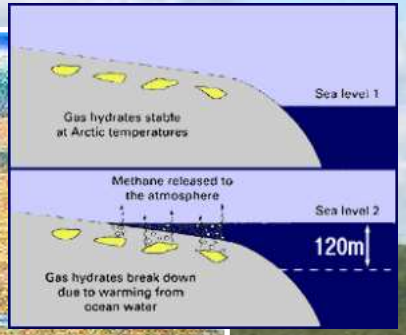
Source: Wetlands International and Delft Hydraulics

Northern peatlands: 20-30% of the global soil C stock


Decomposition of drained peatlands to 800 million tonnes CO_2 a year
4%
1%
16%
9%
8%
62%
South East Asia
Rest of Asia (without Russia)
Europe (without Russia)
Americas
Africa
Russia

Vulnerable Carbon Pools





Melting permafrost peatlands at Noyabrsk, Western Siberia. Succow (IMCG)

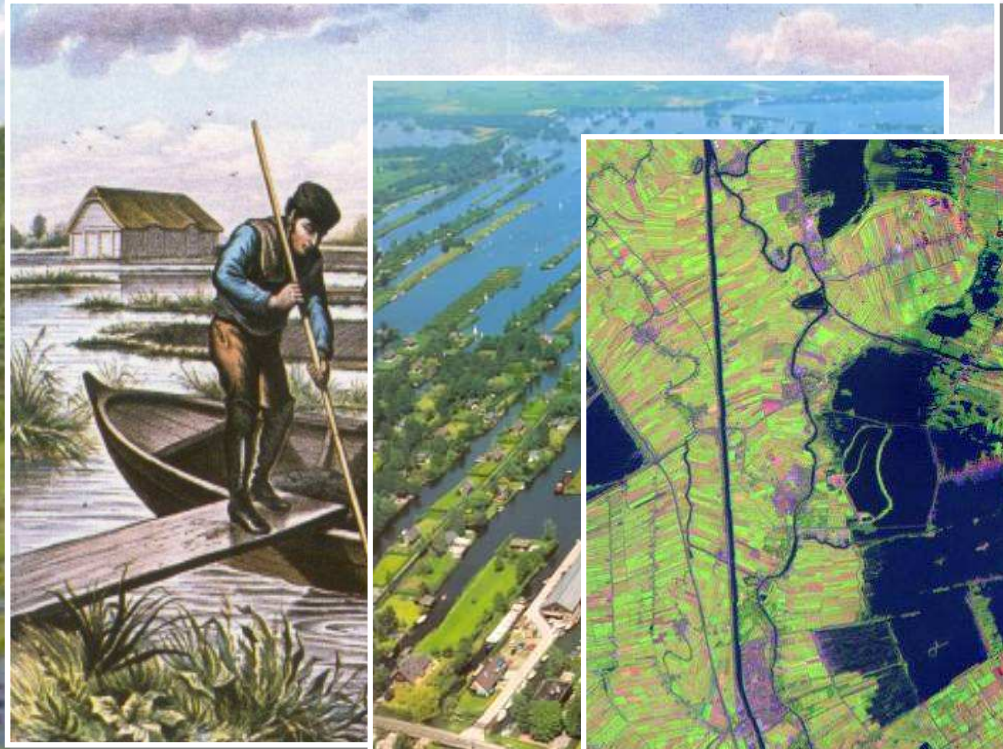
Carbon from the Pleistocene era

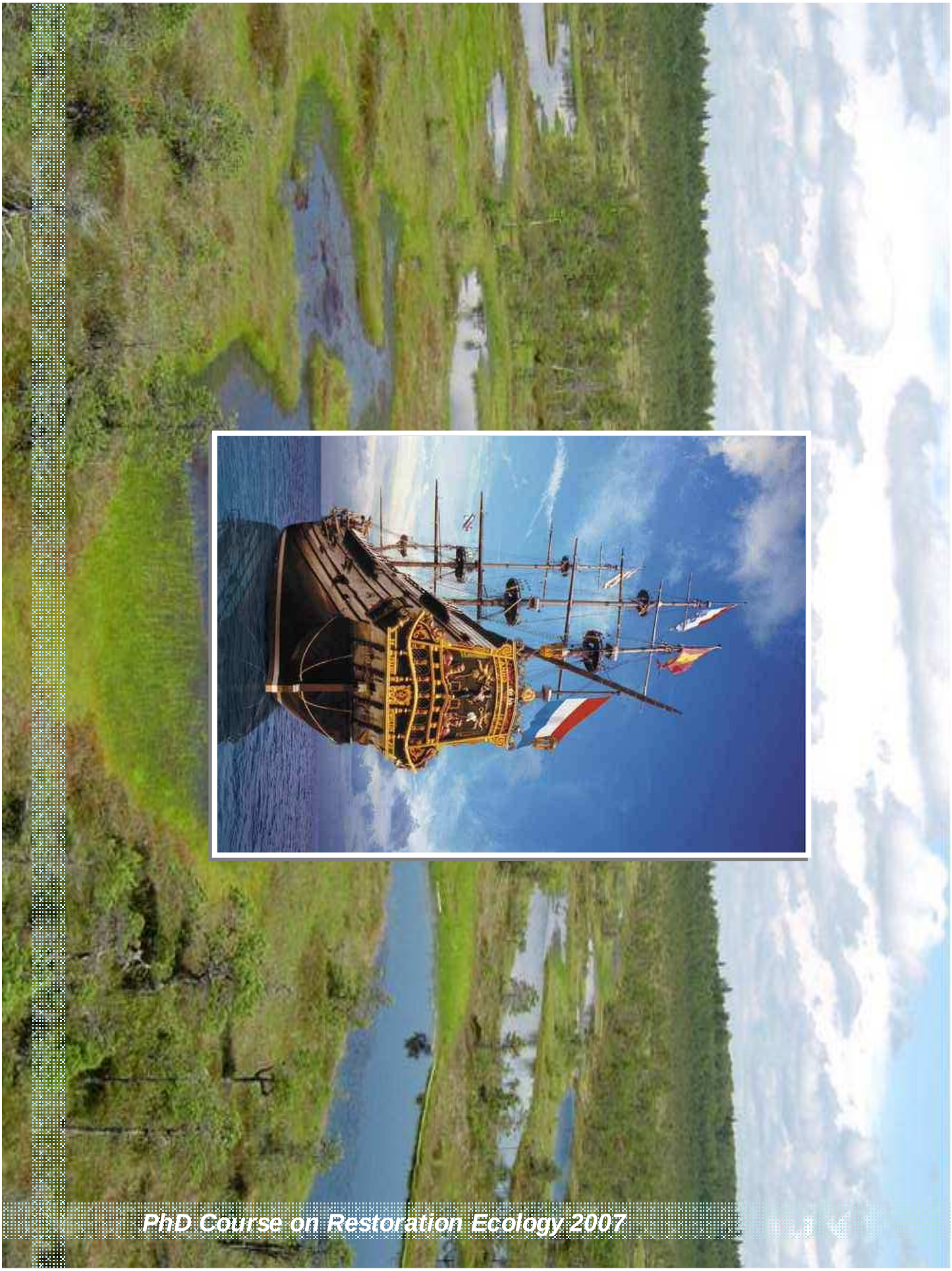
Pristine peat swamp forest, Sumatra.

Kalimantan: Peatland forest on fire

- Peatlandscape: lakes, marshes, bogs, meadows - gradients pH-O_2-nutrients
- High biodiversity: succession
- Deterioration: desiccation, eutrophication, Spp loss, C sink-source transition

II: Fens





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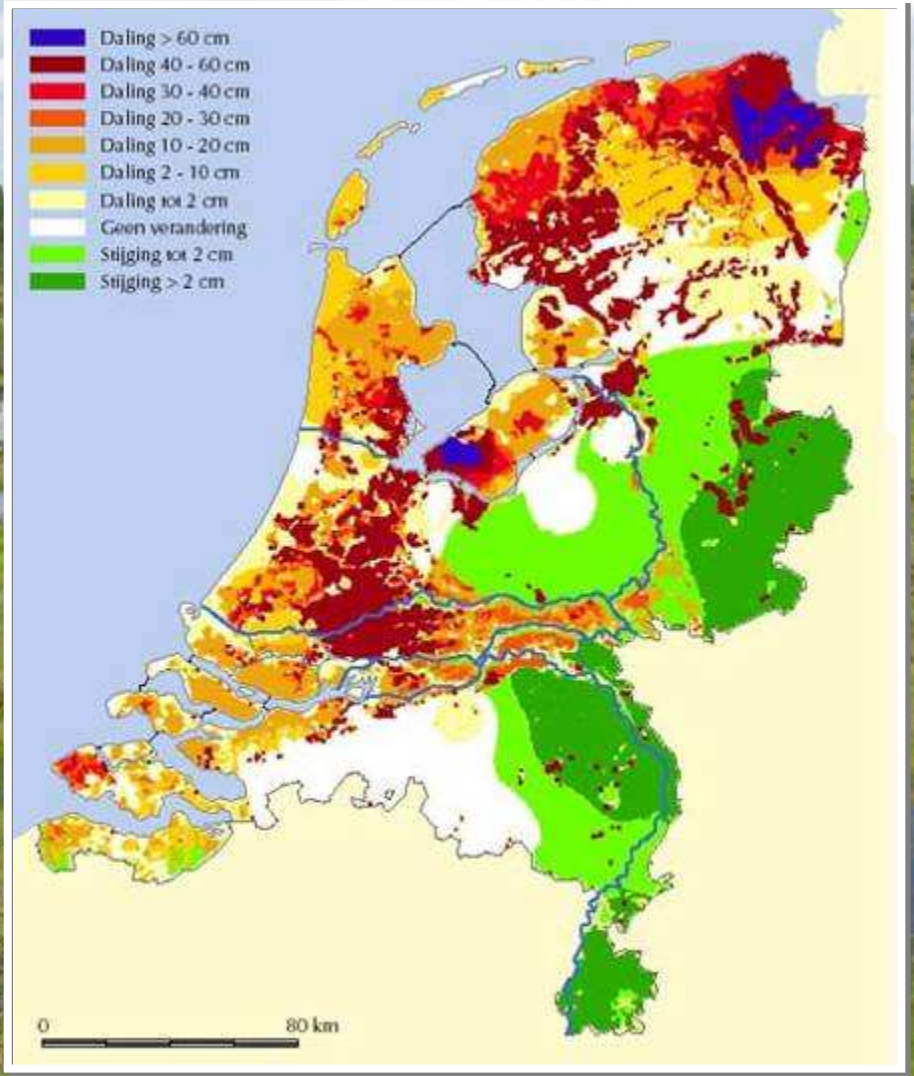
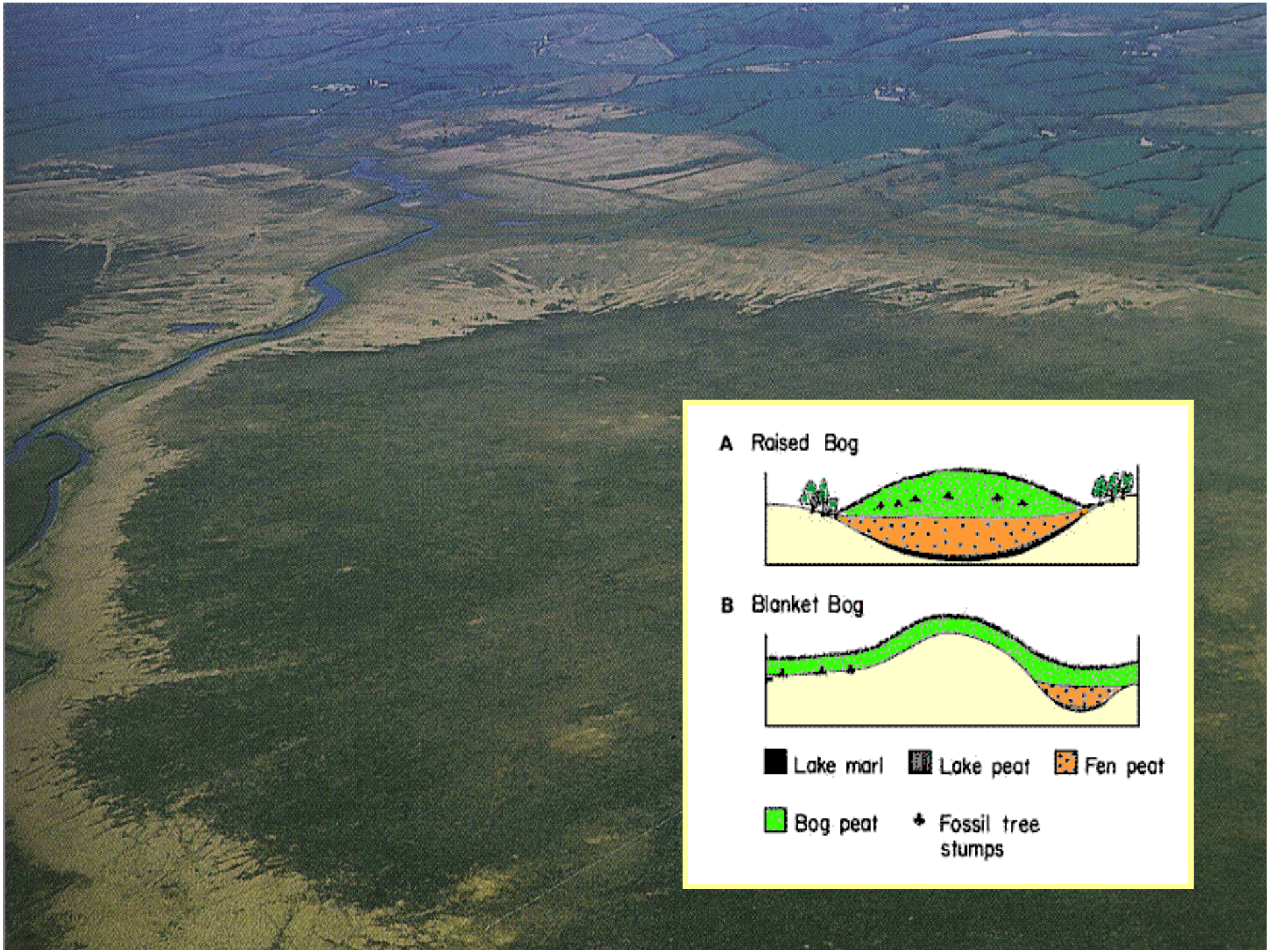
C-loss & land subsidence



TNO / NITG / RWS


A Raised Bog
B Blanket Bog
Lake marl
Lake peat
Fen peat
Bog peat
Fossil tree stumps

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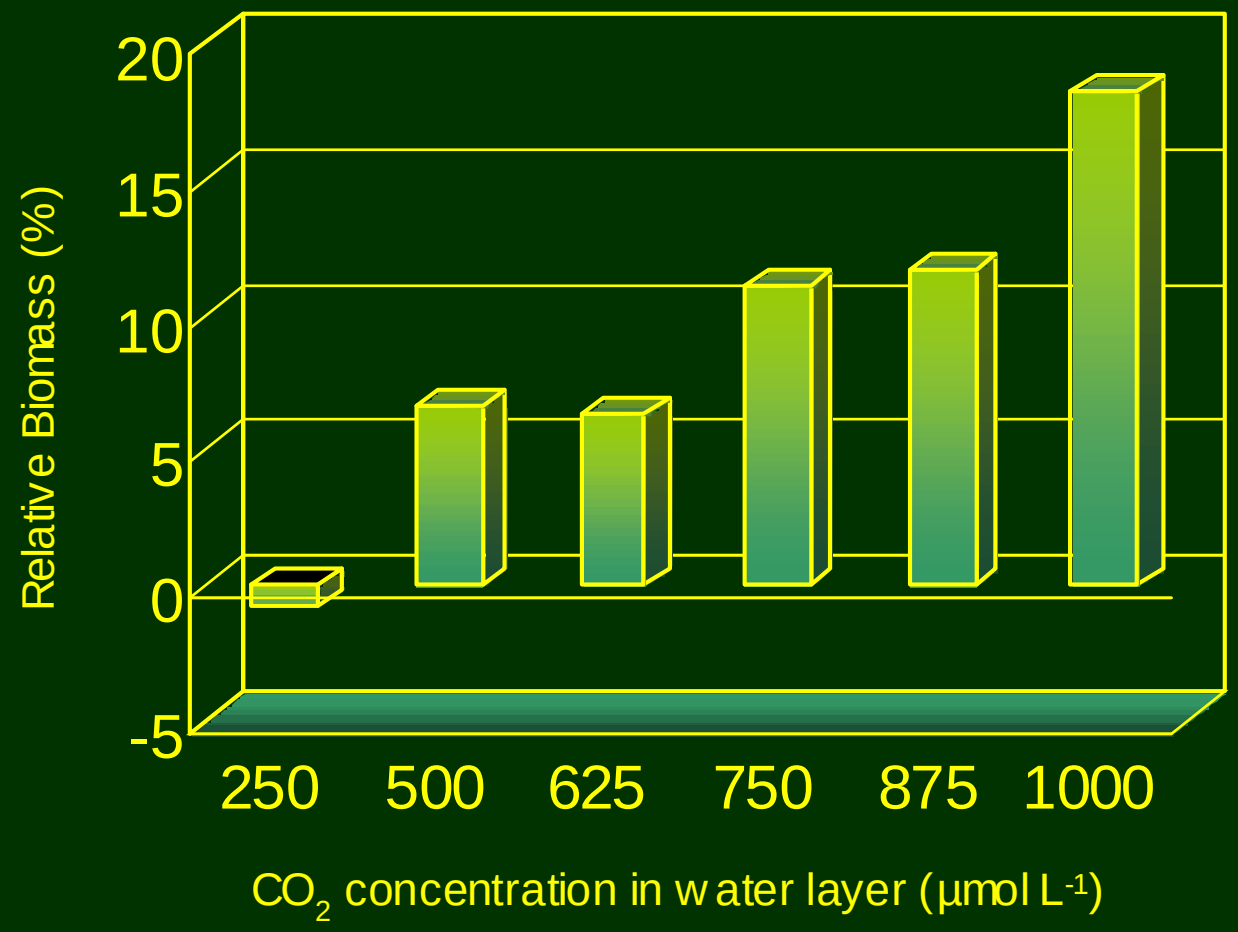
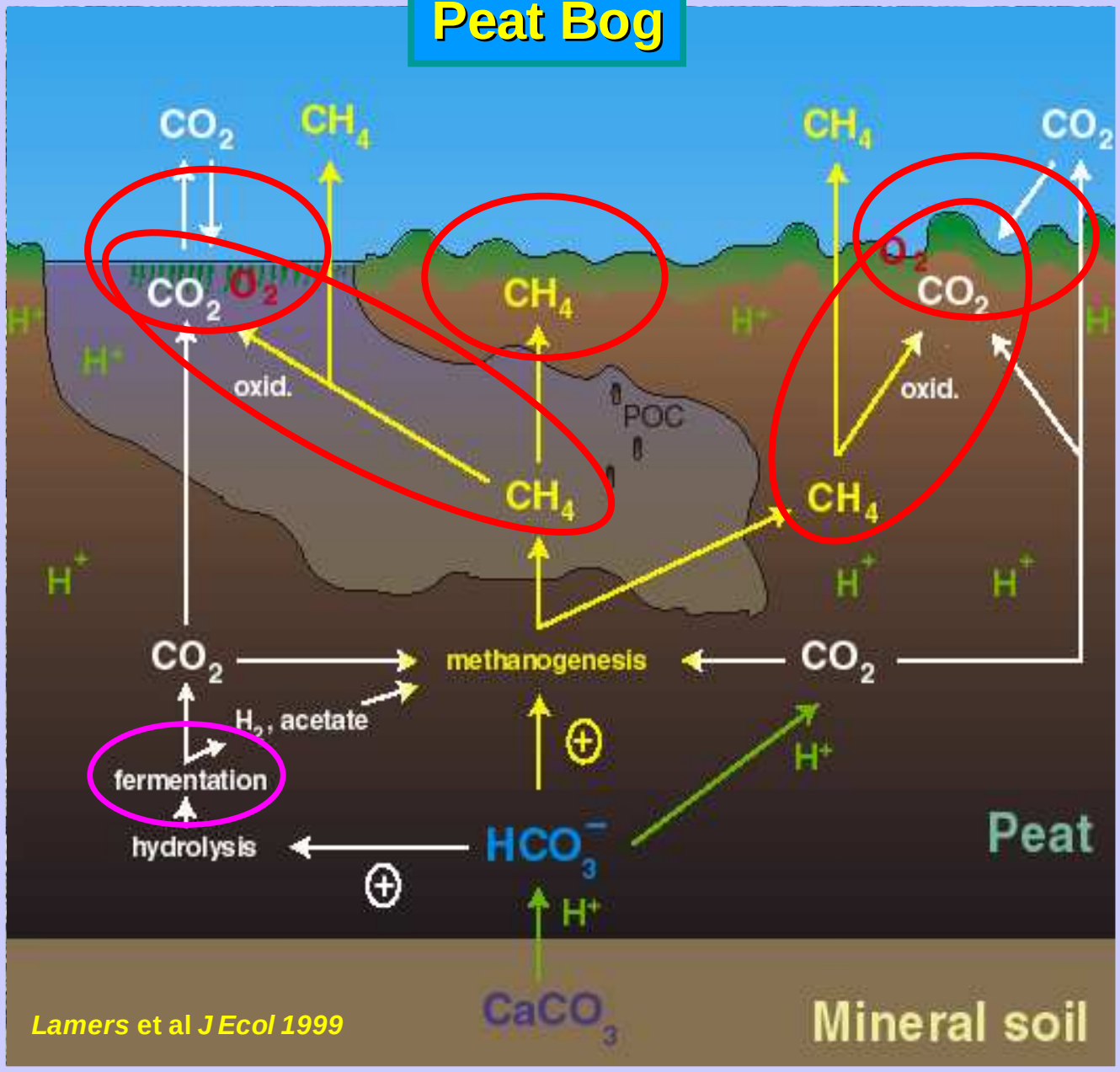


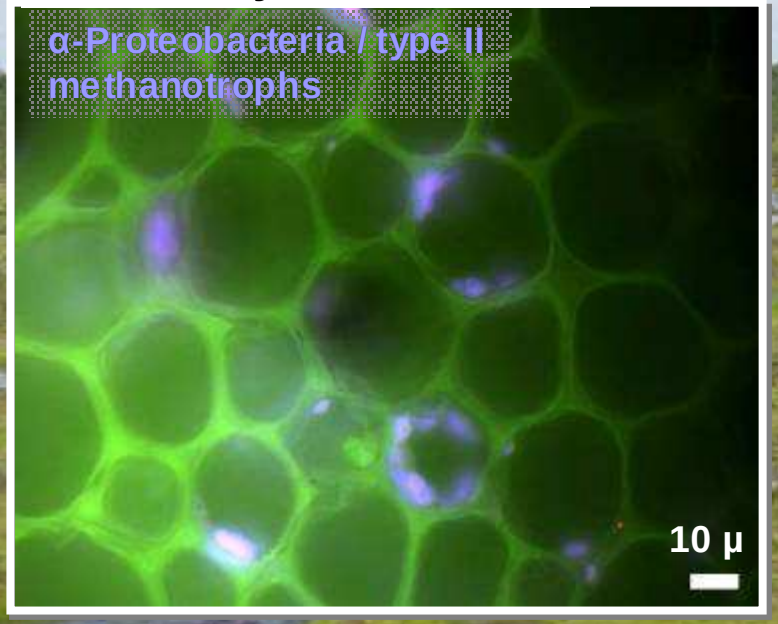
Paffen & Roelofs Aquat Bot 1991

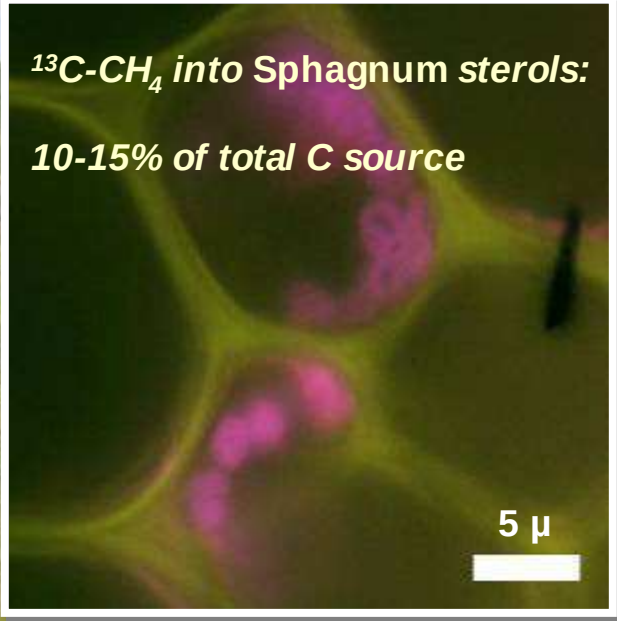
Peat Bog



Lamers et al *J Ecol 1999*

C-efficiency

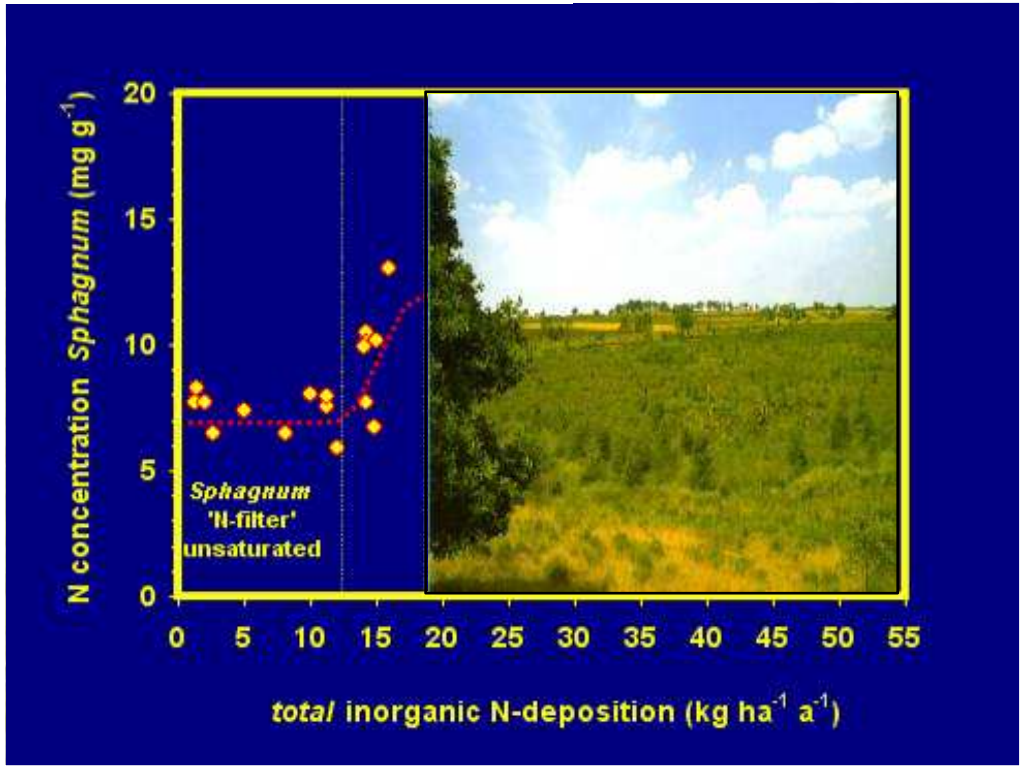




Raghoebarsing et al *2005 Nature*

Peat extraction

Airborne pollution



Lamers et al Global Change Biol. 2000

Malmer Oikos 1988
Aerts et al J Ecol 1992
Berendse et al Global Change Biol 2001
Heijmans et al J Ecol 2001
Thomassen et al J Ecol 2003 J Appl Ecol 2004
Limpens et al. New Phytol 2003 Oecologia 2003
Bragazza et al. PNAS 2006

Eutrophication

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Nutrient limitation

- **P** o-phosphate

  e.g. marshes, fens

- **N** ammonium, nitrate

  e.g. fen vegetations, moorland pools, bogs

  often: N+P limitation

- **C** inorganic carbon

  e.g. moorland pools, lakes, bogs

  (C+N limitation)

- **K** *some fen meadows*

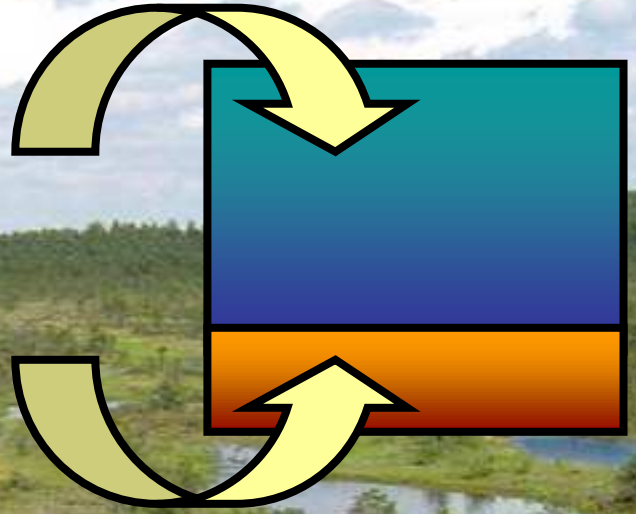
(Eutrophication always related to kind of nutrient)

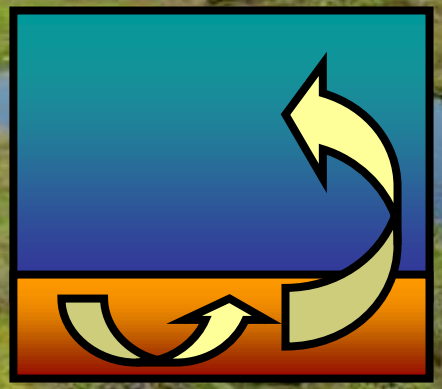
External eutrophication:

Eutrophication by extra input of nutrients from outside the system

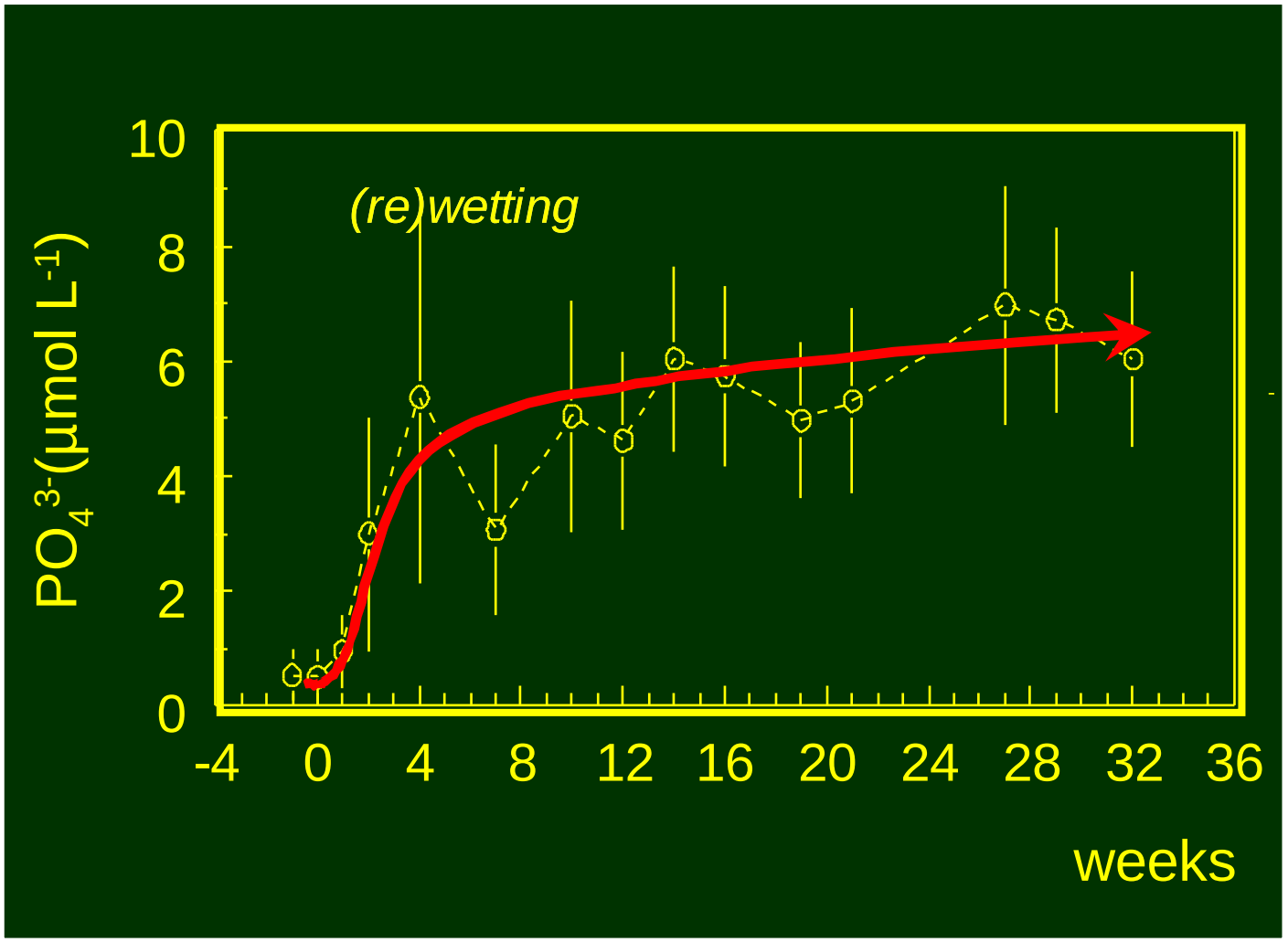
Internal eutrophication:

Eutrophication by increased mobilization of nutrients inside the system (particularly in peatlands)

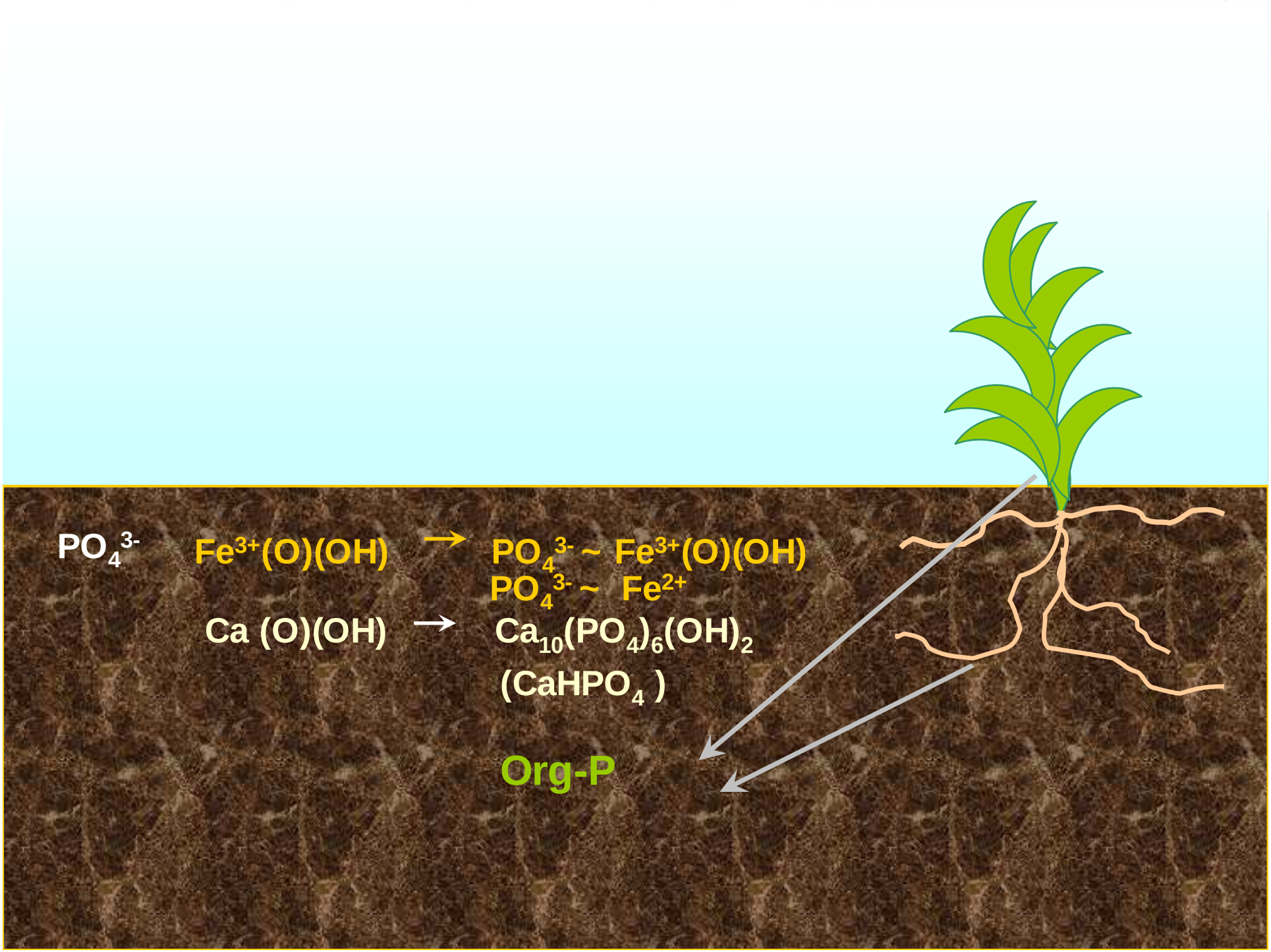


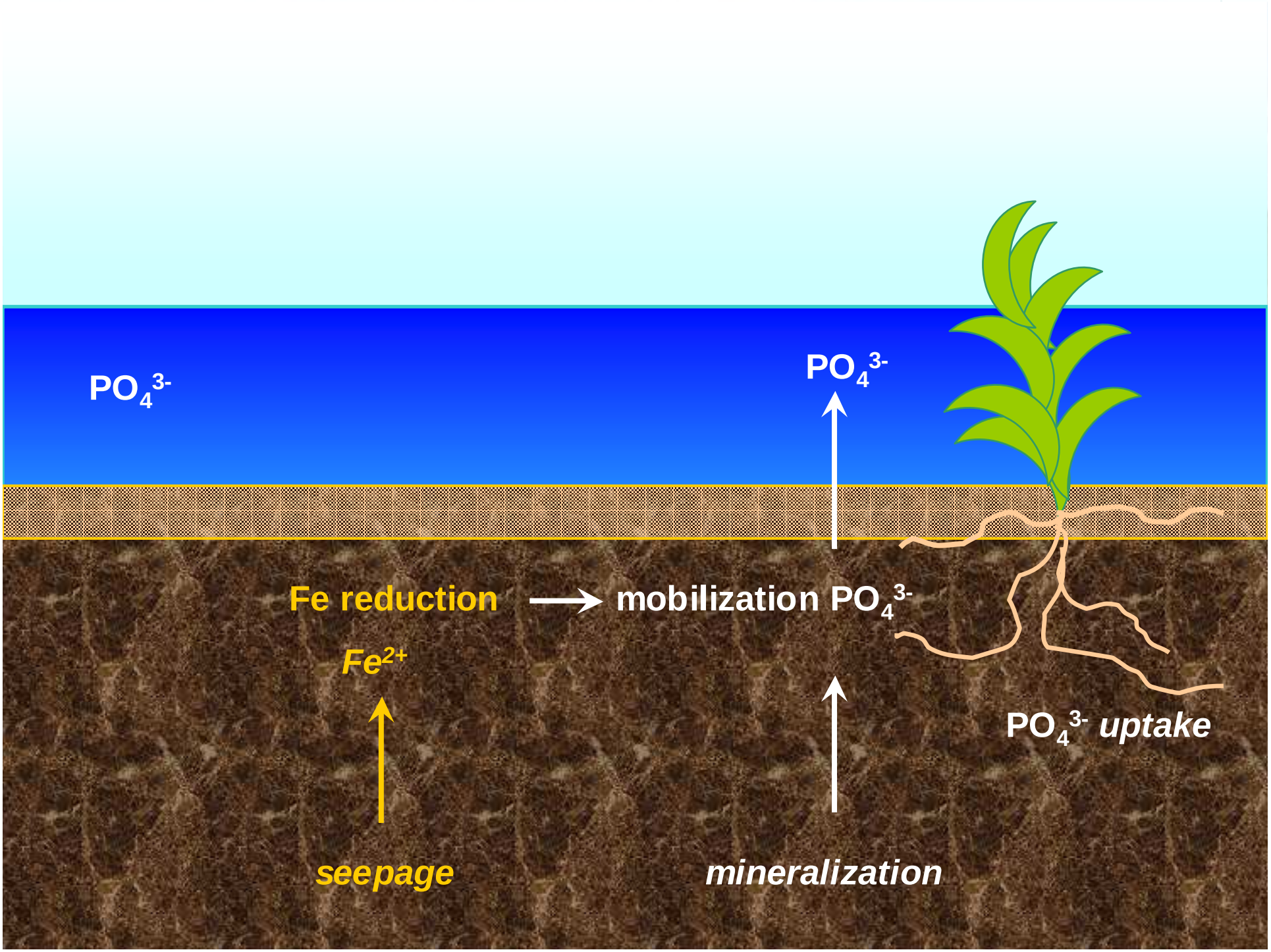


Roelofs Aquat. Bot. 1991



Lamers et al. ES&T 1998
Lamers et al. Biogeochem. 2001
Lamers et al H_2O 2005


PO_4^{3-}
$Fe^{3+}(O)(OH)$ → $PO_4^{3-} \sim Fe^{3+}(O)(OH)$
$PO_4^{3-} \sim Fe^{2+}$
$Ca\ (O)(OH)$ → $Ca_{10}(PO_4)_6(OH)_2$
$(CaHPO_4)$
Org-P


PO_4^{3-}
PO_4^{3-}
Fe reduction
mobilization PO_4^{3-}
Fe^{2+}
PO_4^{3-} uptake
seepage
mineralization

ten Noorde

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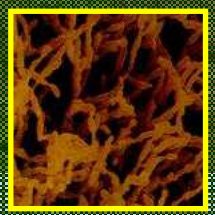
Decomposition:

Metabolic breakdown of organic matter (humus, peat) to simple organic and inorganic molecules, generating energy.

Mineralisation:

The transition of a nutrient or another substance from organically-bound form to water soluble inorganic form, as a result of biological or (inorganic) chemical processes.



Regulation of decomposition / mineralisation in peatlands

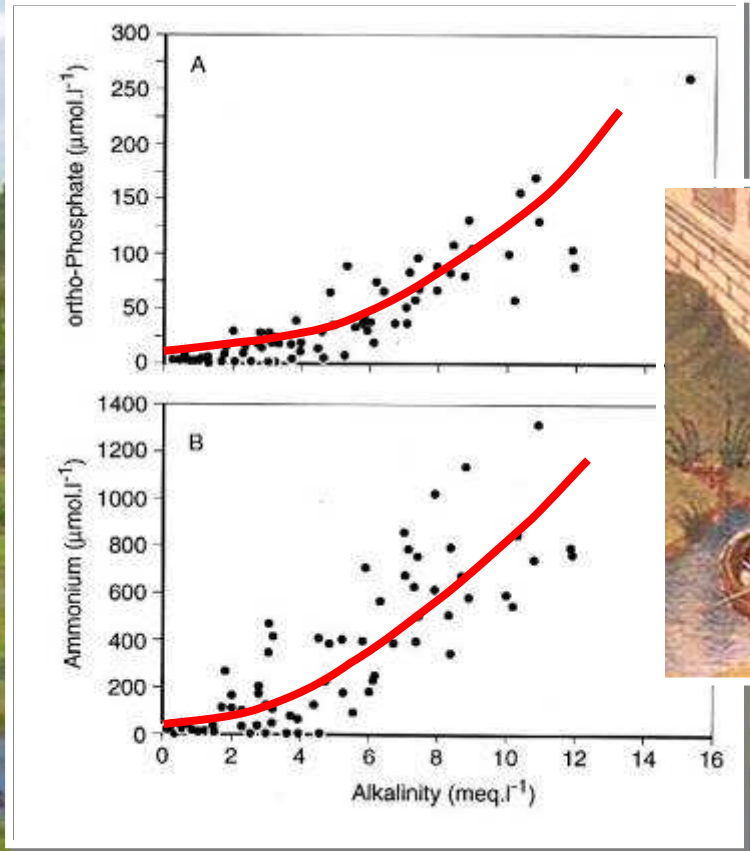
- **Nutrient concentrations**
- **Concentration / degradability organic matter**
- **Alkalinity (ANC)**
- **Ion strength: Cl^-**
- **Electron acceptor availability (microbial redox reaction):**

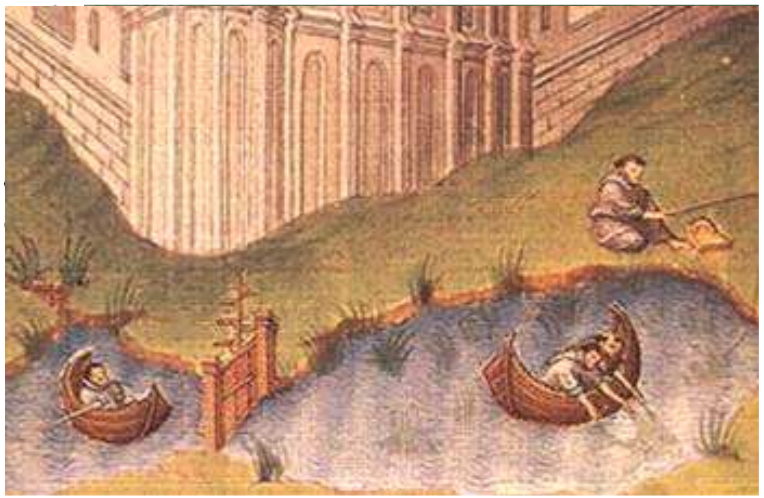
O_2, NO_3, Fe, SO_4^{2-} :

$$SO_4^{2-} + 2\ CH_2O \rightarrow HS^- + HCO_3^- + CO_2 + H_2O$$

mineralisation (N, P, K)
sulphide
P mobilisation (Fe ~ P)
acid buffering

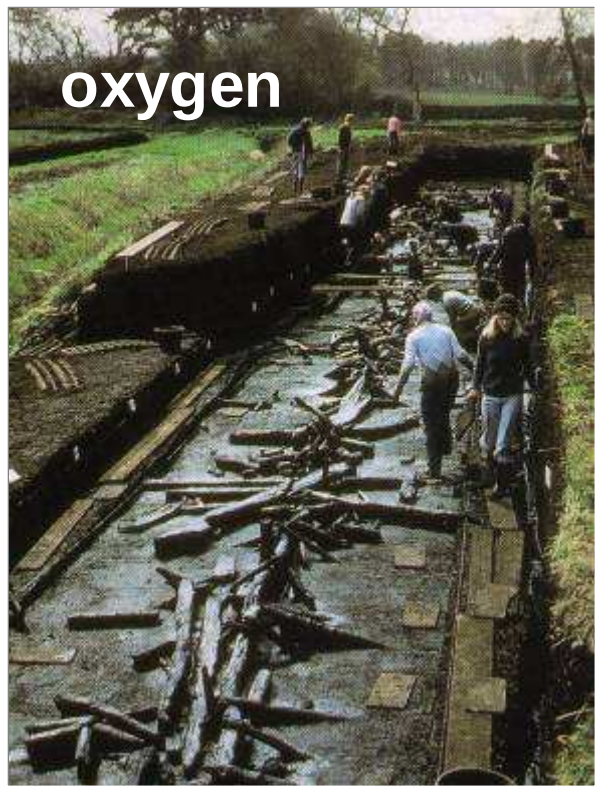
(bicarbonate) alkalinity



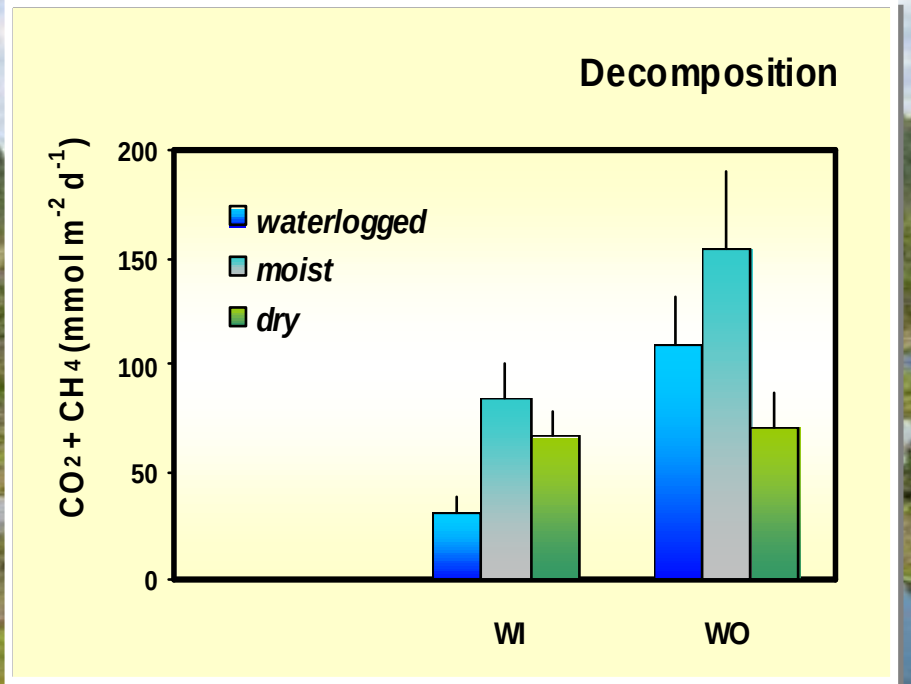


Smolders Ph.D. Thesis 1995
Smolders et al. Chem. Ecol. 2006

electron acceptor availability



Sweet track – Somerset Levels – 3806 BC



S: low high

Lamers et al in prep.

Regulation of decomposition / mineralisation in peatlands

- **Phenolic compounds regulate hydrolase activity**
- **Drainage (O_2 intrusion) stimulates phenol oxidase, lowering phenolics, stimulating decomposition**

Freeman* et al. *Nature 2001

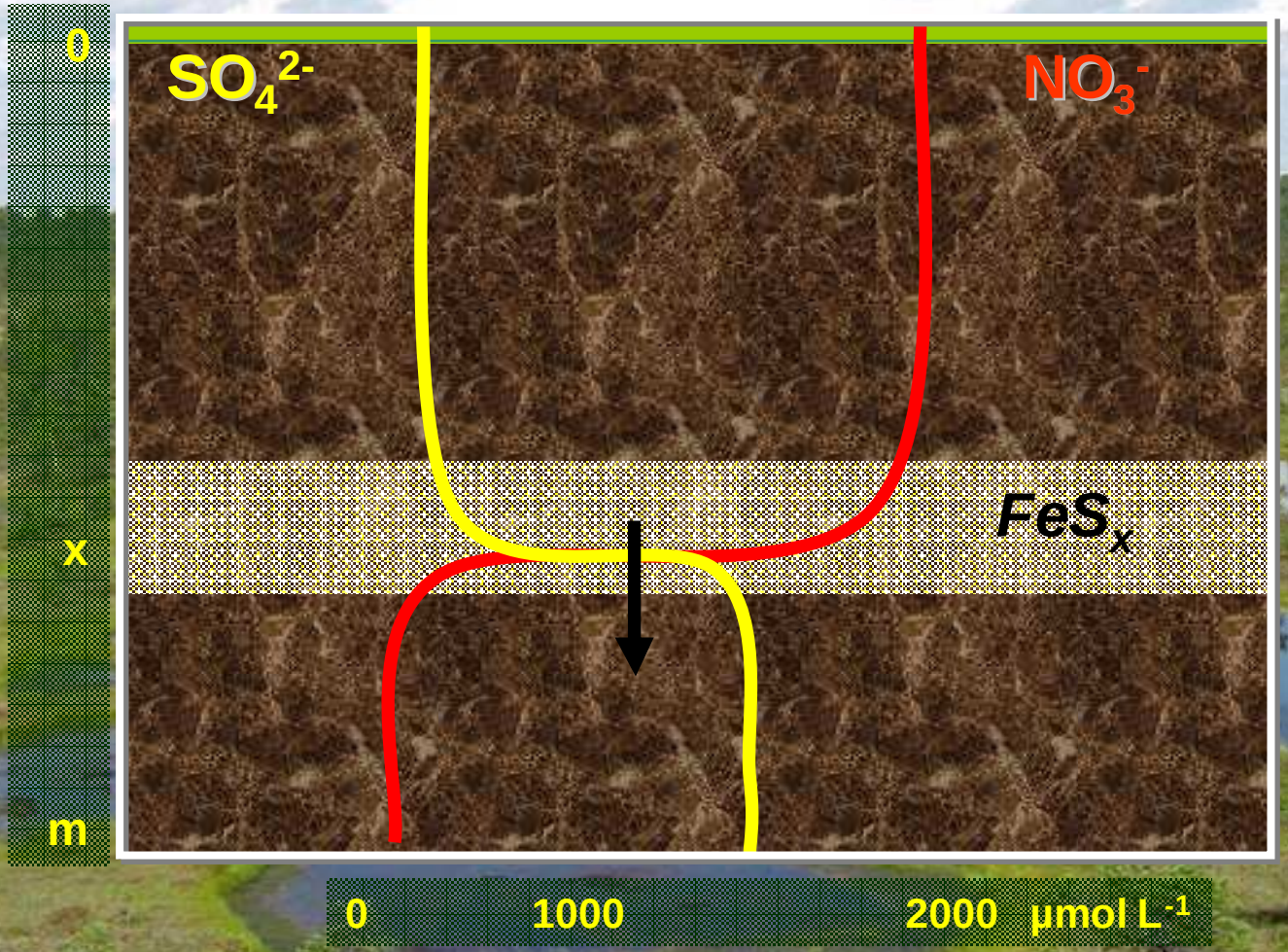
Table 1 Effects on enzyme activities

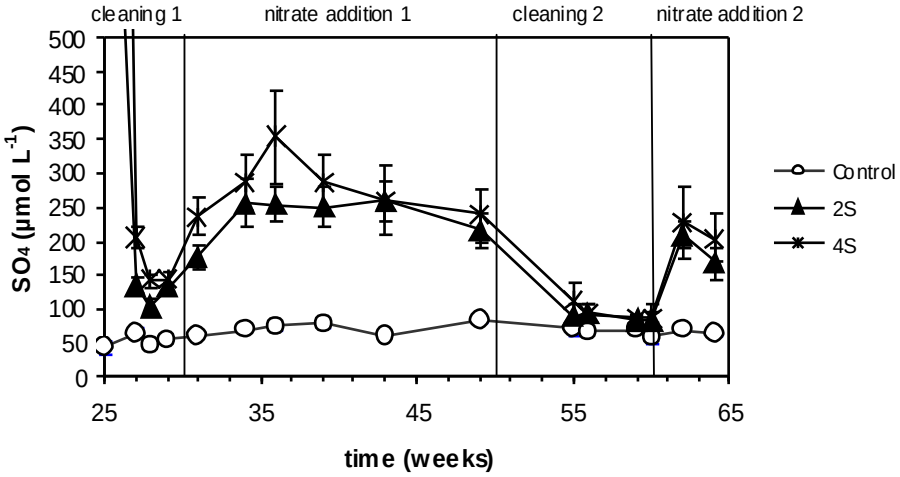
	Control	*Manipulated*
Effect of oxygen on enzyme activity		
Sulphatase	66 ± 2.3	35 ± 1.4
Phosphatase	571 ± 2.4	387 ± 7.9
β-Glucosidase	237 ± 2.3	177 ± 12
Phenol oxidase	615 ± 93	4,350 ± 27
Effect of increasing phenol oxidase abundance		
Phenolics (μg l^{-1})	1,985 ± 55.4	1,444 ± 9.9
β-Glucosidase	1,677±280	10,111±380
Effect of phenolic removal on hydrolase activity		
Sulphatase	579 ± 36	849 ± 43
Phosphatase	3,707 ± 25	4,369 ± 180
β-Glucosidase	1,723 ± 120	2,183 ± 180
Xylosidase	116 ± 2.5	134 ± 5
Chitinase	243 ± 14	296 ± 3.5

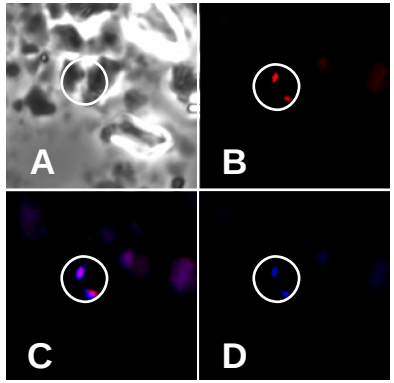
Phenol oxidase activity (nmol 2-carboxy-2,3-dihydroindole-5,6-quinone formation min^{-1} per g peat), hydrolase activities (nmol methylumbelliferone formation min^{-1} per g peat) and phenolic compound concentrations (μg l^{-1}) are reported as mean ± s.e.

nitrate

Under investigation


0
x
m
SO_4^{2-}
NO_3^-
FeS_x
0
1000
2000 µmol L^{-1}



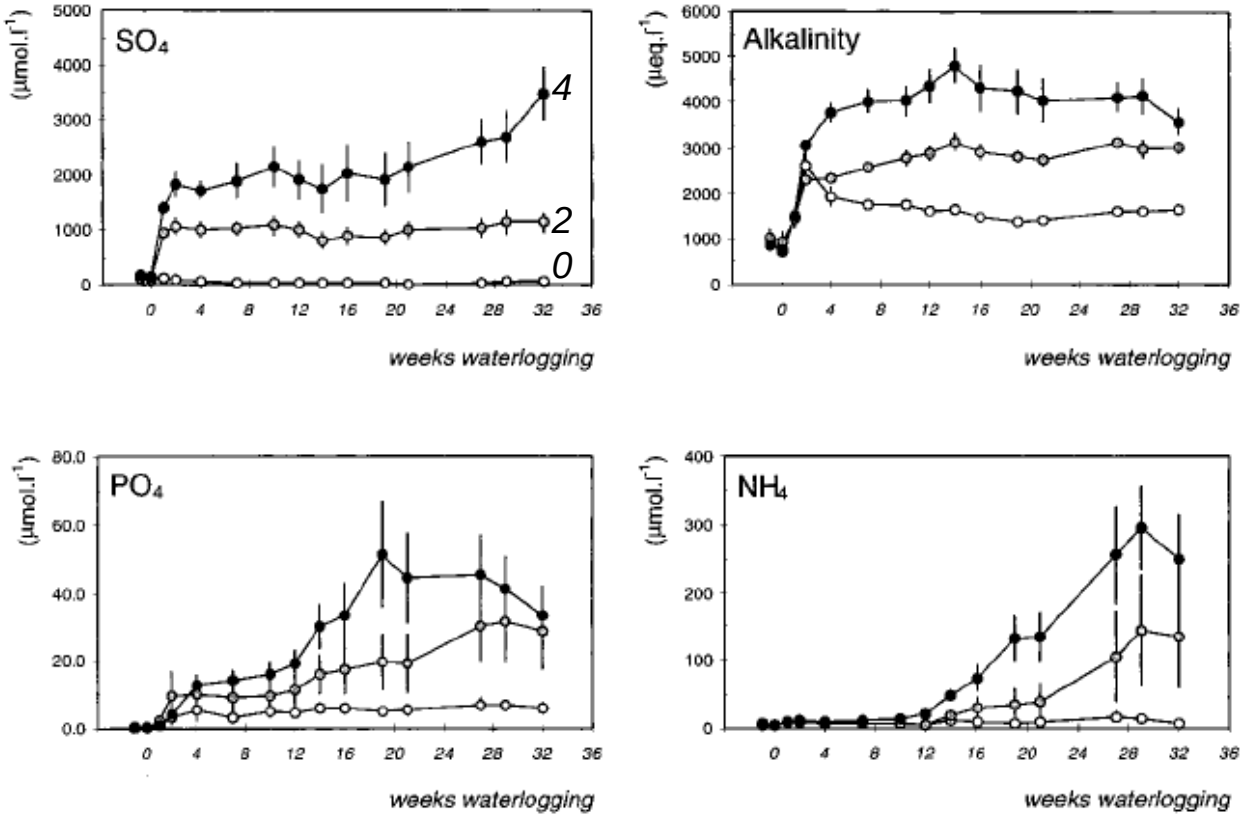


FISH: betaproteobacterial *Thiobacilli*

***Haaijer* et al. FEMS Micr. Biol. 2006**
Van der Welle* et al. *subm.

Total N-loss: 10-15 kg N ha^{-1} day^{-1}
C (TIC) loss!

sulfate

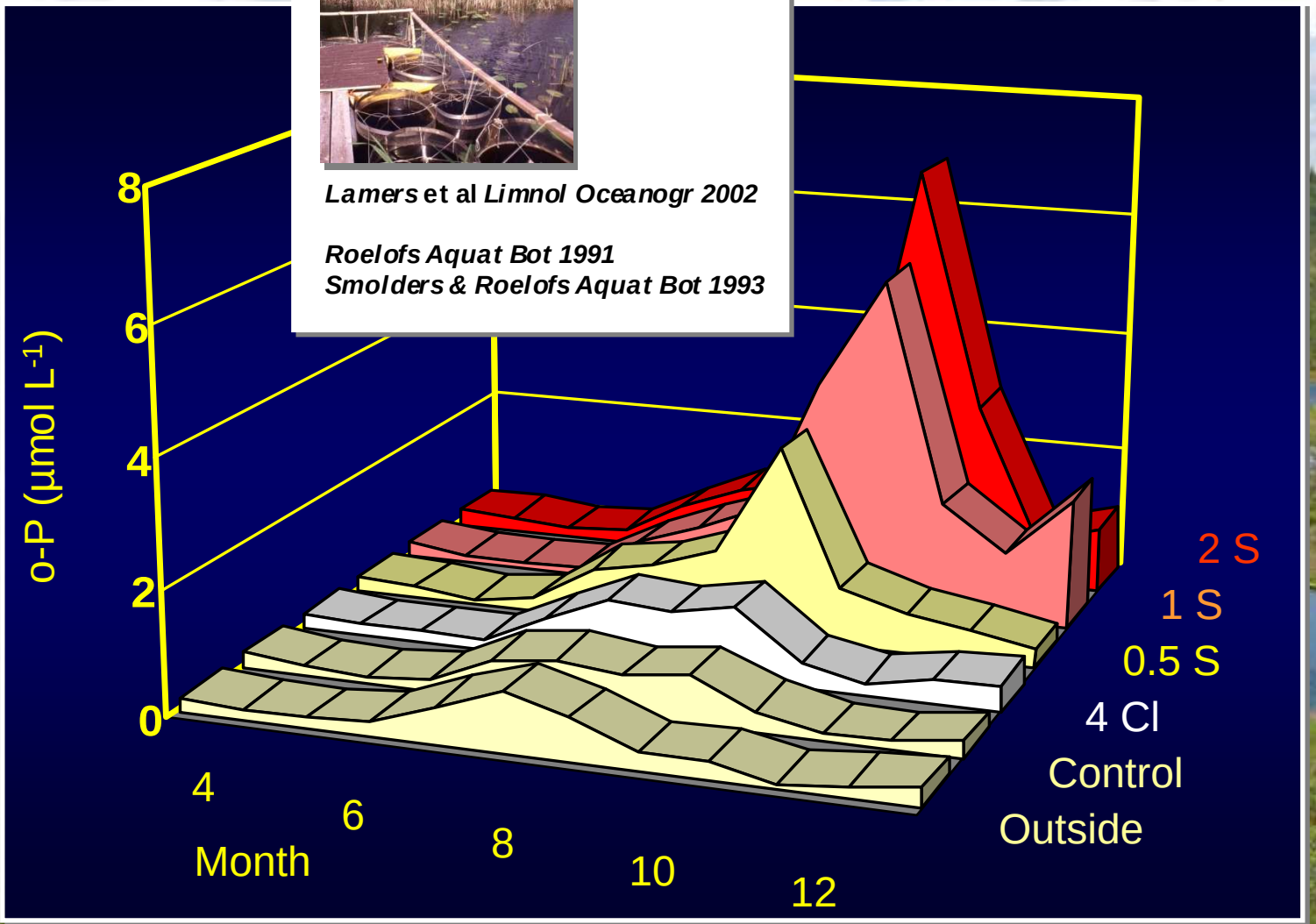


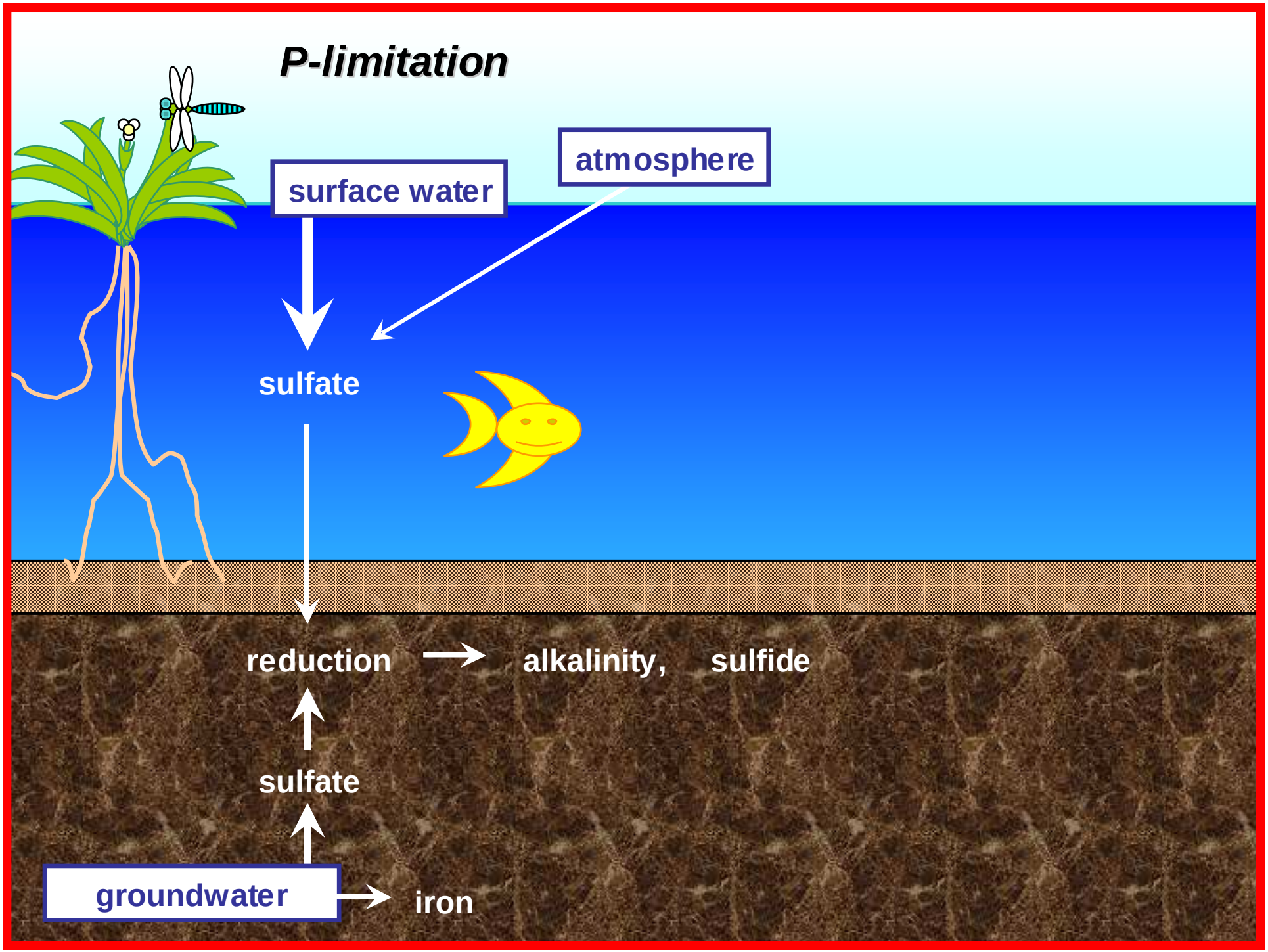
Lamers et al. ES&T 1998

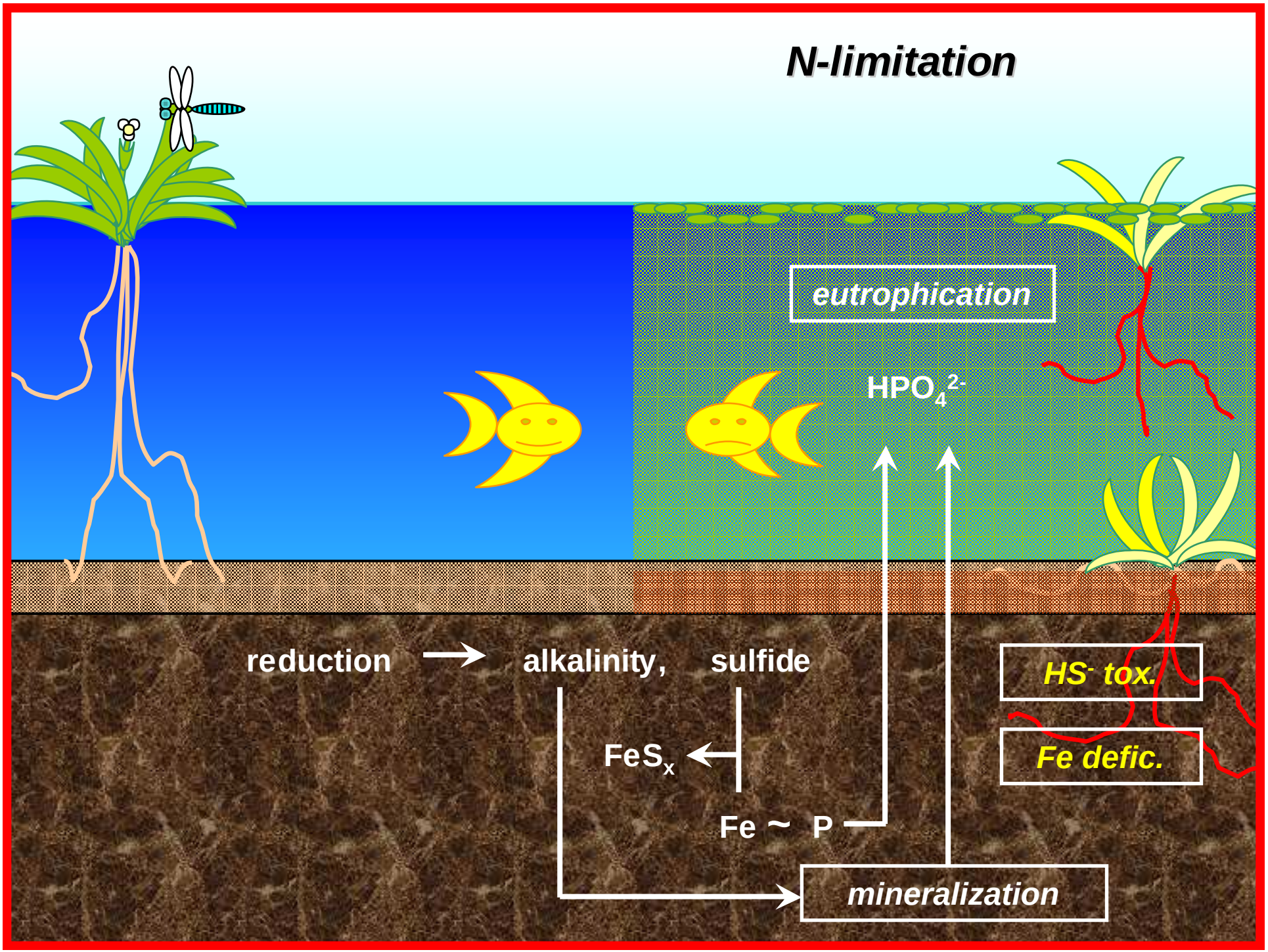
sulfate

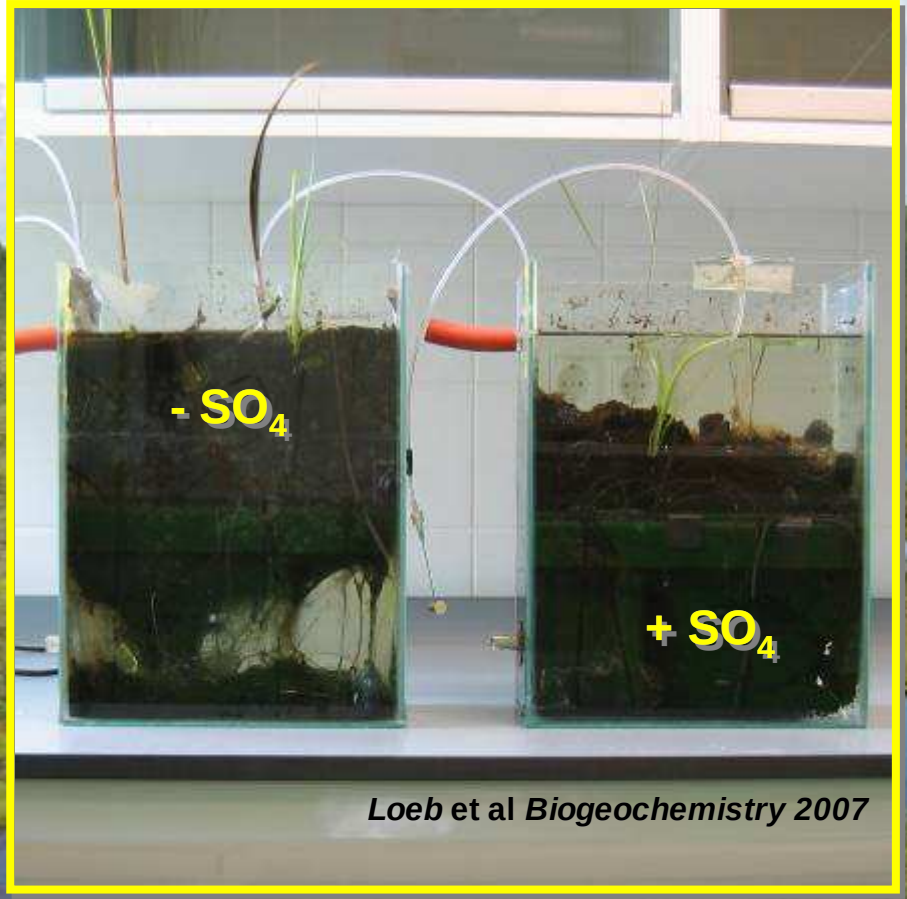
Lamers et al *Limnol Oceanogr 2002*

Roelofs Aquat Bot 1991
Smolders & Roelofs Aquat Bot 1993

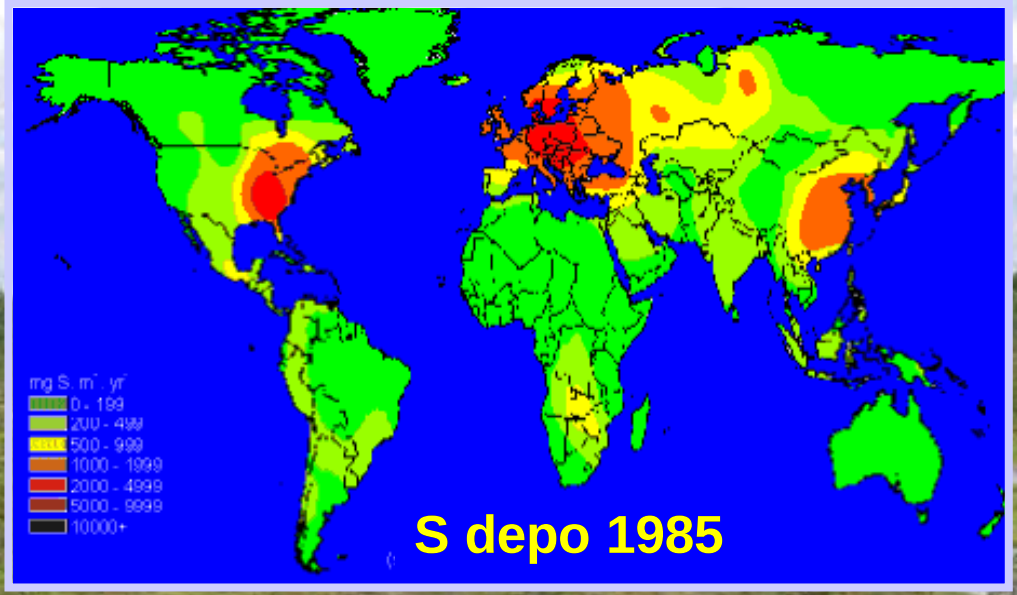


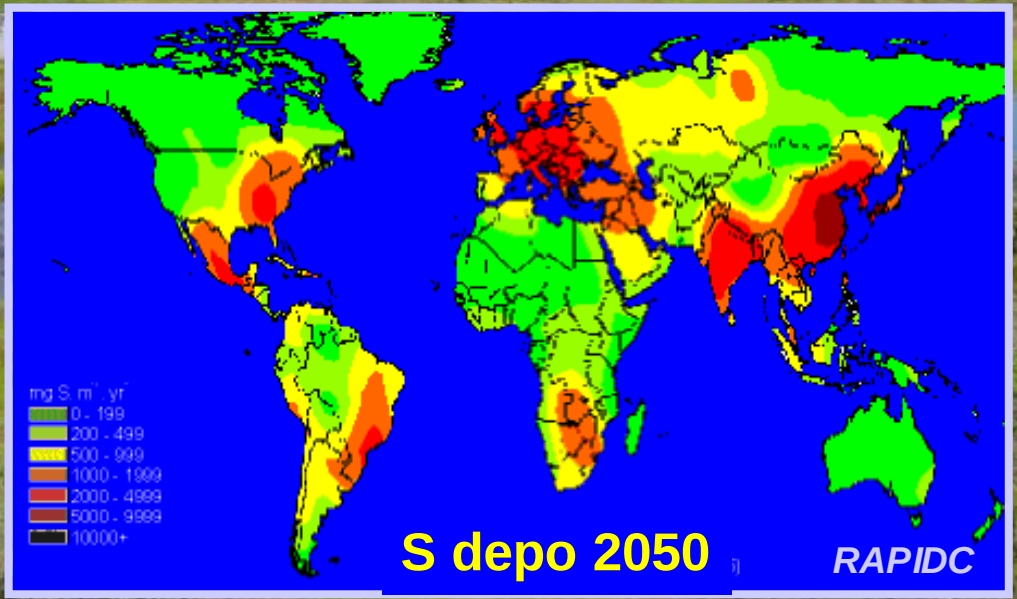

P-limitation
atmosphere
surface water
sulfate
reduction
alkalinity,
sulfide
sulfate
groundwater
iron

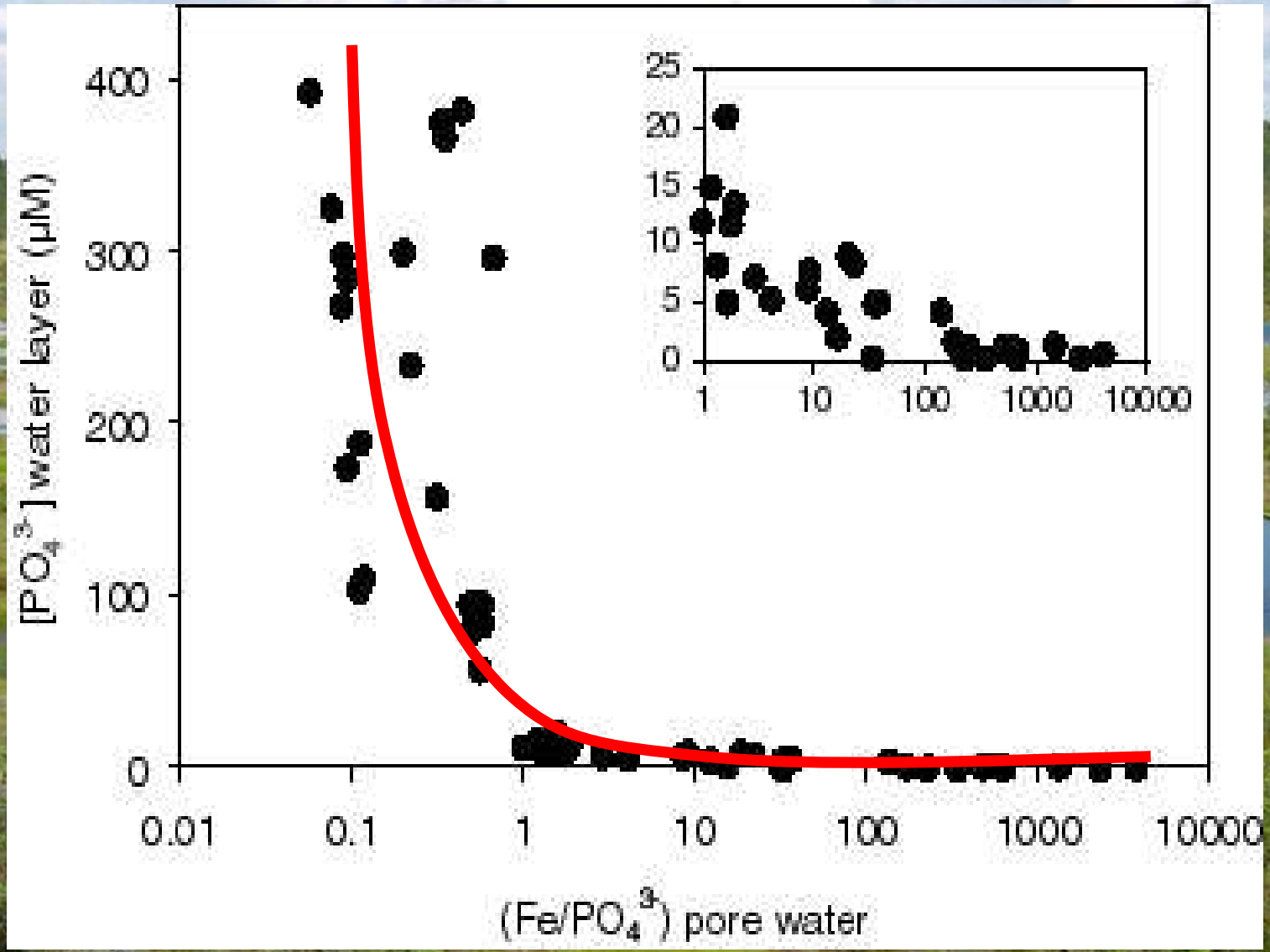

N-limitation
eutrophication
HPO_4^{2-}
reduction
alkalinity,
sulfide
FeS_x
Fe ~ P
HS^- tox.
Fe defic.
mineralization

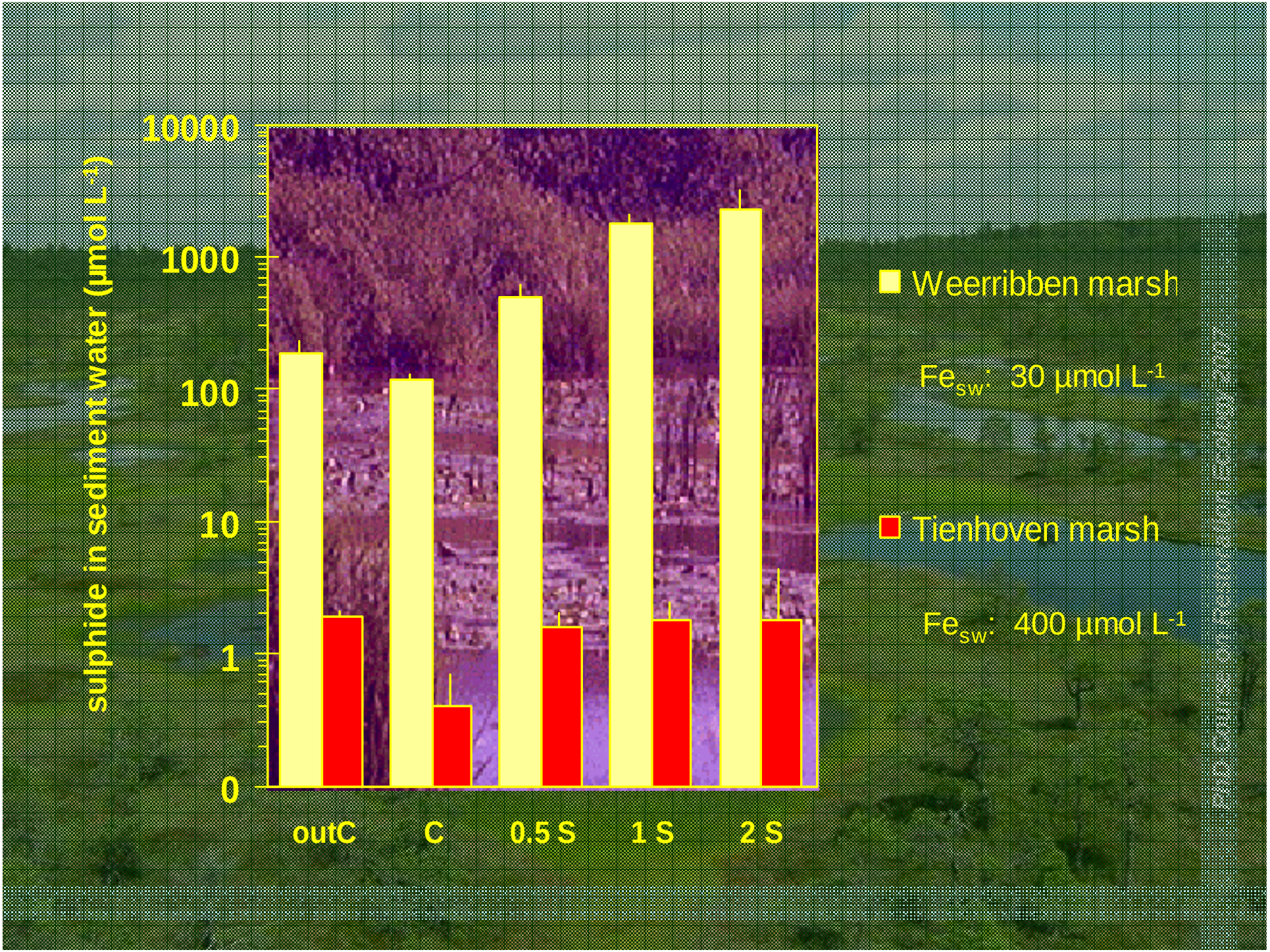


Loeb et al *Biogeochemistry 2007*


mg S m⁻² yr⁻¹
0 - 199
200 - 499
500 - 999
1000 - 1999
2000 - 4999
5000 - 9999
10000+
S depo 1985


mg S m⁻² yr⁻¹
0 - 199
200 - 499
500 - 999
1000 - 1999
2000 - 4999
5000 - 9999
10000+
S depo 2050
RAPIDC


400
300
200
100
0
[PO4 3-] water layer (µM)
0.01
0.1
1
10
100
1000
10000
(Fe/PO4 3-) pore water
25
20
15
10
5
0
1
10
100
1000
10000


10000
1000
100
10
1
0
sulphide in sediment water (µmol L-1)
outC
C
0.5 S
1 S
2 S
Weerribben marsh
Fesw: 30 µmol L-1
Tienhoven marsh
Fesw: 400 µmol L-1

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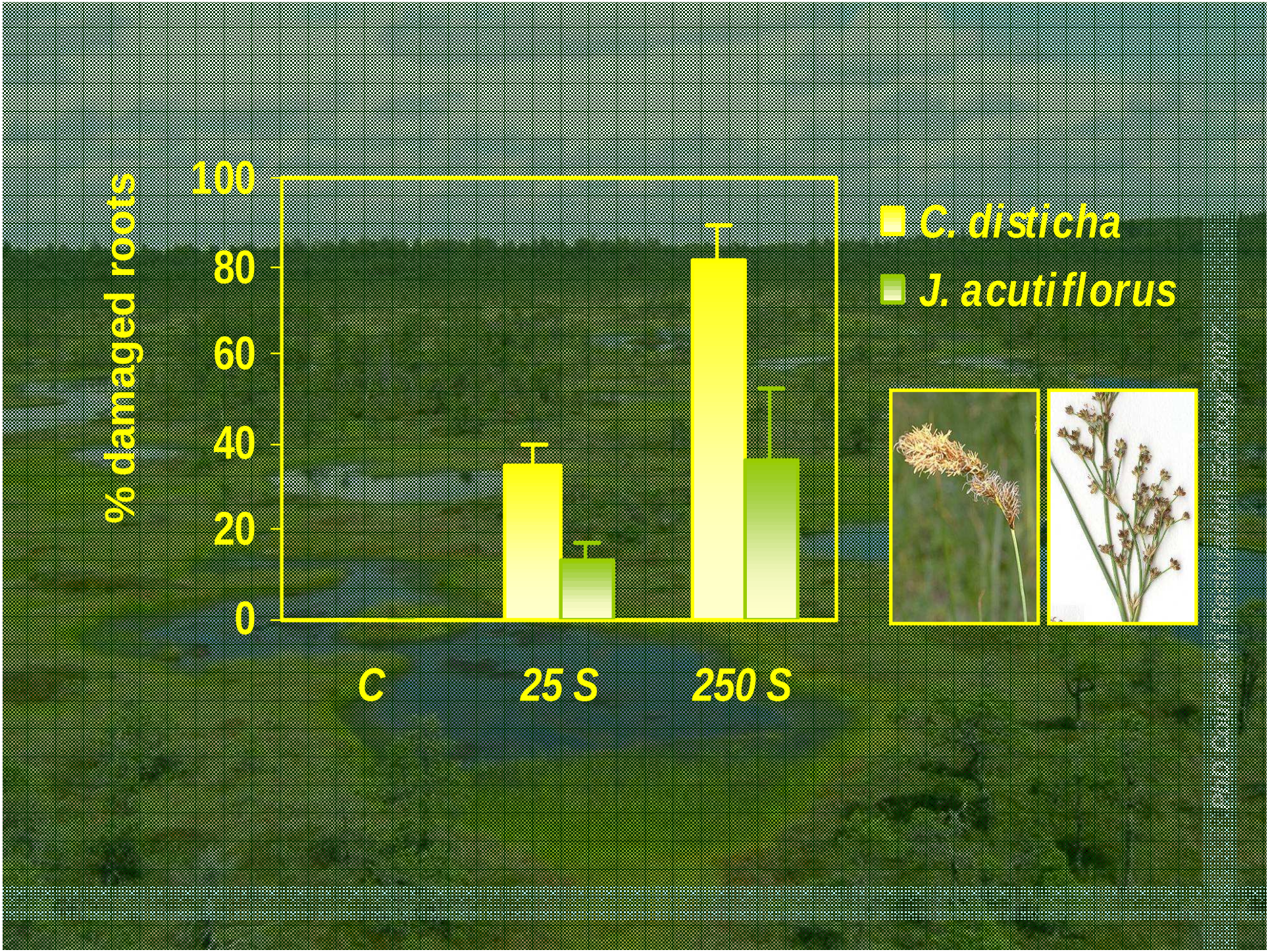
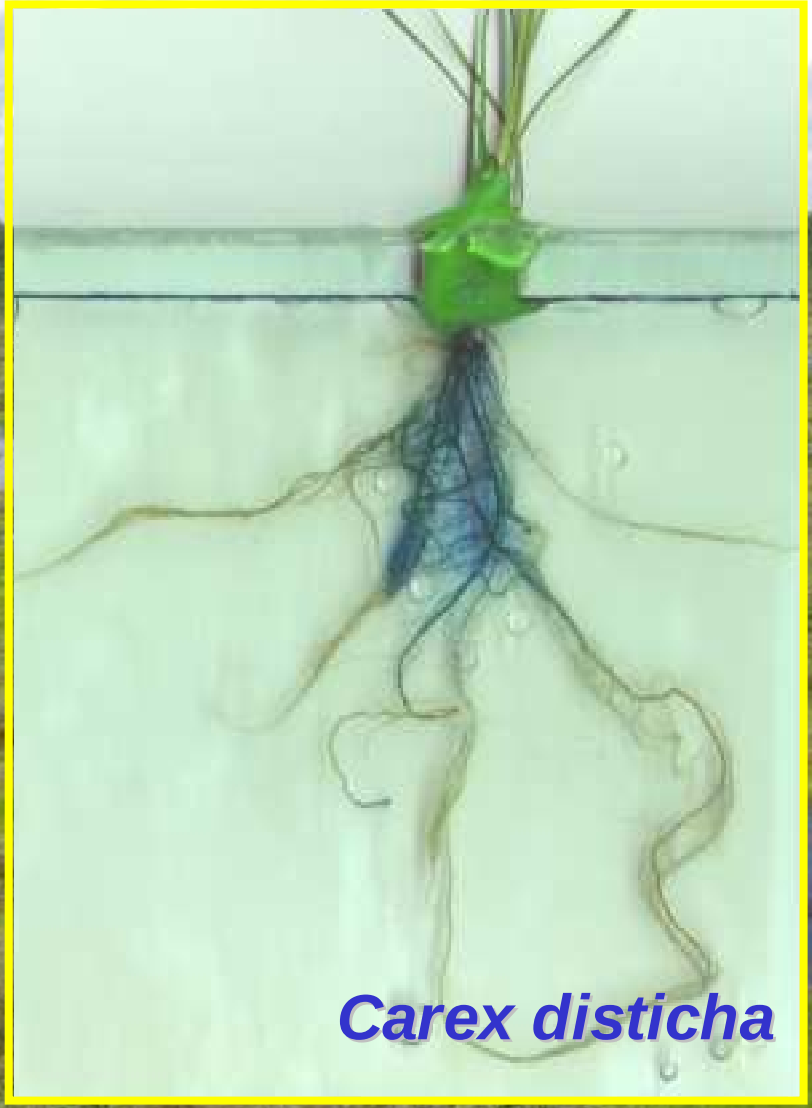
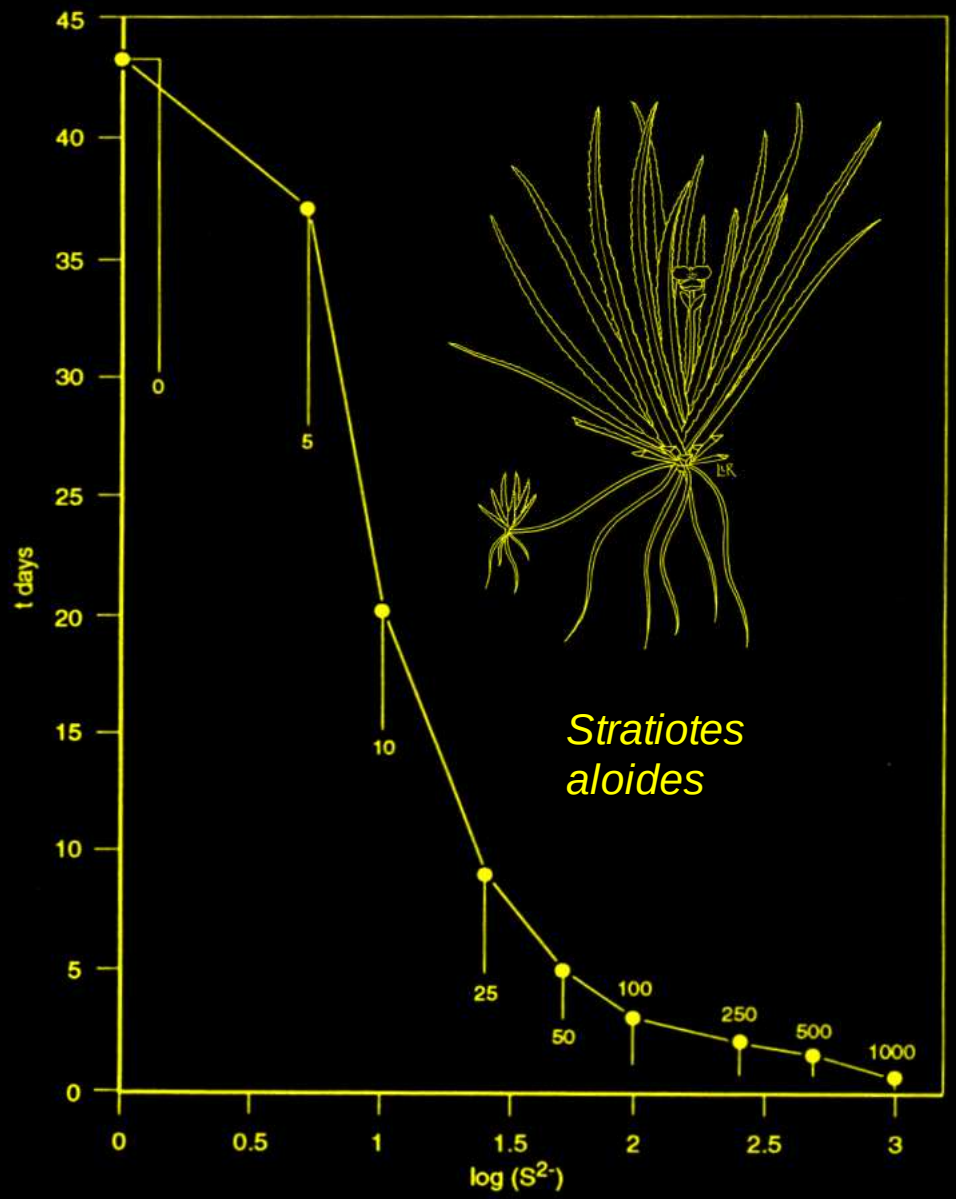

% damaged roots
100
80
60
40
20
0
C
25 S
250 S
C. disticha
J. acutiflorus


Carex disticha

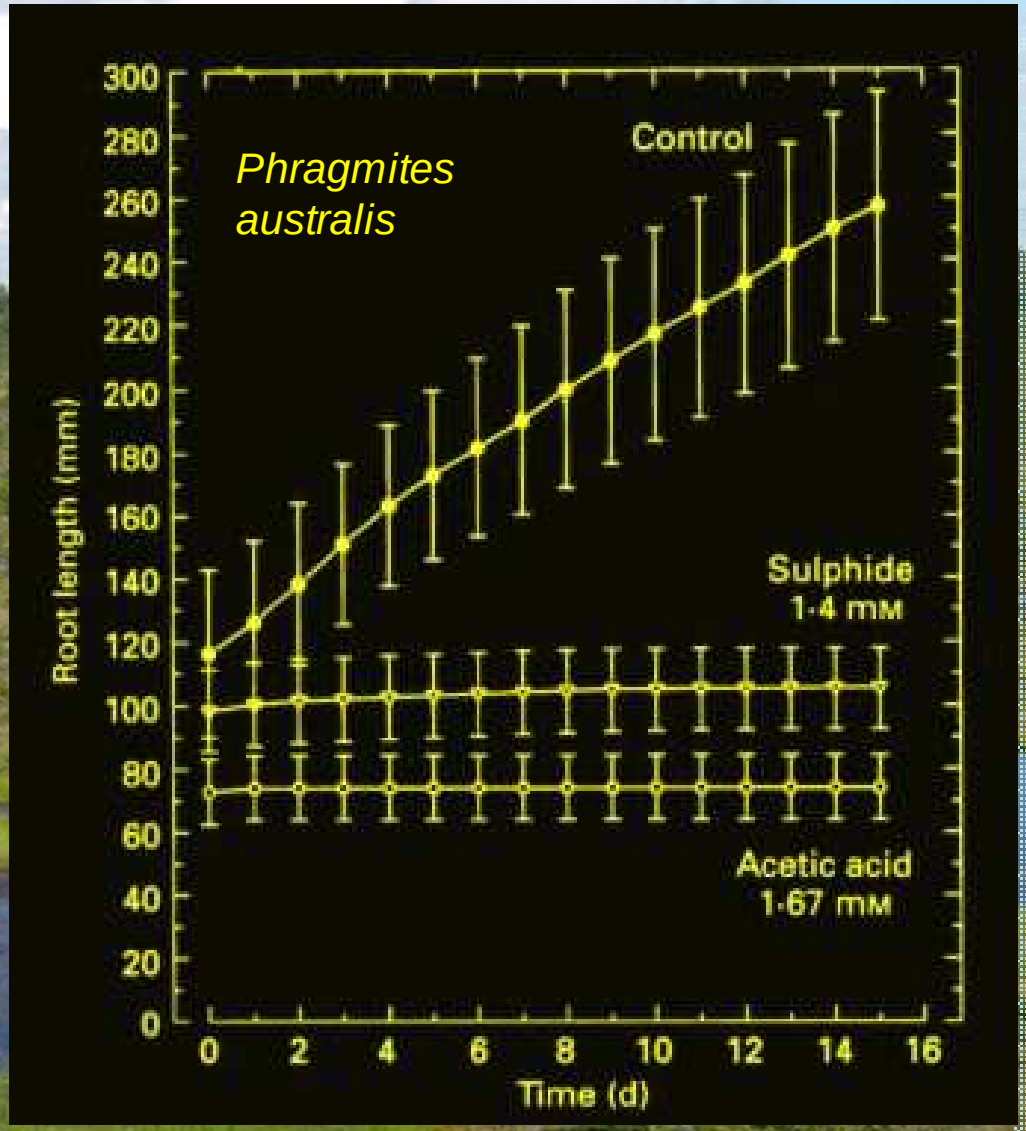

Juncus acutiflorus

Control

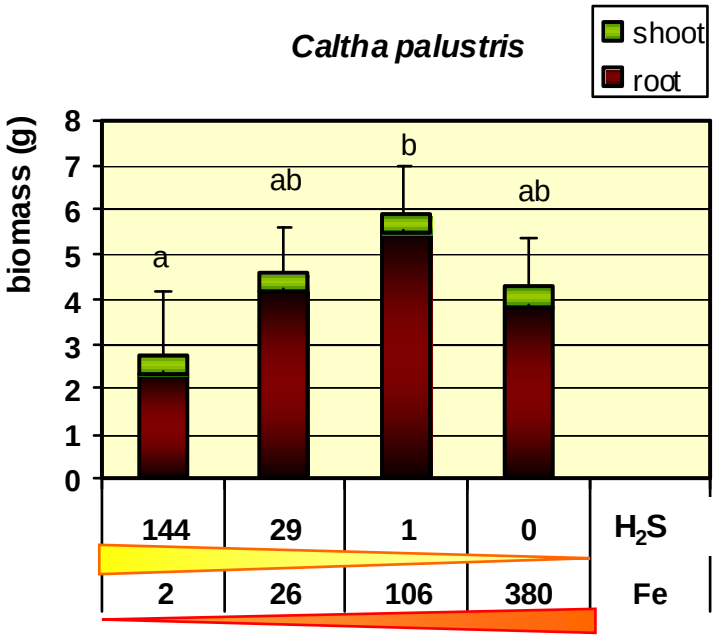
Sulphide treatment



Smolders et al..1996



Armstrong et al. 1996



detoxifying toxicants

Van der Welle et al. *Environ.Tox.Chem. 2006*

Smolders & Roelofs New Phytol.1996

Wetland restoration ?!
Rewetting measures in carr woods oxbow lakes

before

after

Stagnating high water table during summer generates strong eutrophication!!

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Intensification of agriculture resulted in lower groundwater tables and desiccation of fens

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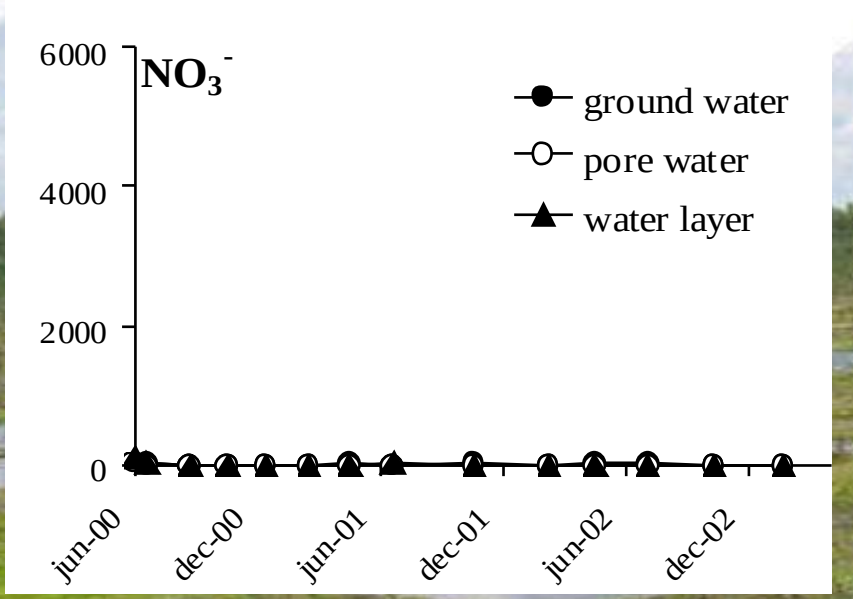
Rewetting by damming groundwater or inlet of allochthonous surface (river) water:

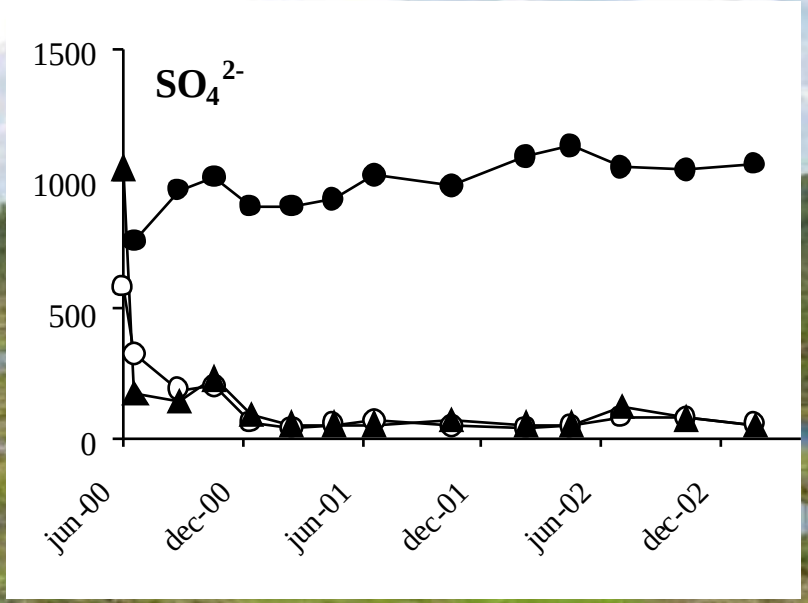
Kaldenbroek fen

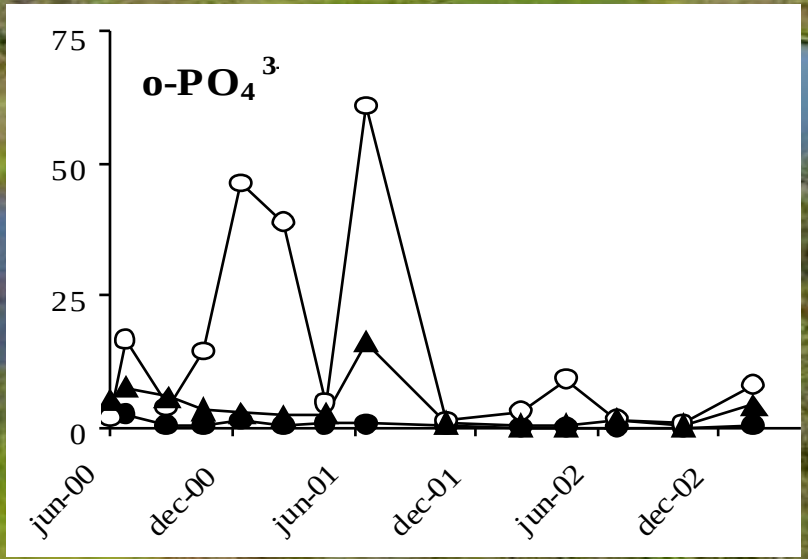
Dubbroekkant

Stagnant, NO_3 low

Flowing, NO_3 high



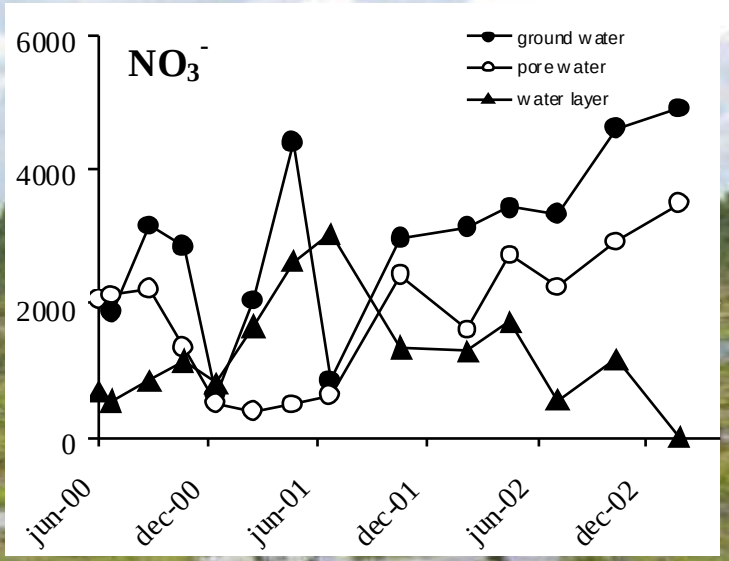


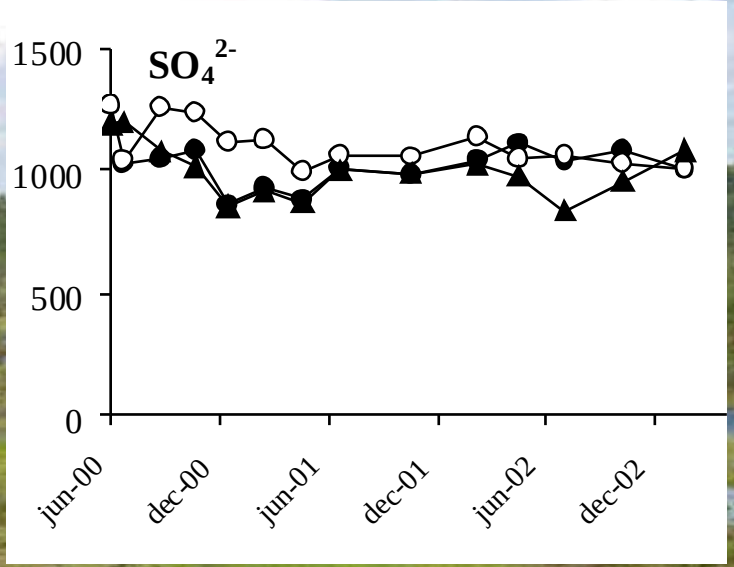


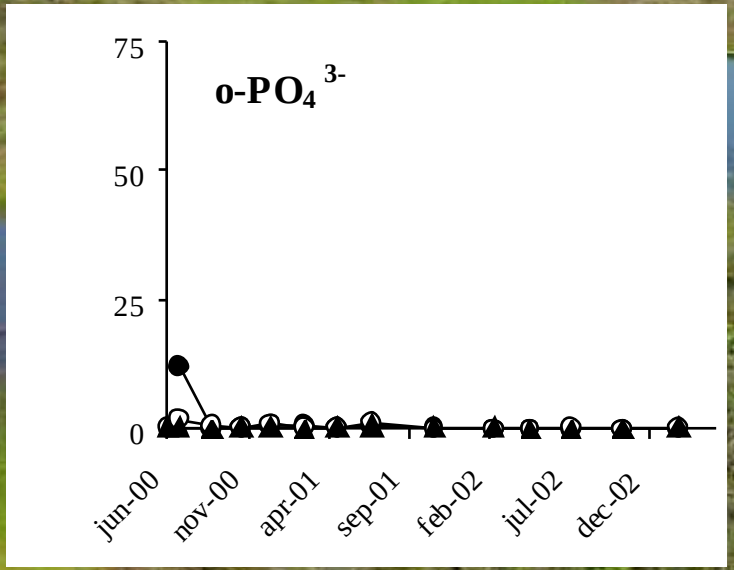
Stagnant, NO_3 low

(µmol L^{-1})

Lucassen et al 2004







Flowing, NO_3 high

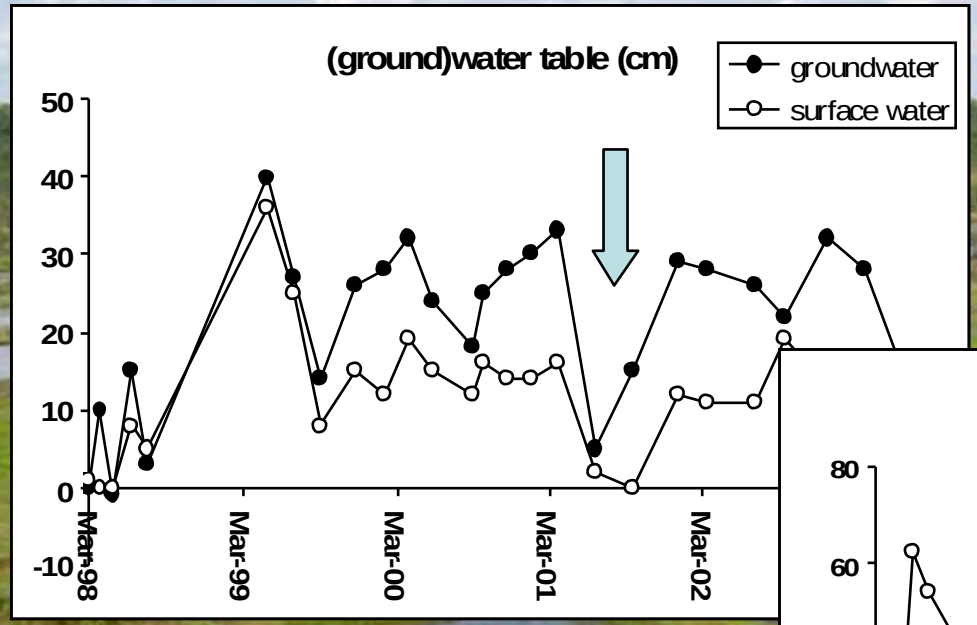
($\mu mol\ L^{-1}$)

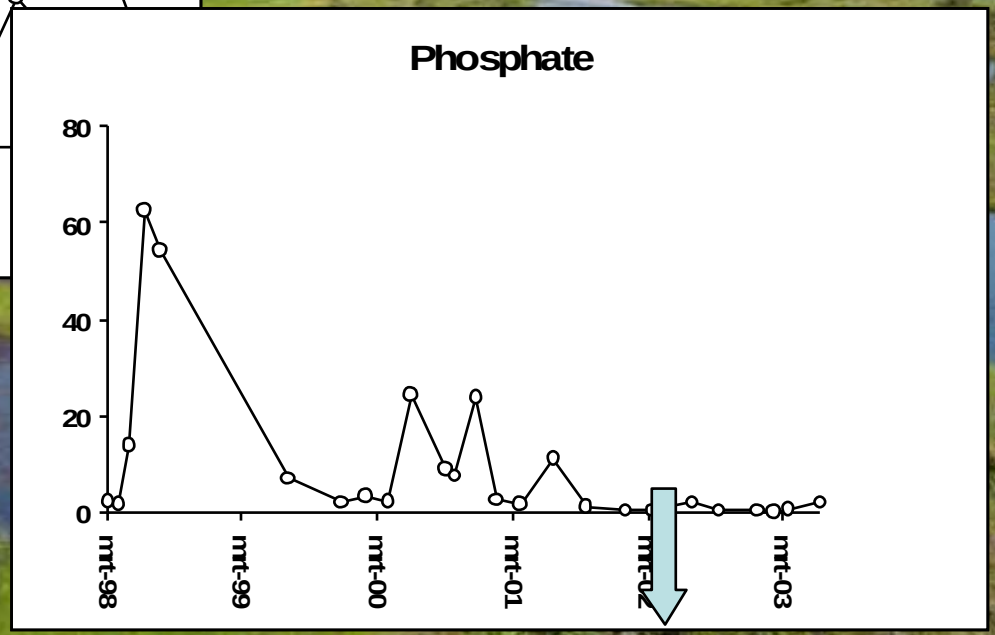
flow

Lucassen et al. *Plant Soil 2005*
Lucassen et al. *Wetl. Ecol. Manag. 2005*
Van der Welle et al. *Freshw. Biol. 2007*

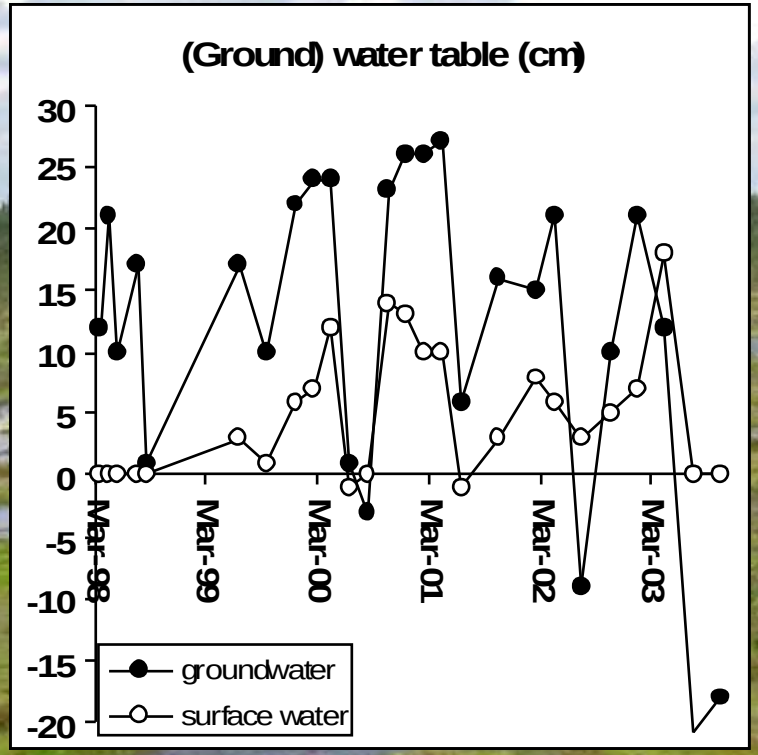
stagnant + chloride

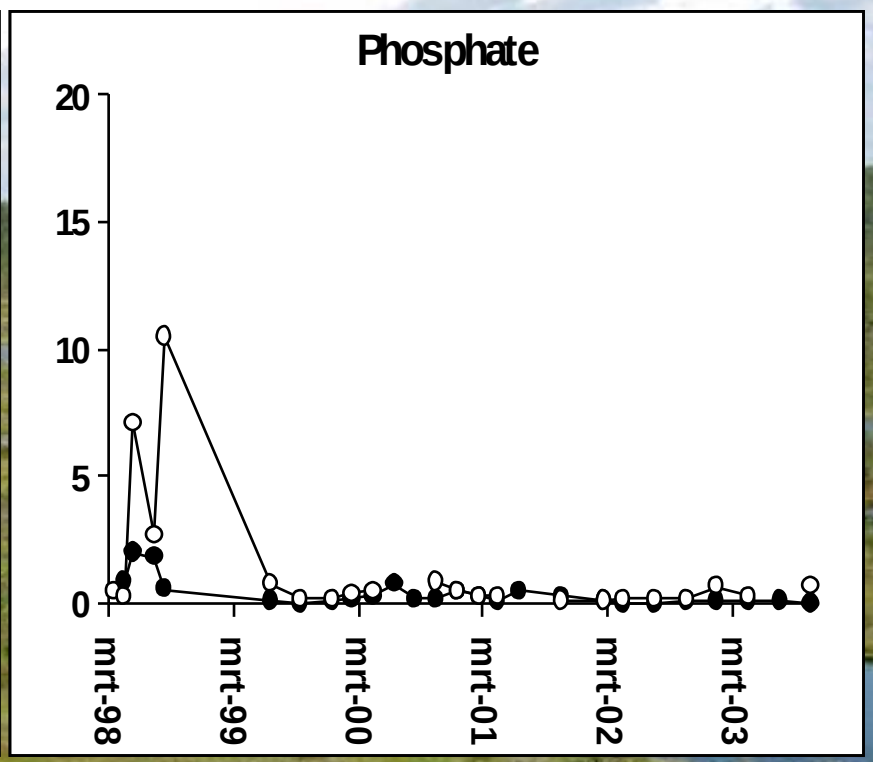
stagnant + sulfate





Kaldenbroek fen: no temporary desiccation (first two years)





Dubbroek: temporary desiccation

Lucassen et al 2005

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Natural water table fluctuation: proof from 1617!

Rubens & Brueghel: Pan & Syrinx in Arcadia (Hollandica)

Towards a more natural hydrological regime:

- Now: Winter *low*: drainage (agriculture)
  Summer *hoog*: supply (agriculture, nature)

  Artificial regime!

- Future: Winter *higher*: water storage
  Summer *lower*: modest desiccation

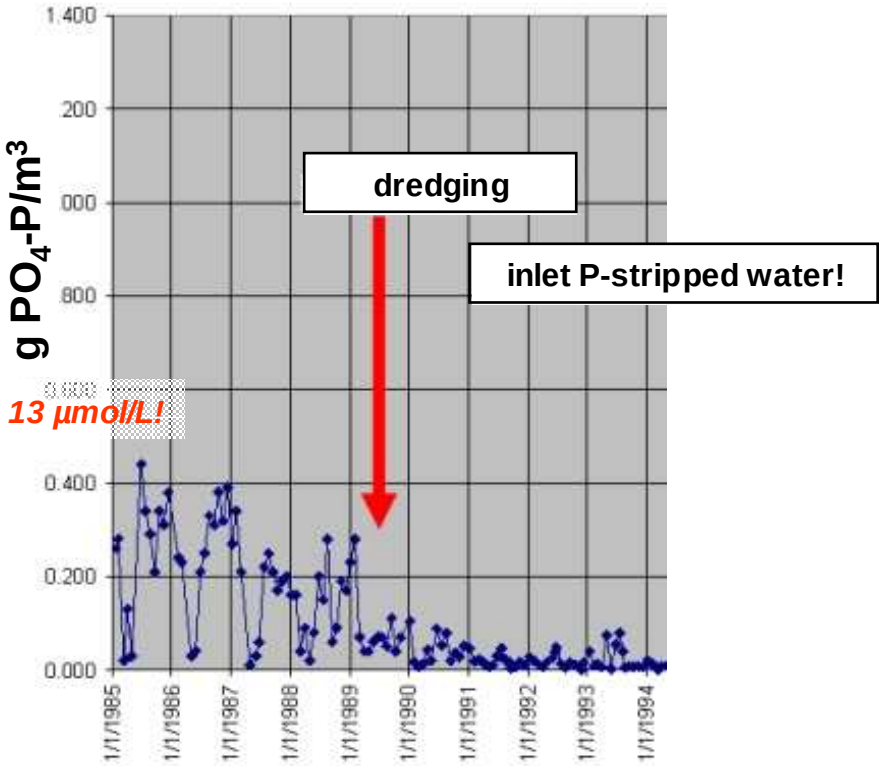
Profits:

- Less allochthonous water
- Less P-mobilisation, more P-binding
- Stimulation growth and germination helophytes (e.g. Reed)
- Stimulation germination aquatic macrophytes
- Detoxification (e.g. for sulphide)

Drawbacks (?):

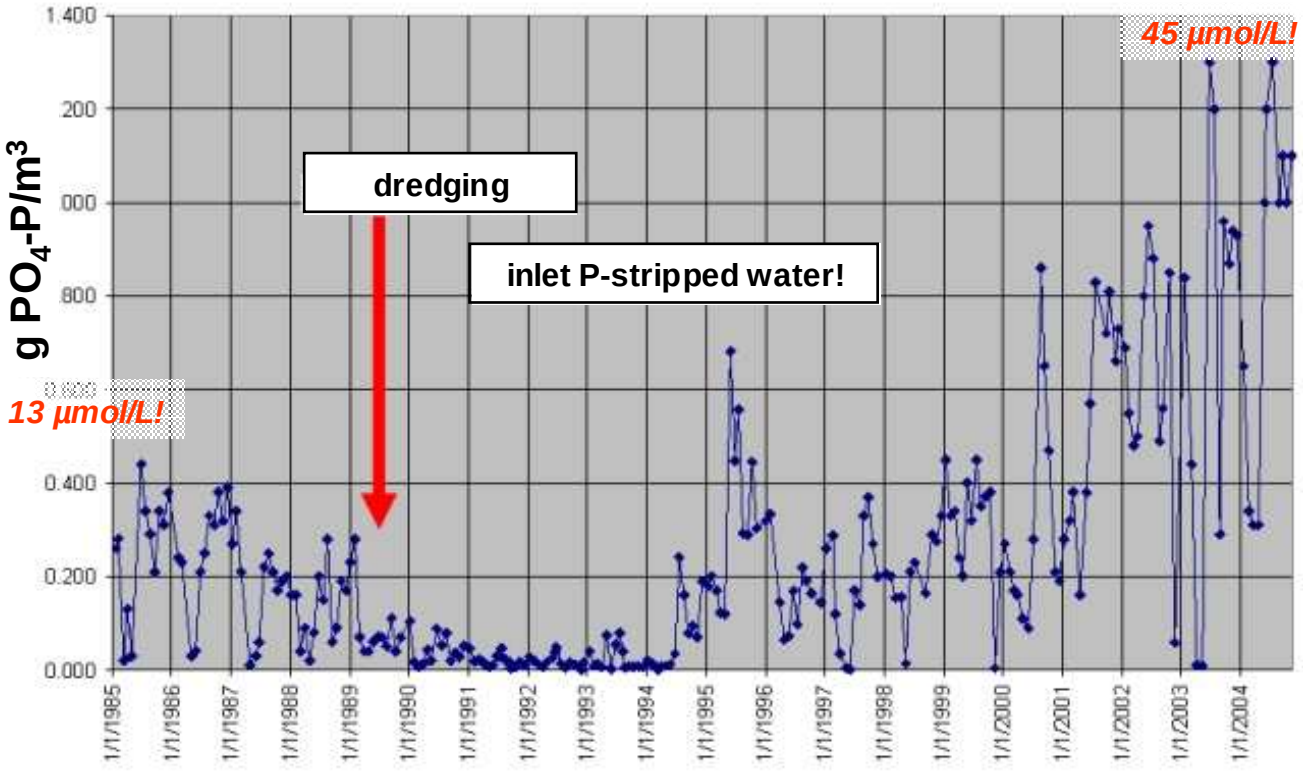
- Desiccation and S mobilisation (?)
- Increased mineralisation (?)
- Problems for infrastructure, recreation, homes

Shallow peat lake (Geerplas, the Netherlands)

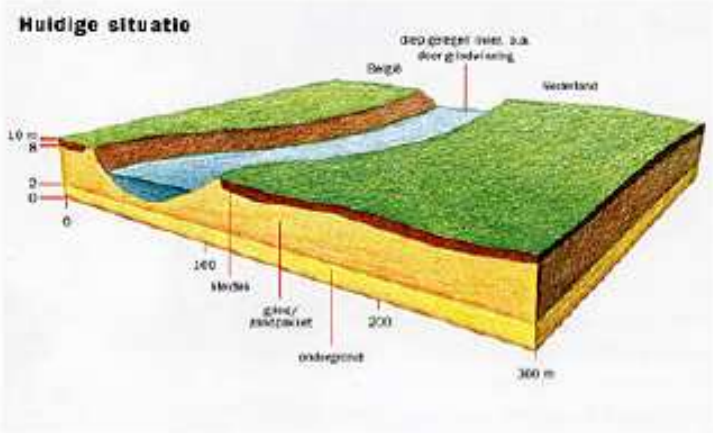


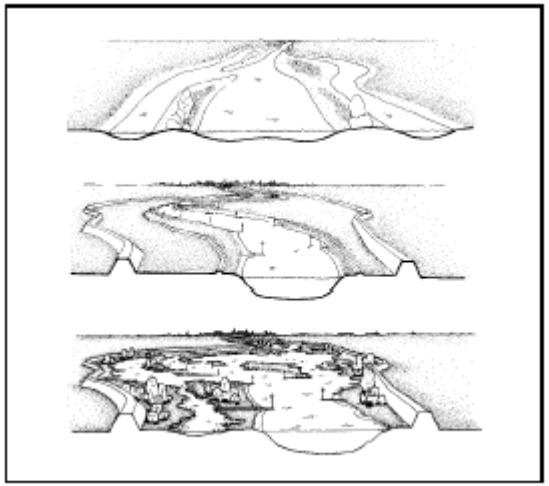
Michielsen et al. 2007

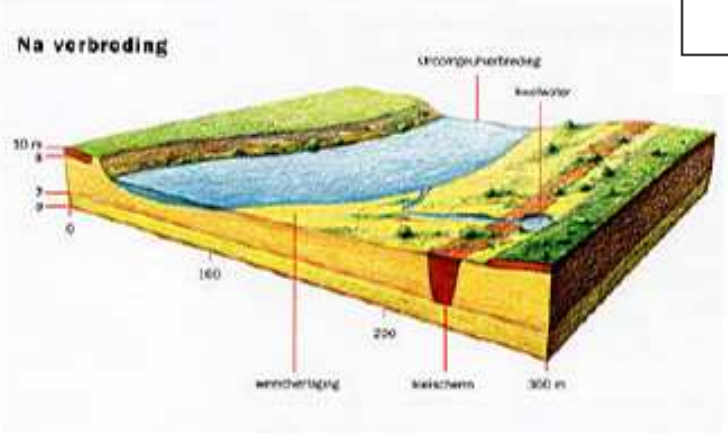
Shallow peat lake (Geerplas, the Netherlands)

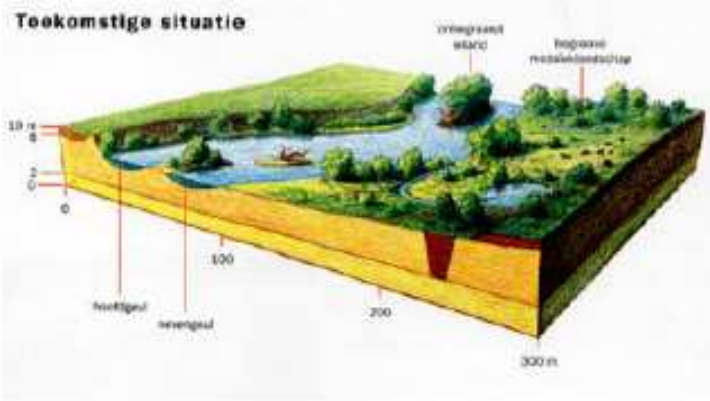


Michelsen et al. H2O 2007

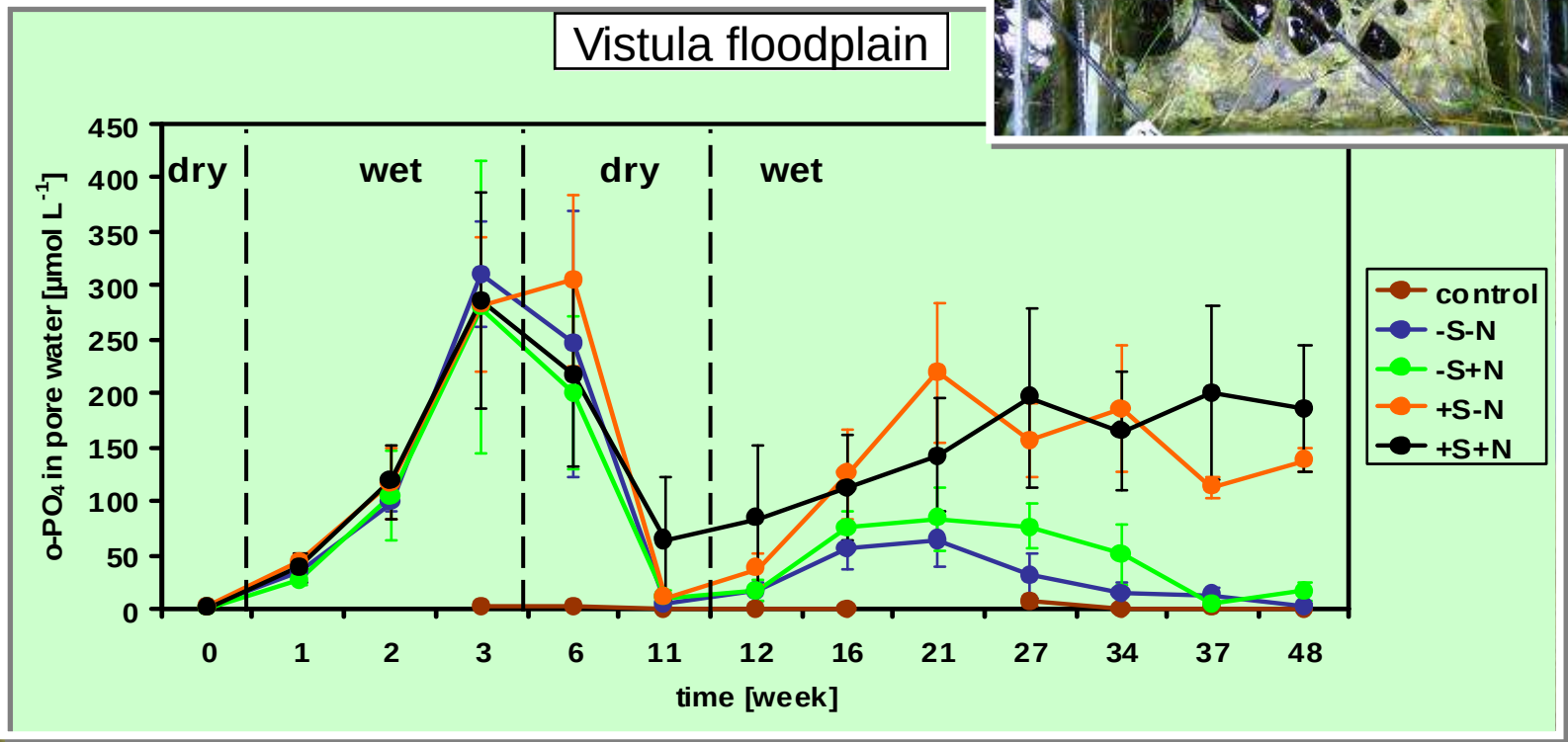

Huidige situatie
Begrip
Nederland
10 m
8
2
0
0
100
kleiblok
gras/
zeekraalvlet
200
ondergrond
300 m




Na verbreding
10 m
8
2
0
0
100
200
verschertlaging
kleischerm
300 m

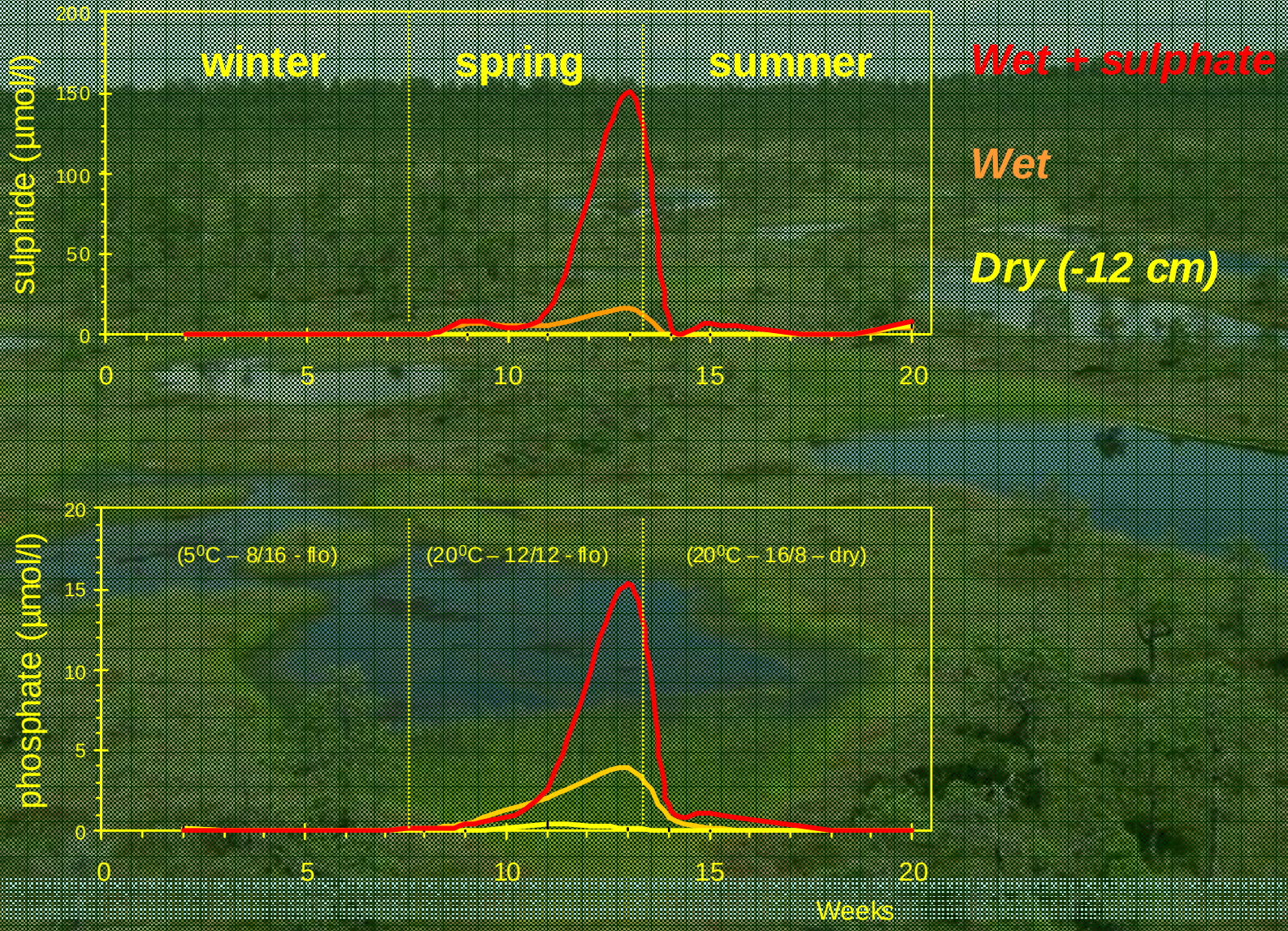

Toekomstige situatie
10 m
8
2
0
0
100
200
300 m

sulfate



Banach et al. *in prep.*

Flooding and wetland creation / restoration: seasonal effect?



Wet + sulphate

Wet

Dry (-12 cm)

Water storage

- **Winter: less harm**

In existing wetlands

- **Spring / summer: high eutrophication risk (especially with alkaline, S-rich water)**
  -> *not in oligo- / mesotrophic wetlands*

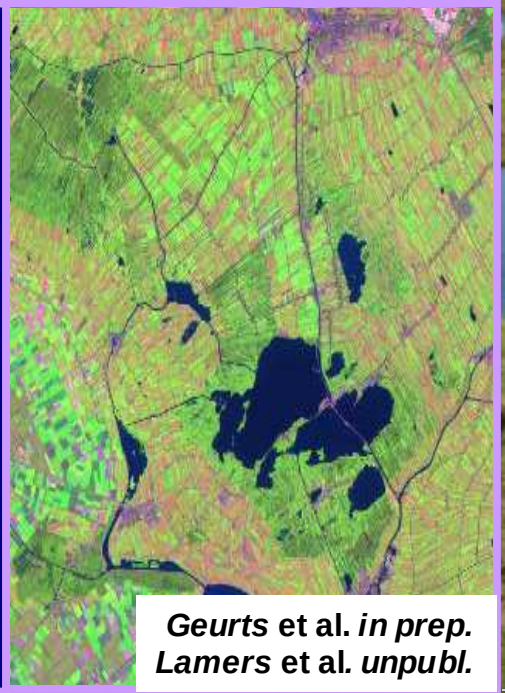
In combination with wetland creation?

Low conc. mobilisable P: - ok
High conc. mobilisable P: - either remove top layer and P
- or hypertrophic wetland

Measures?

1. Lower influx P N
2. Hydrological measures: decreased internal mobilization!

	Input	*Weerribben*		
		'82-'92	*'98*	
Water				
HCO_3^-	3	2	1.5	(mmol L^{-1})
SO_4^{2-}	1.5	0.3	0.2	
Cl^-	3	1	1	
PO_4^{3-}	0.5 / 1.5	2	0.3	(µmol L^{-1})
Sediment				
PO_4^{3-}		25	3	(µmol L^{-1})
Fe		3	30	



Geurts et al. *in prep.*
Lamers et al. *unpubl.*

Conclusions

- Global change effects complex: decomposition, primary production, changes vegetation
- Mineralization (partly) coupled to decomposition
- Internal eutrophication: pollutants from the past
- Water en soil quality
- Management (e.g. wetland restoration) should take account of these internal processes