



RESEARCH CENTRE

BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

Restoration management in degraded fens and bogs

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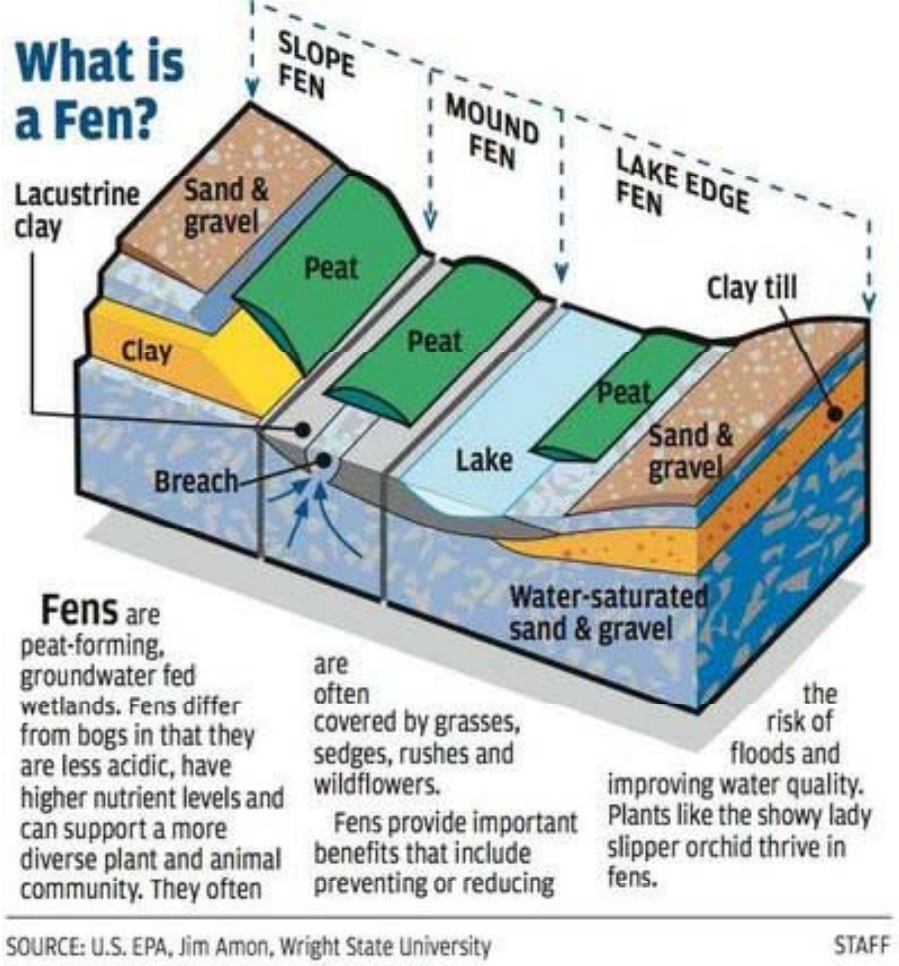
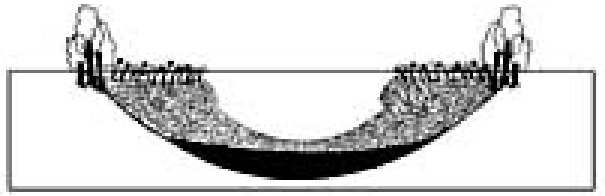
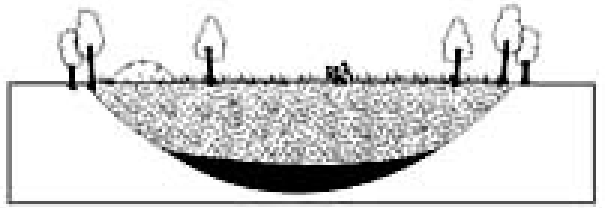
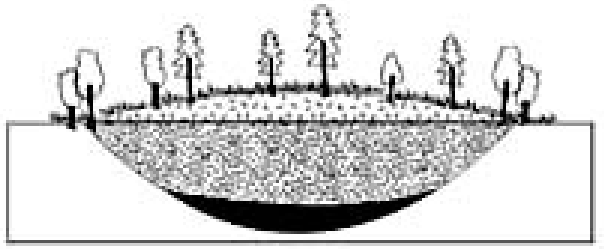
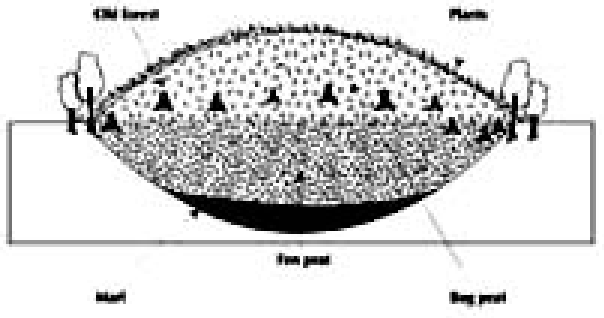


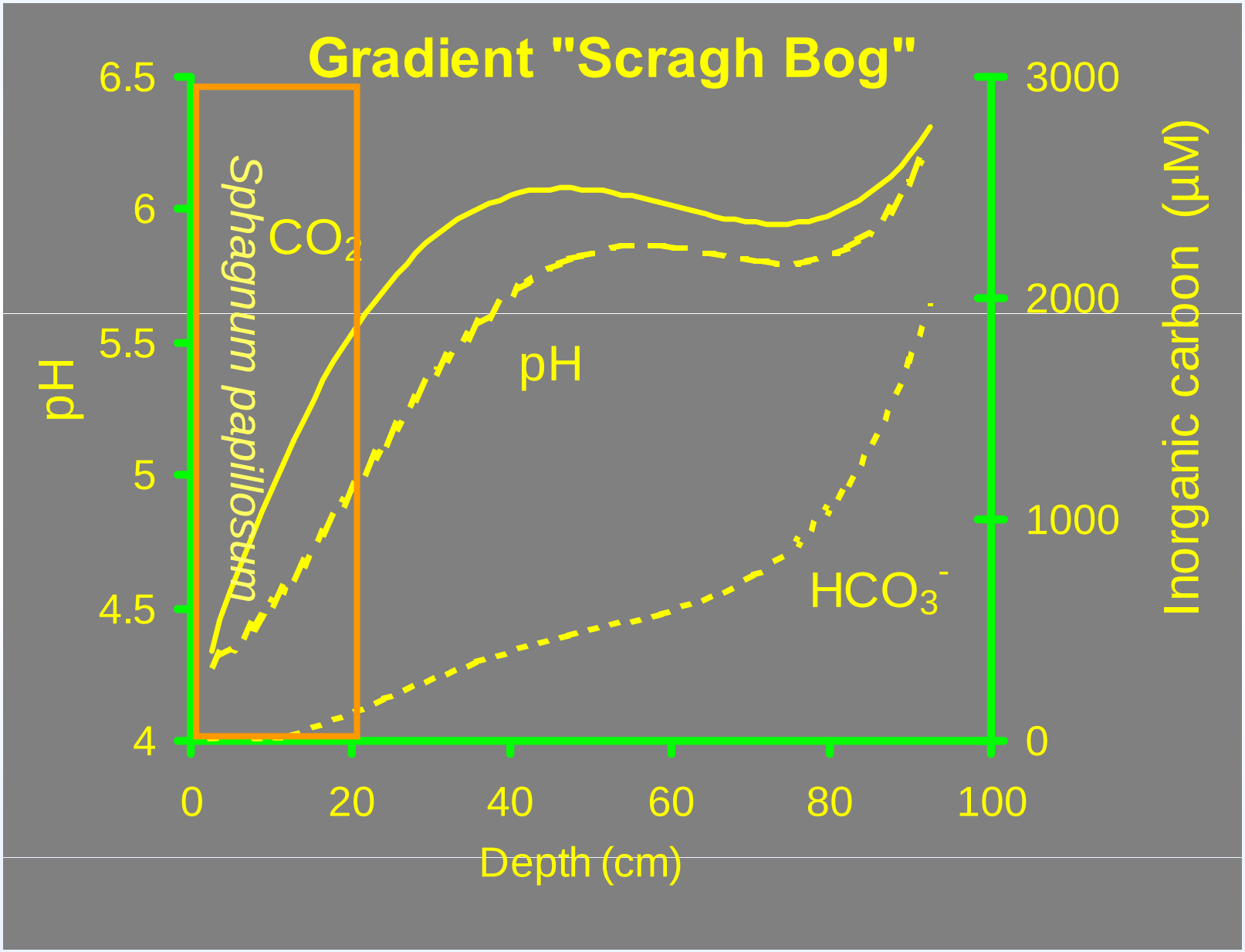


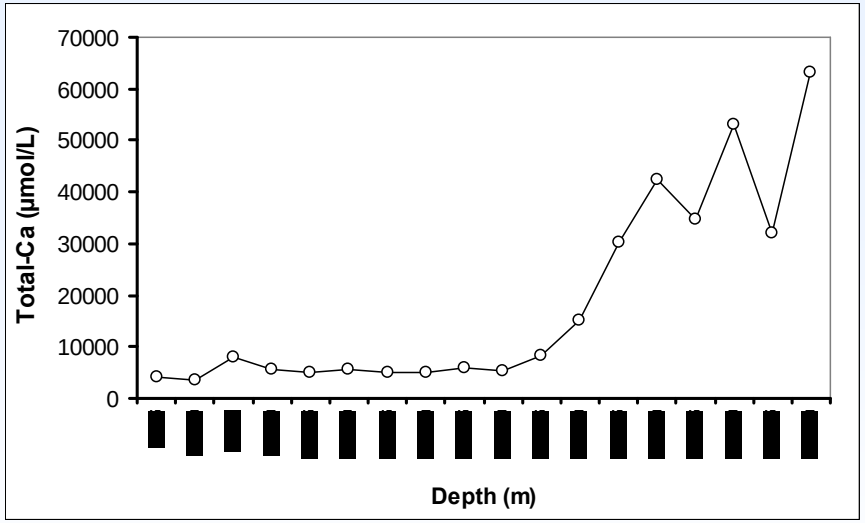


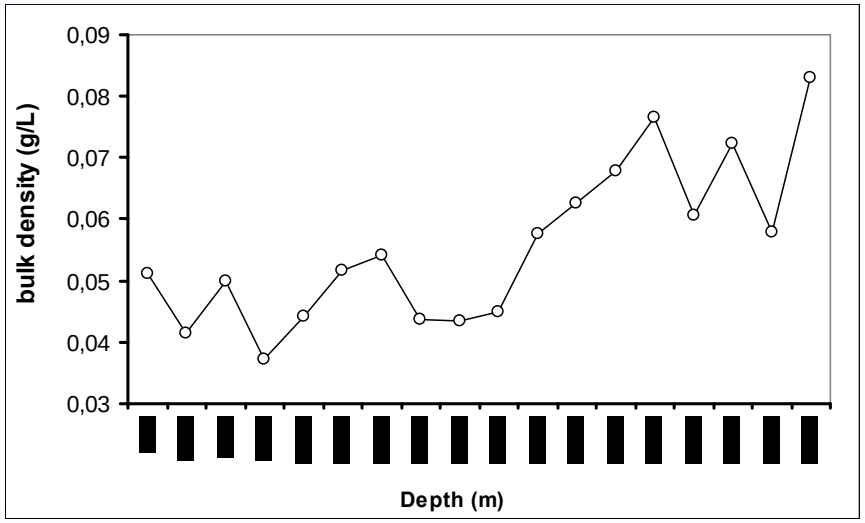


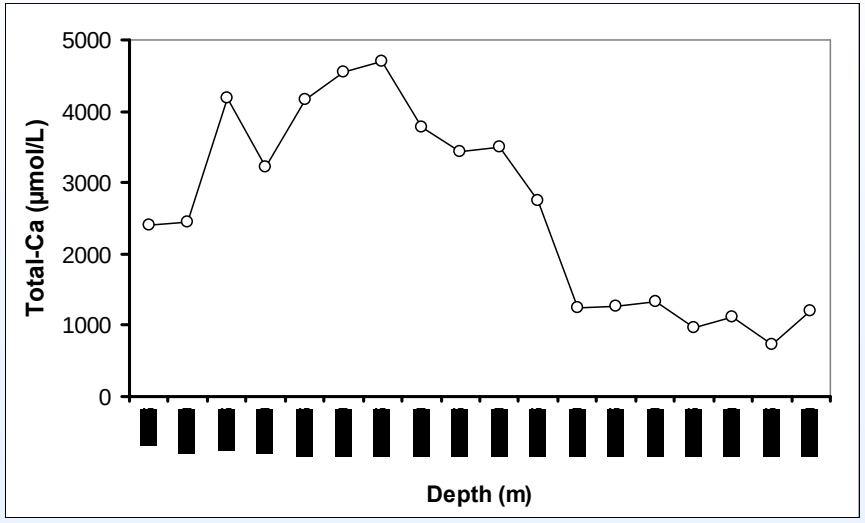


Growth of *Sphagnum* is often observed in minerotrophic fens where the top layer is acidified




Total-Ca (µmol/L)
70000
60000
50000
40000
30000
20000
10000
0
Depth (m)


bulk density (g/L)
0,09
0,08
0,07
0,06
0,05
0,04
0,03
Depth (m)


Total-Ca (µmol/L)
5000
4000
3000
2000
1000
0
Depth (m)

B ware
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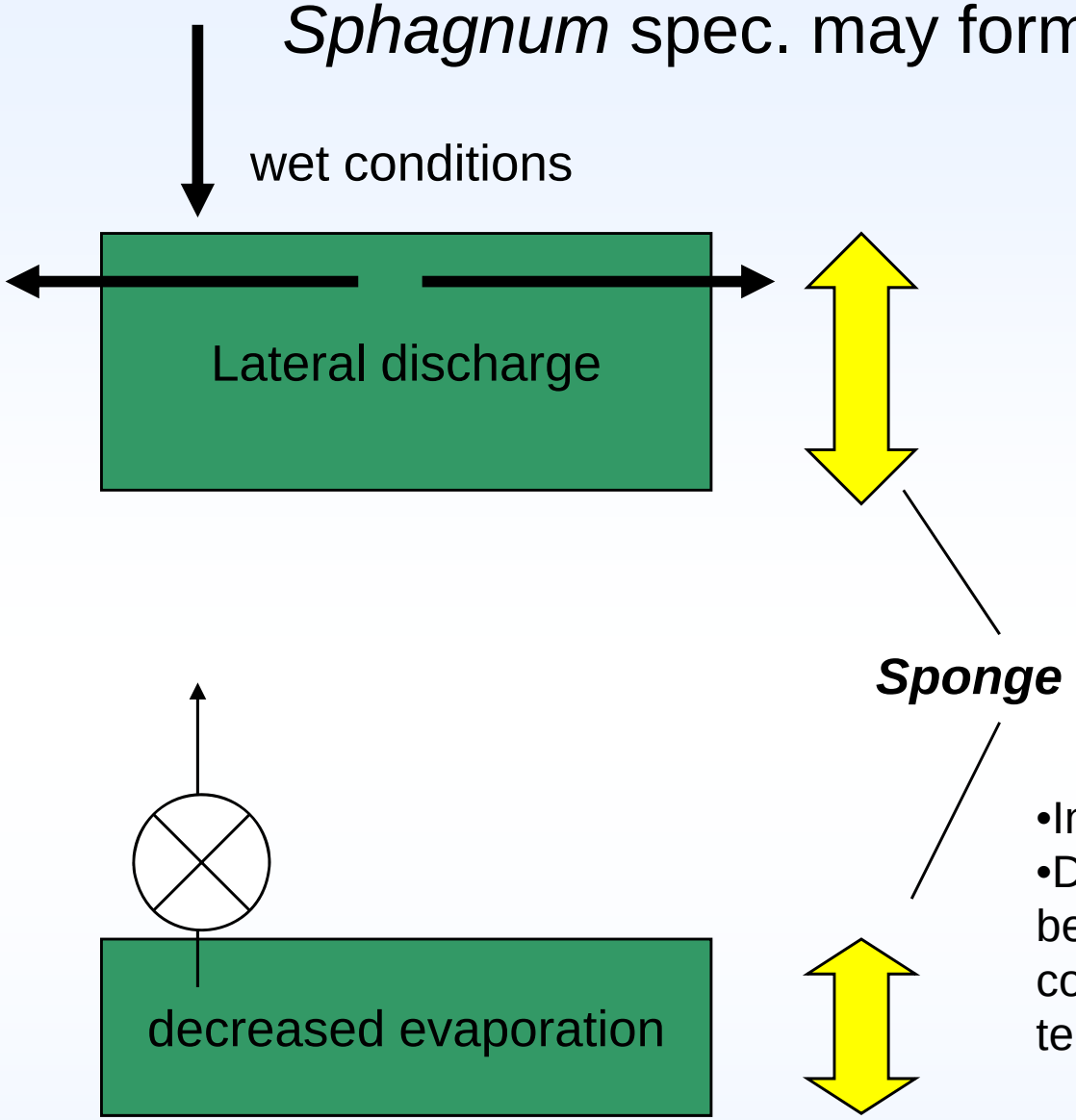
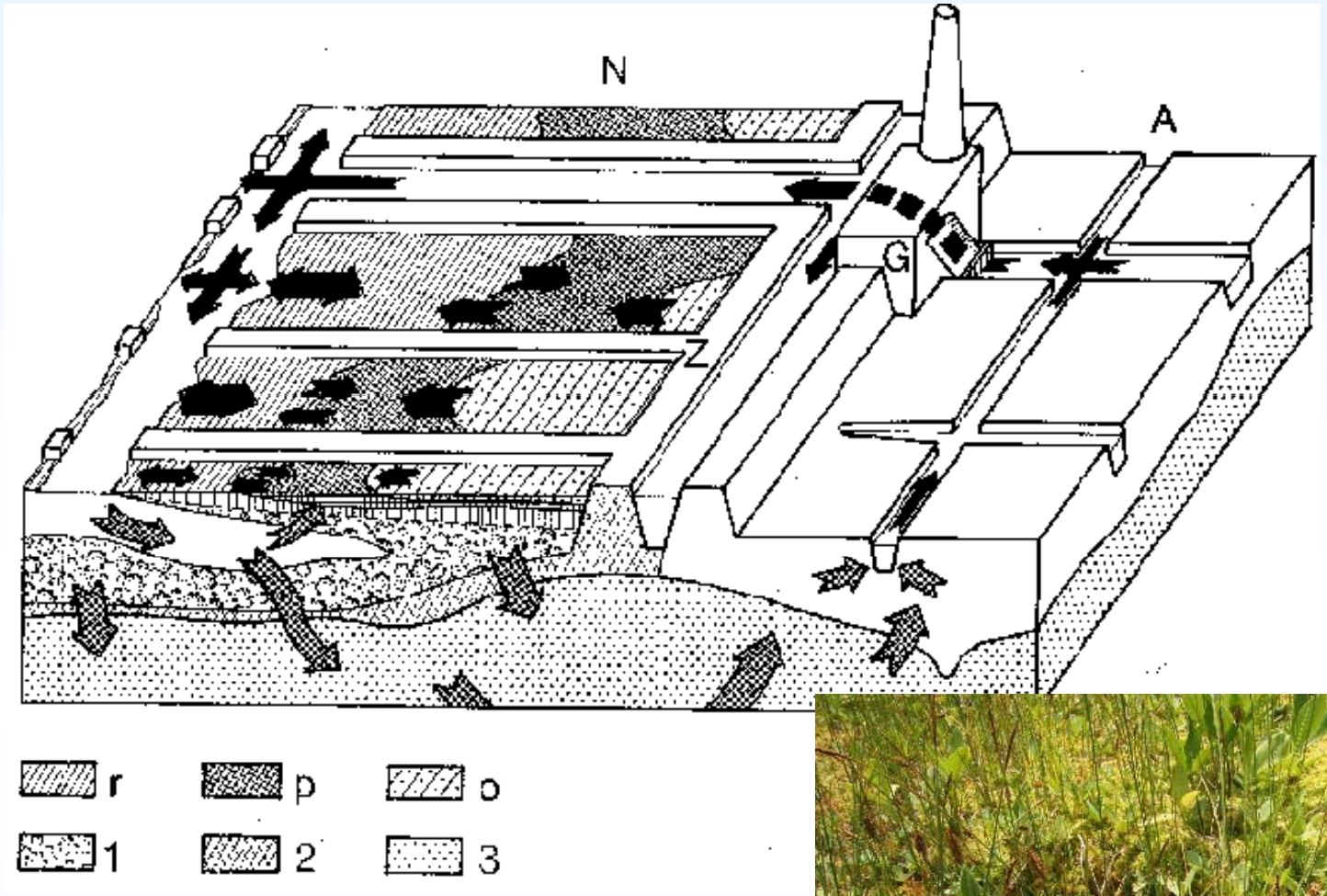
Sphagnum spec. may form an Acrotelm



- Increased retention of rain water
- Desiccation capitulae → Hyaline cells become filled with air and show white coloration → increased albedo and lower temperatures

Sphagnum magellancium, Sphagnum papillosum, Sphagnum rubellum

Acidification of floating fens



Acidifying processes

- **Accumulation of rainwater (dillution)**
- **Desiccation (oxidation)**

Nitrification of ammonium:

(1) $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

Oxidation of reduced iron:

(2) $4Fe^{2+} + O_2 + 6H_2O \rightarrow 4FeOOH + 8H^+$

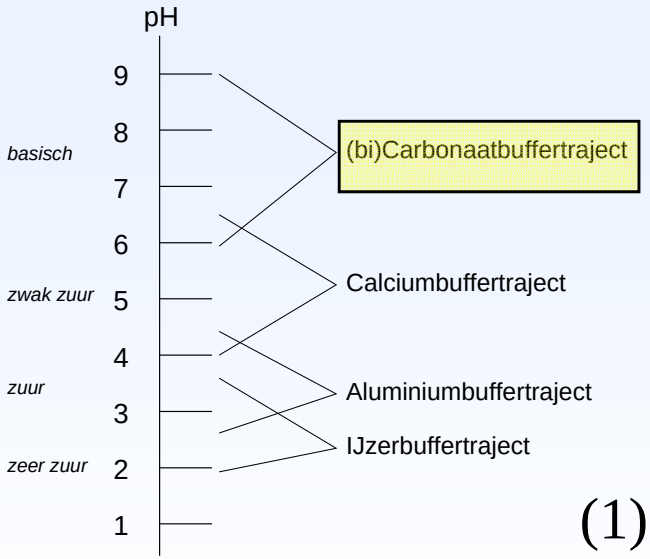
Oxidation of iron sulfide:

(3) $4\ FeS + 9\ O_2 + 6H_2O \rightarrow 4FeOOH + 4SO_4^{2-} + 8H^+$

Oxidation of pyrite:

(4) $4\ FeS_2 + 15\ O_2 + 20H_2O \rightarrow 4FeOOH + 8SO_4^{2-} + 16H^+$

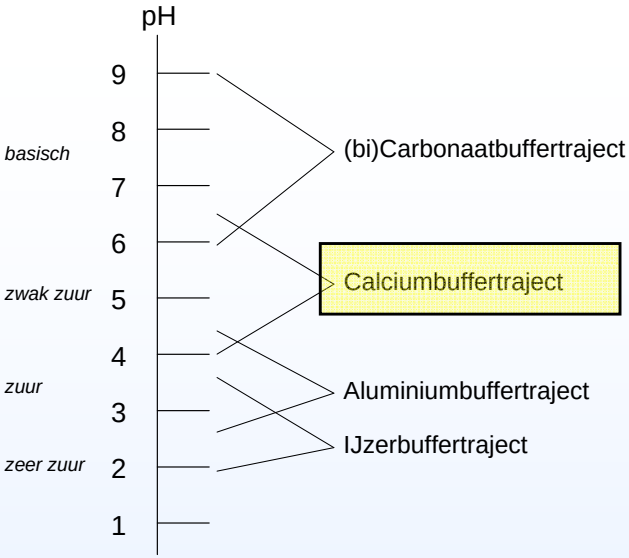
Buffering processes



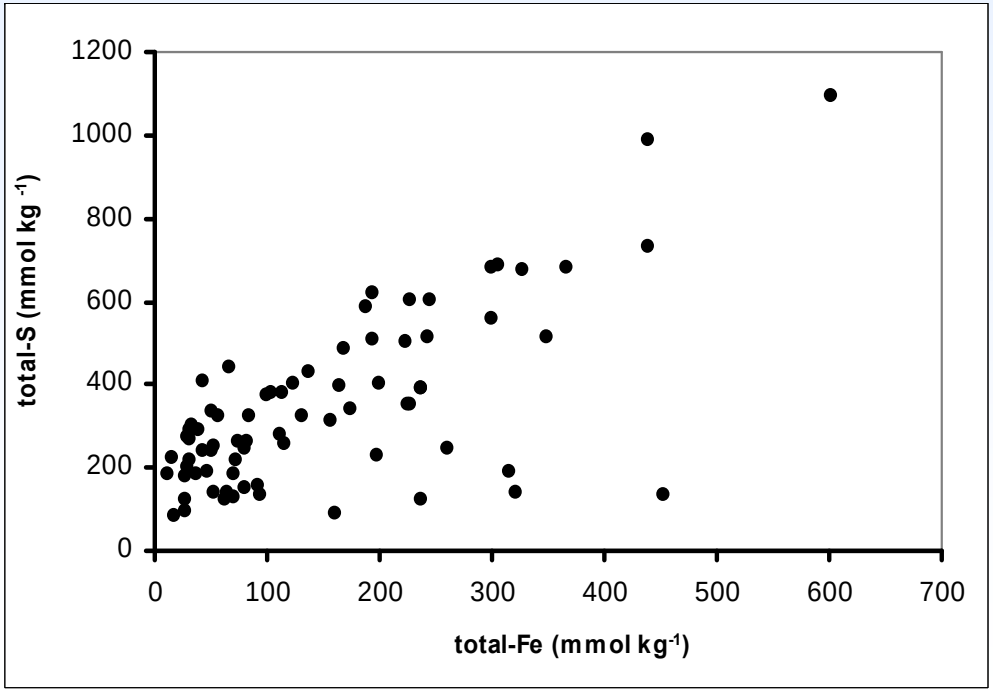
(1) $H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \Leftrightarrow H_2O + CO_2$

(2) $CaCO_3 + 2\ H^+ \Rightarrow Ca^{2+} + CO_2 + H_2O$

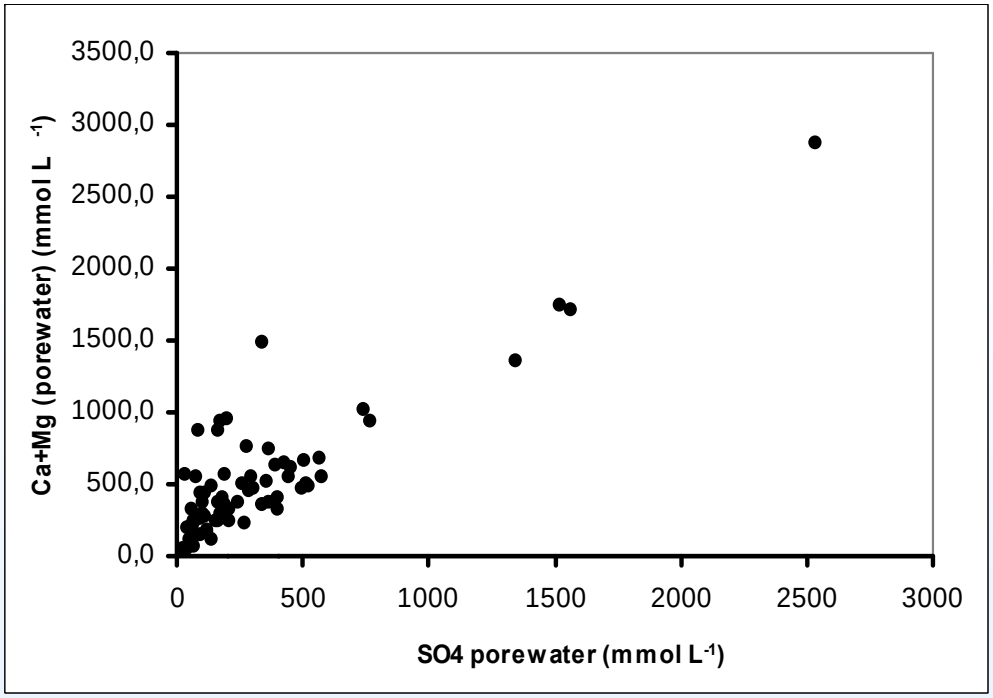
(3) $CaMg(CO_3)_2 + 4\ H^+ \Rightarrow Ca^{2+} + Mg^{2+} + 2\ CO_2 + 2\ H_2O$



(4) $]\text{-}Ca^{2+} + 2\ H^+ \Rightarrow\ ]\text{-}\ 2\ H^+ + Ca^{2+}$



High sulphur content indicates formation of floating fen under relatively sulphur rich conditions (sulphate rich groundwater).

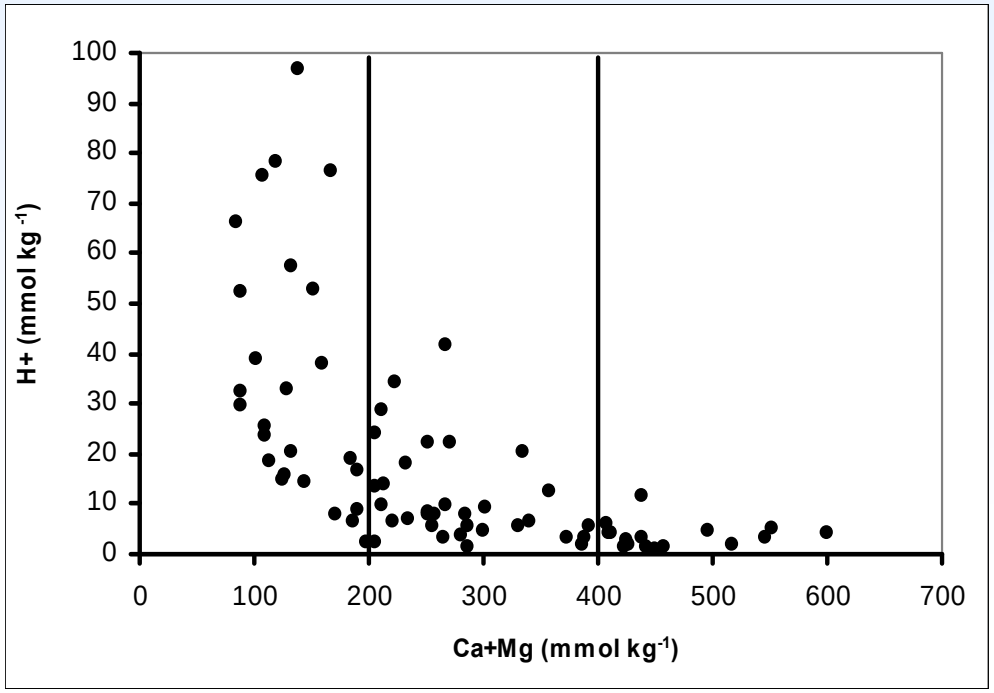


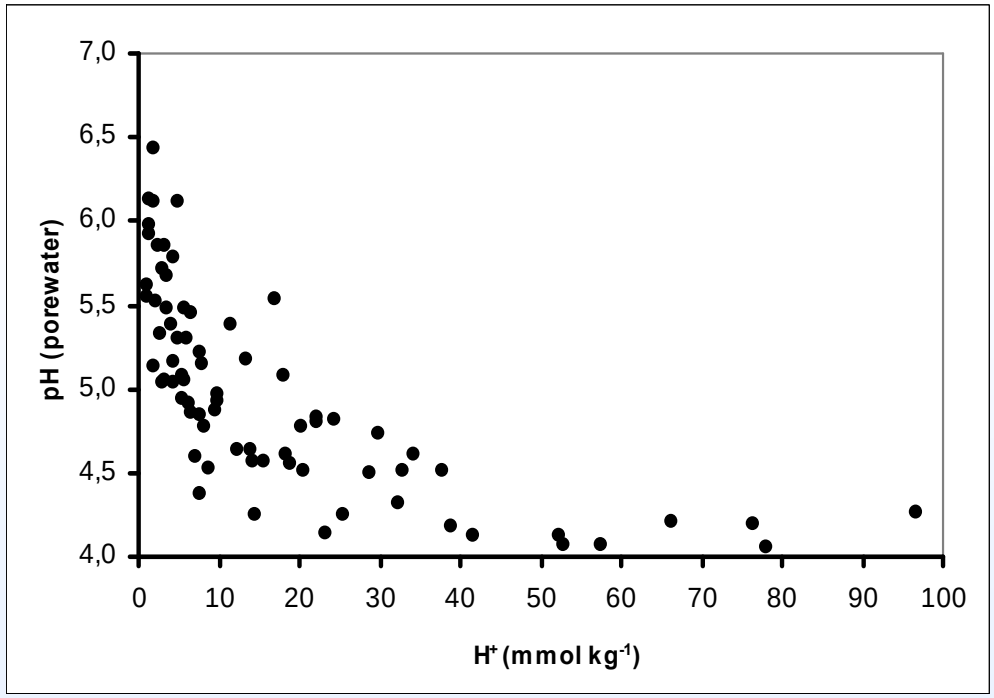
Upon desiccation:

$4\ FeS_2 + 15\ O_2 + 20H_2O \rightarrow 4FeOOH + 8SO_4^{2-} + 16H^+$

$]\text{-}Ca^{2+} + 2\ H^+ \rightarrow\ ]\text{-}\ 2\ H^+ + Ca^{2+}$

$]\text{-}Mg^{2+} + 2\ H^+ \rightarrow\ ]\text{-}\ 2\ H^+ + Mg^{2+}$


H+ (mmol kg-1)
Ca+Mg (mmol kg-1)
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700


pH (porewater)
H+ (mmol kg-1)
4,0
4,5
5,0
5,5
6,0
6,5
7,0
0
10
20
30
40
50
60
70
80
90
100

ELSEVIER

Environmental Pollution 120 (2002) 635–646

ENVIRONMENTAL POLLUTION

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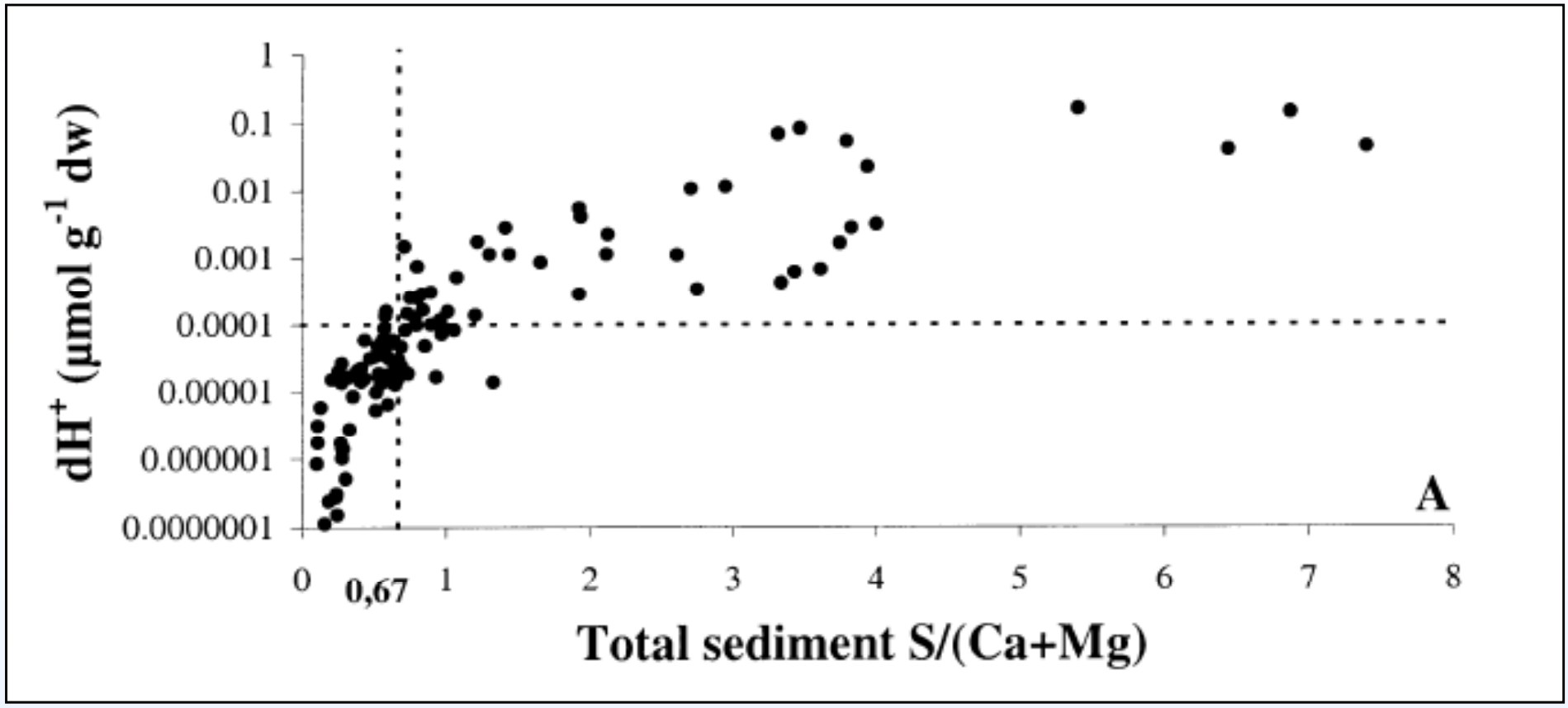
Potential sensitivity of mires to drought, acidification and mobilisation of heavy metals: the sediment S/(Ca + Mg) ratio as diagnostic tool

E.C.H.E.T. Lucassen*, A.J.P. Smolders, J.G.M. Roelofs

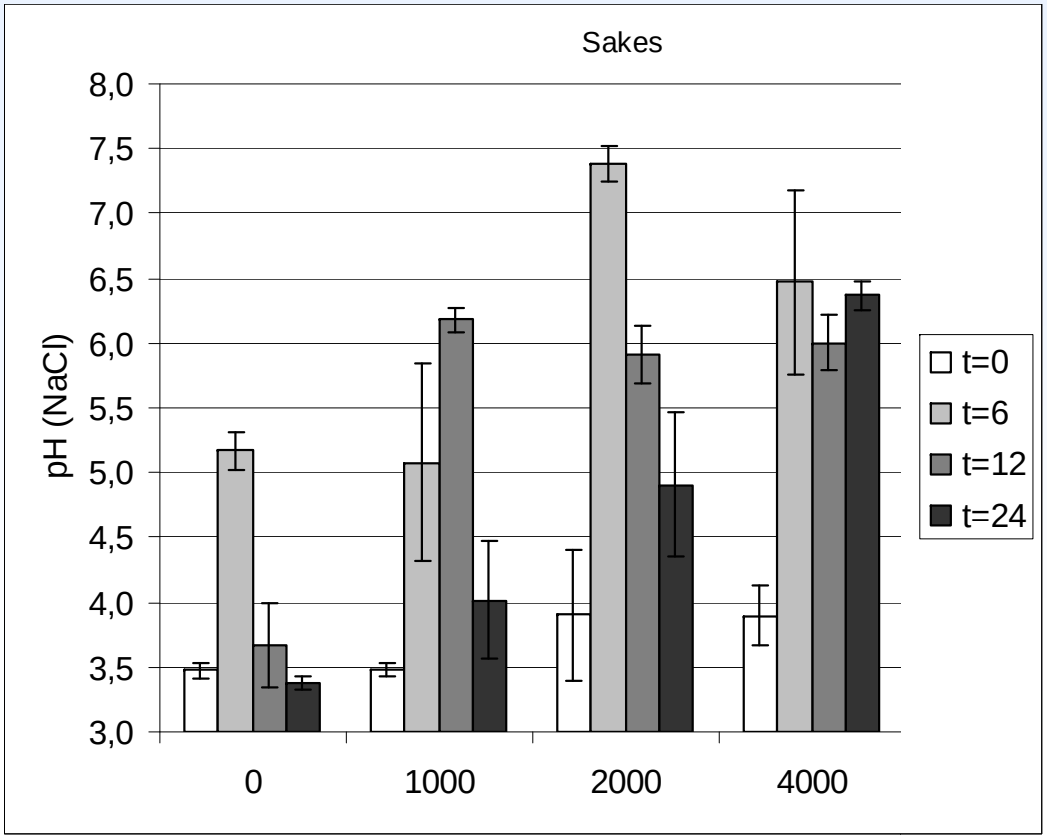


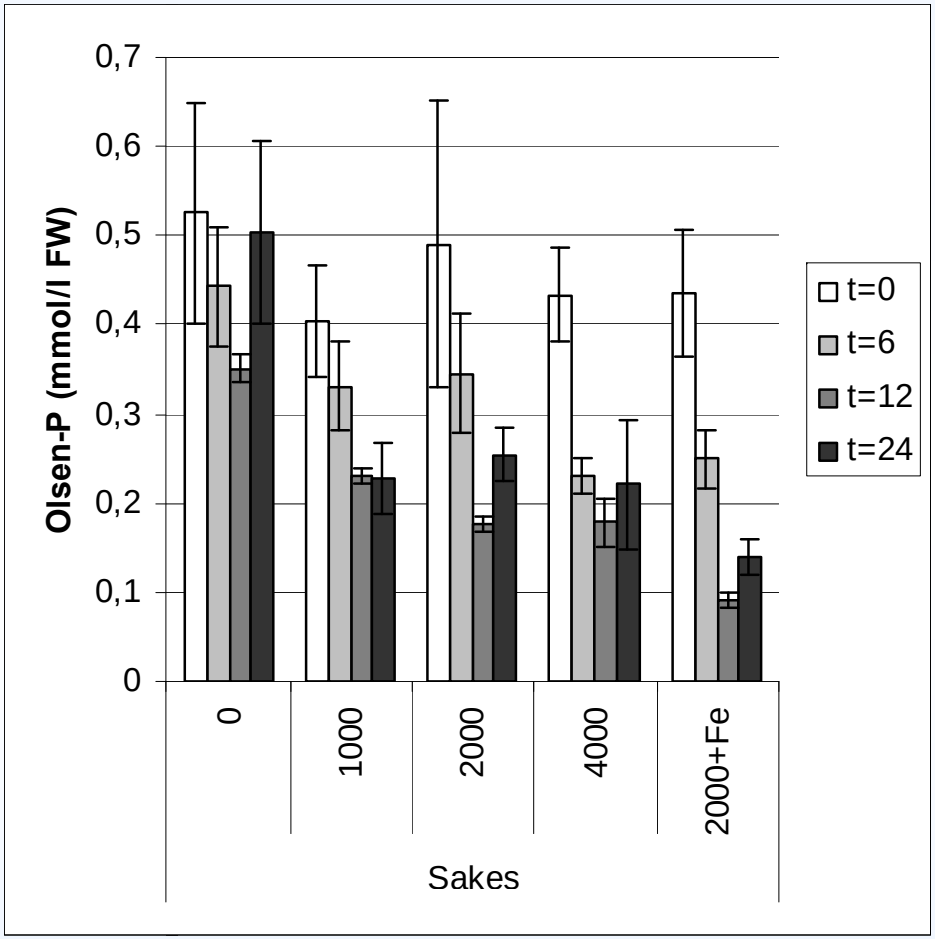
If total-S/(total-Ca+Mg) > 0.67: <u>acidification</u>

Treatments:

0 kg ha^{-1}
1000 kg ha^{-1}
2000 kg ha^{-1}
4000 kg ha^{-1}

Liming of acidfied floating fen in the ‘Nieuwkoopse plassen’

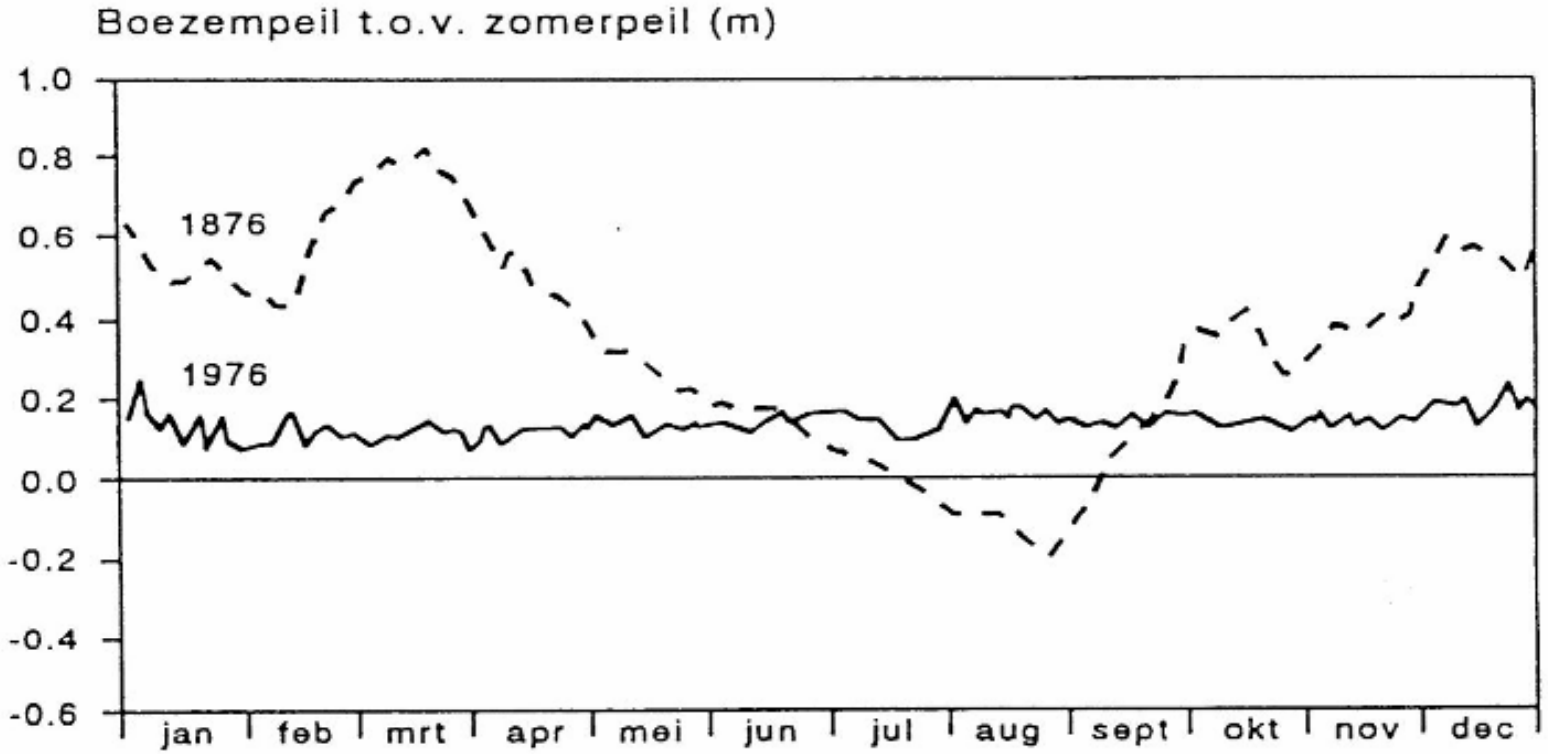




After two years:
Strong decrease of *Sphagnum* spec. after liming

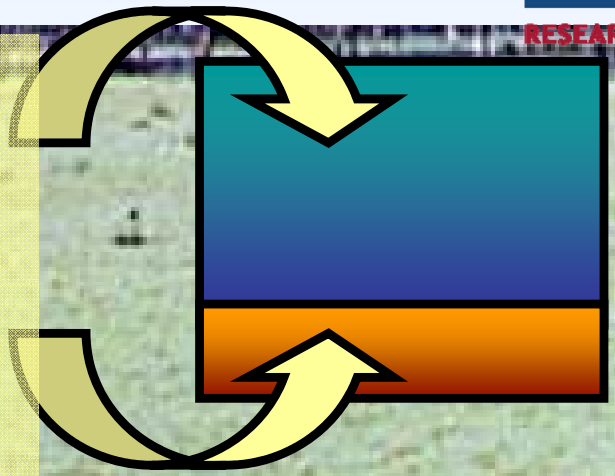
The taming of the water level…

Water shortage in summer:
Is compensated by the inlet of alkaline sulphate rich river water



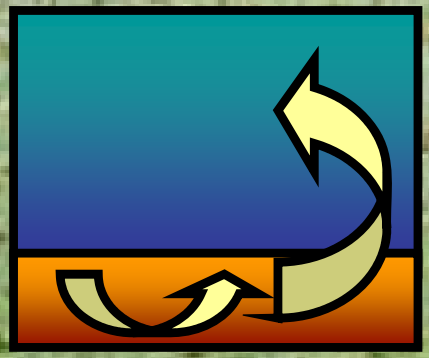
External eutrofication:

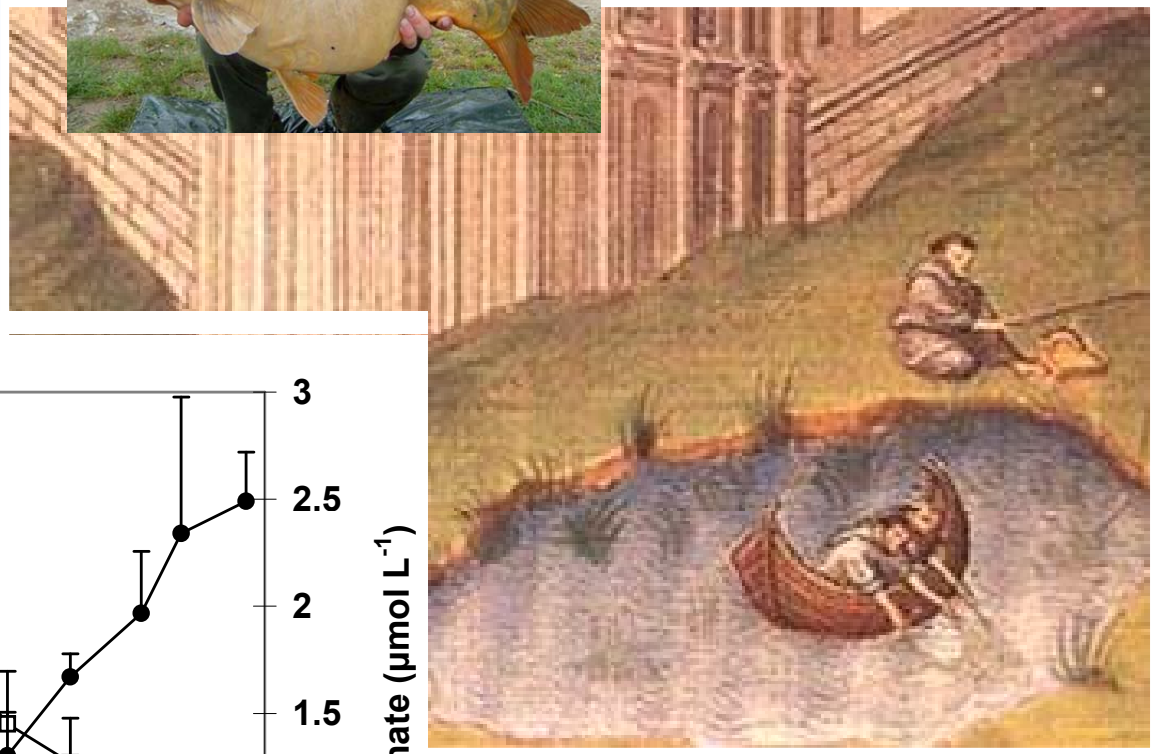
Eutrofication due to an increased external supply of nutrients.

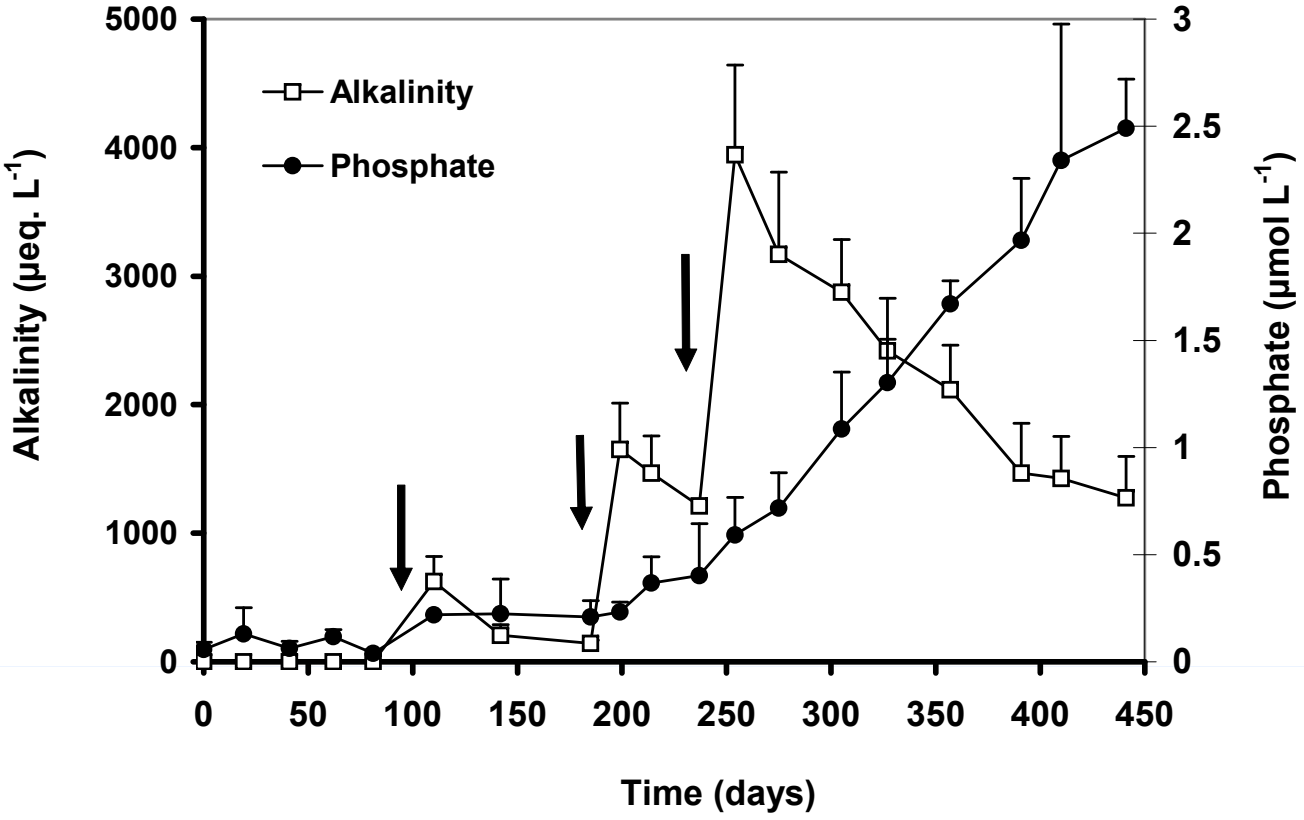


Internal eutrofication :

Eutrofication due to an increased mobilisation of nutrients already present in a system (mainly in shallow waters with a peaty (organic) sediment.







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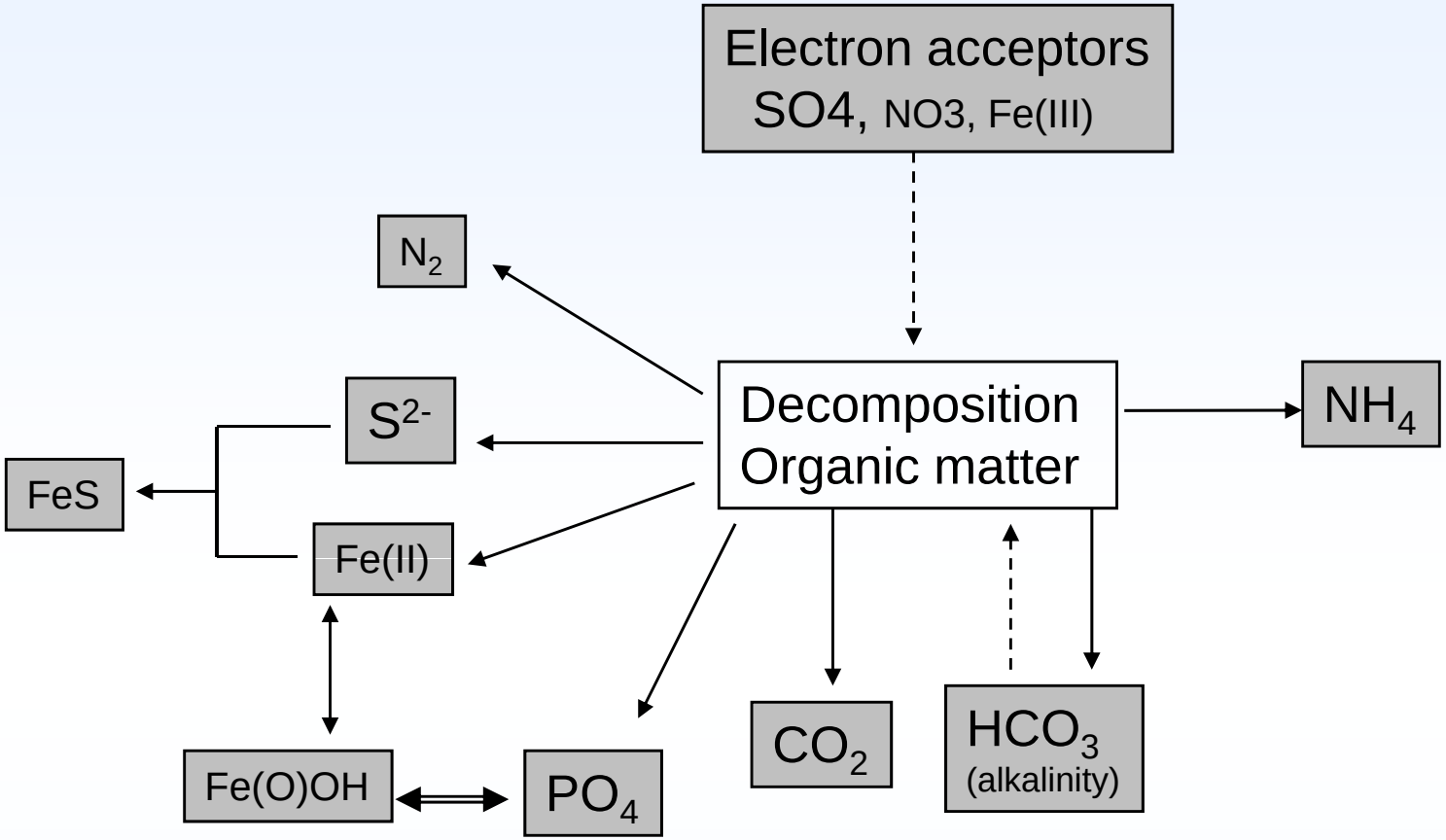
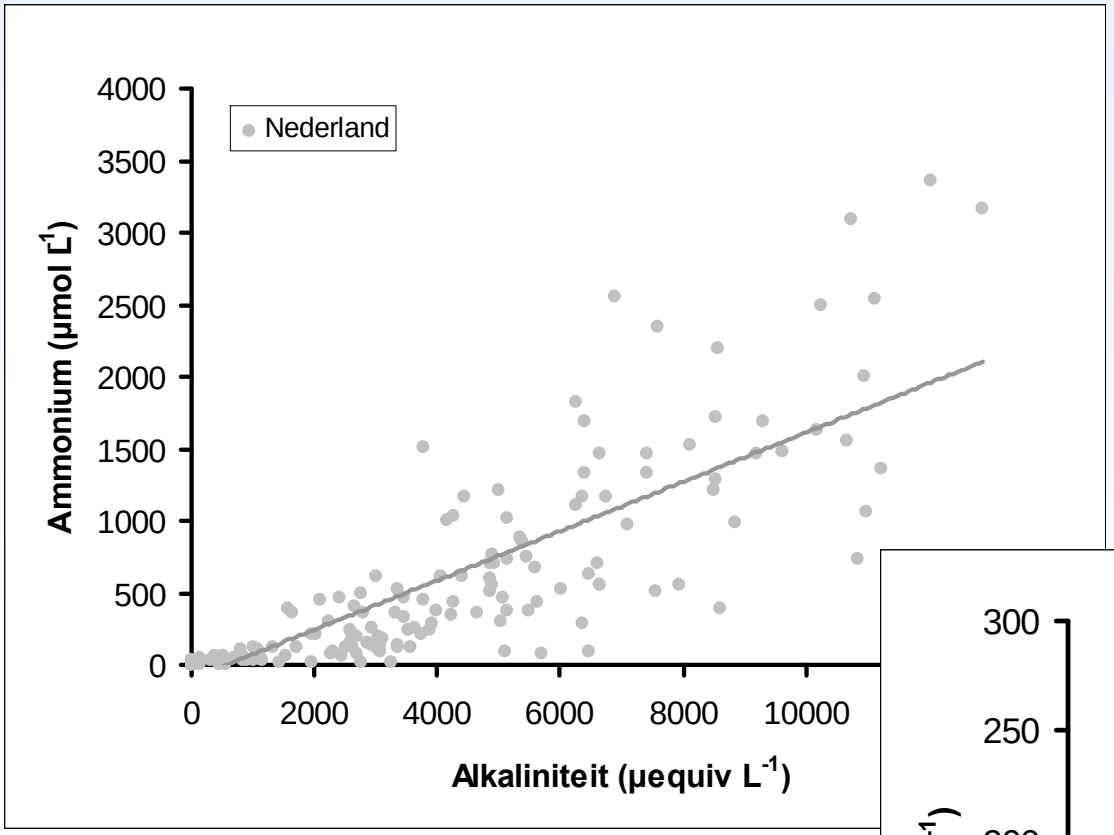


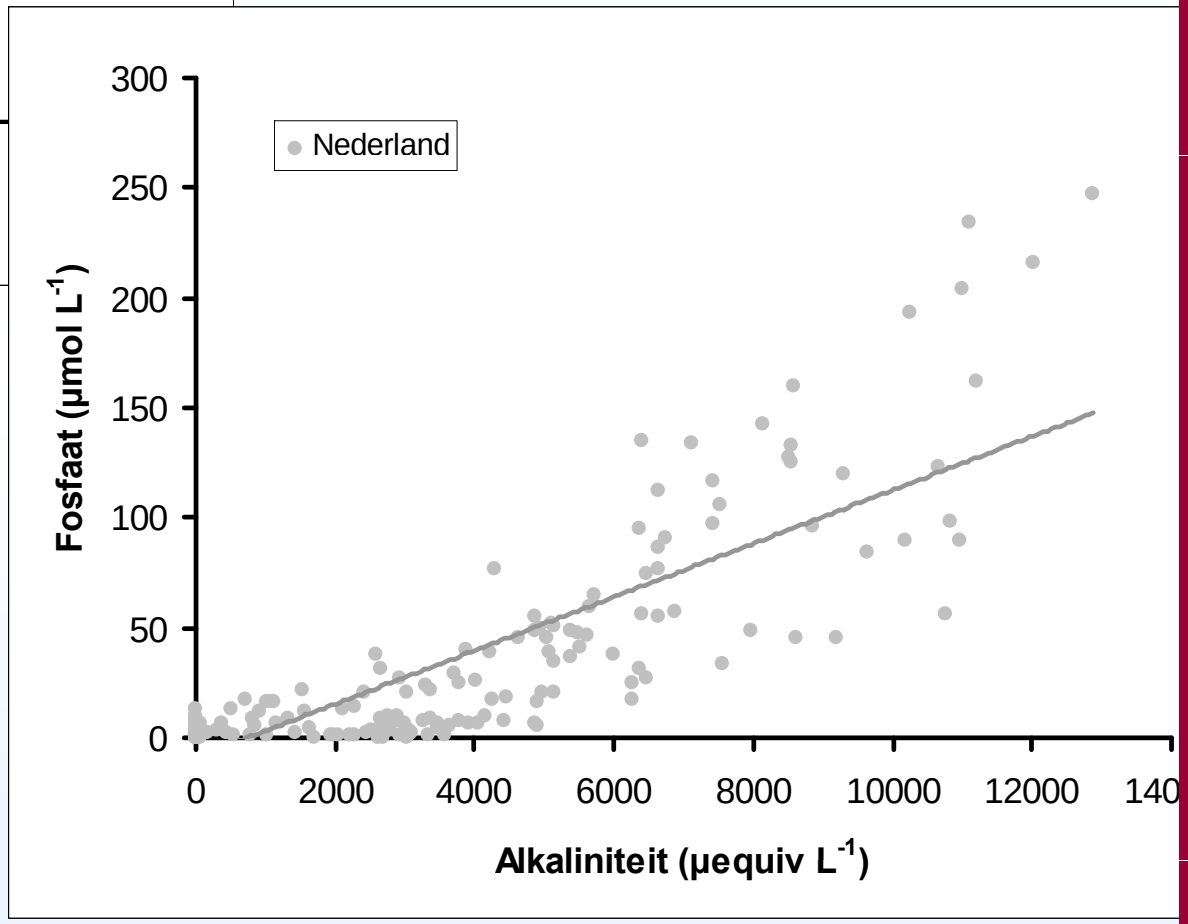
releases

stimulates

reacts with

Co-precipitates with or adsorbs to





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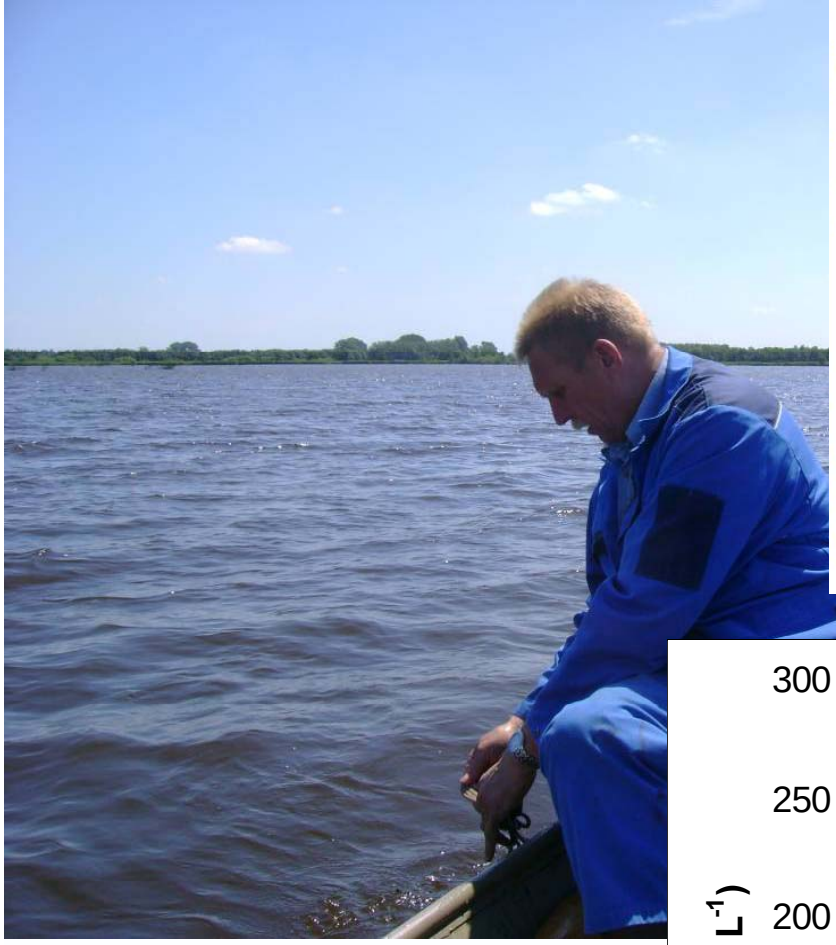
$$SO_4^{2-} + 2CH_2O\text{-}N\text{-}P \text{ -----> } HS^- + HCO_3^- + CO_2 + H_2O + PO4 + NH4$$



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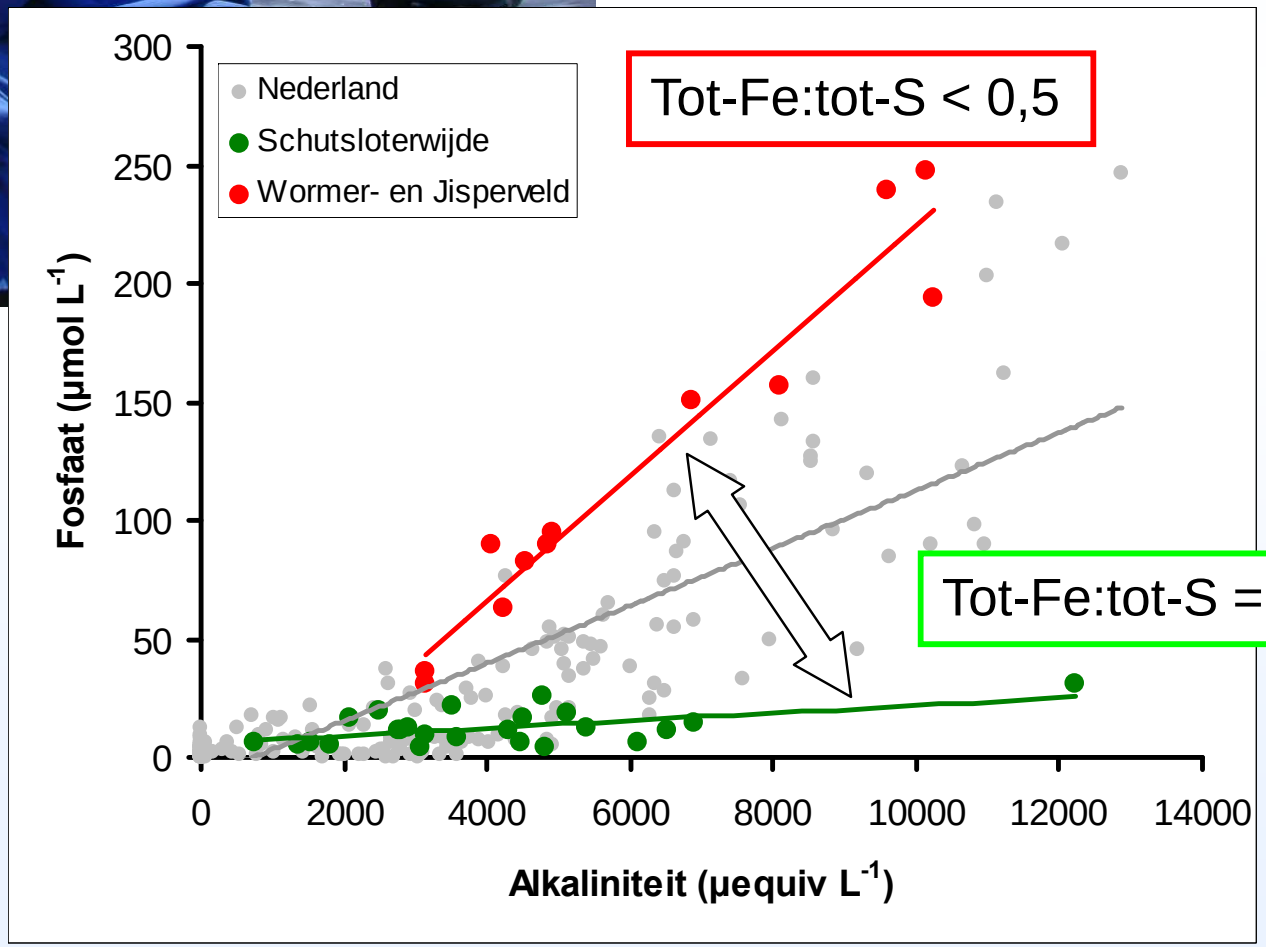

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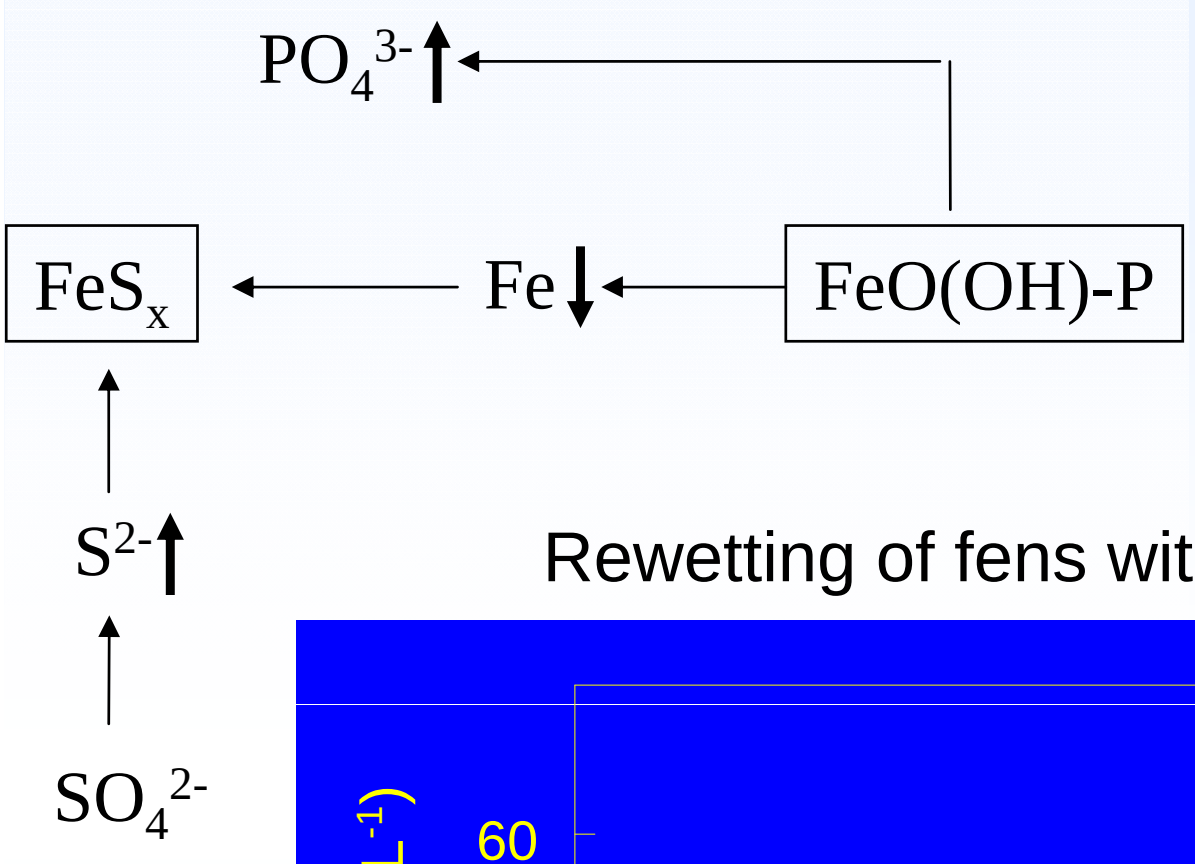
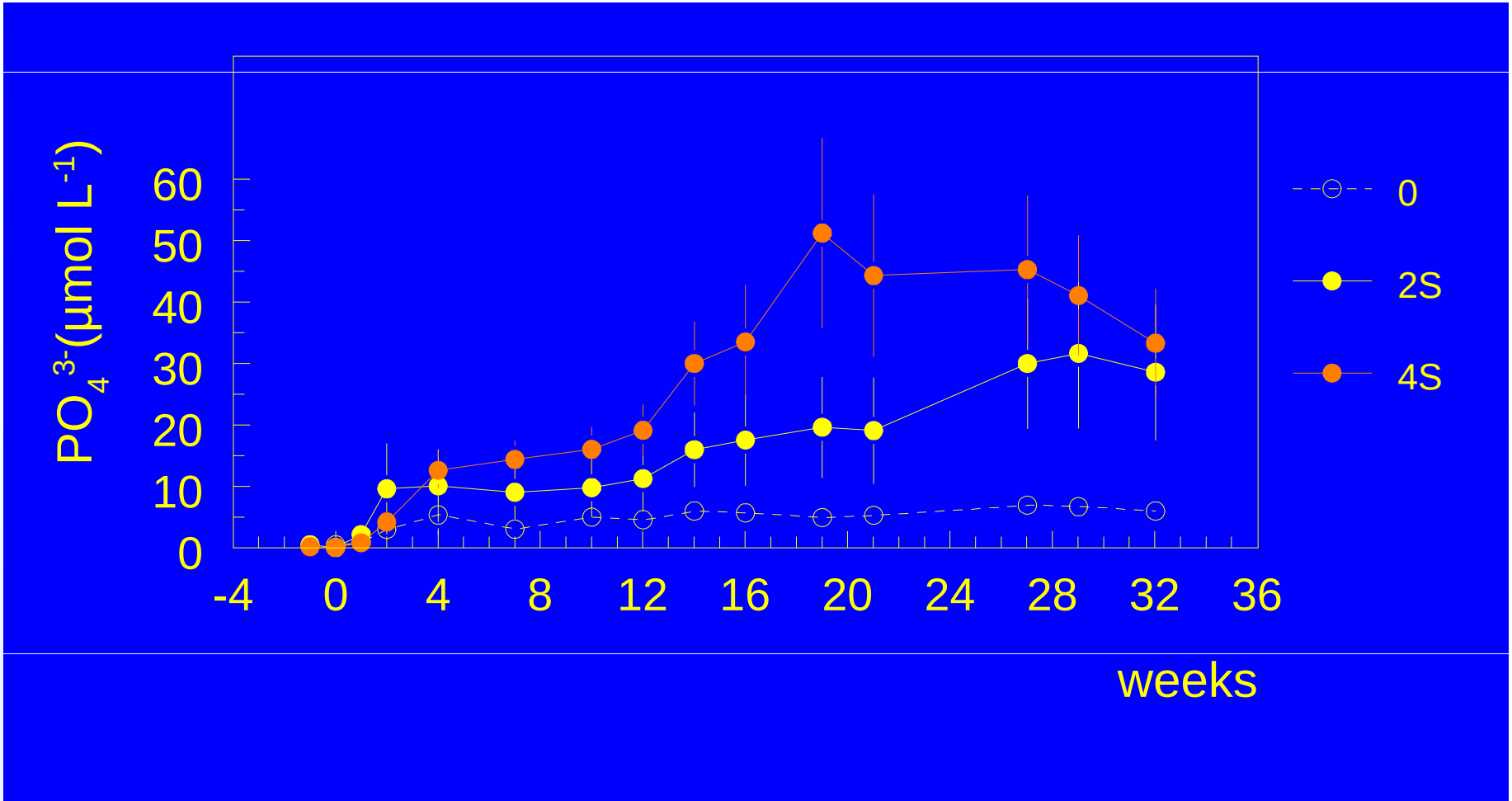


Rewetting of fens with and without sulphate



stagnant + chloride

stagnant + sulfate

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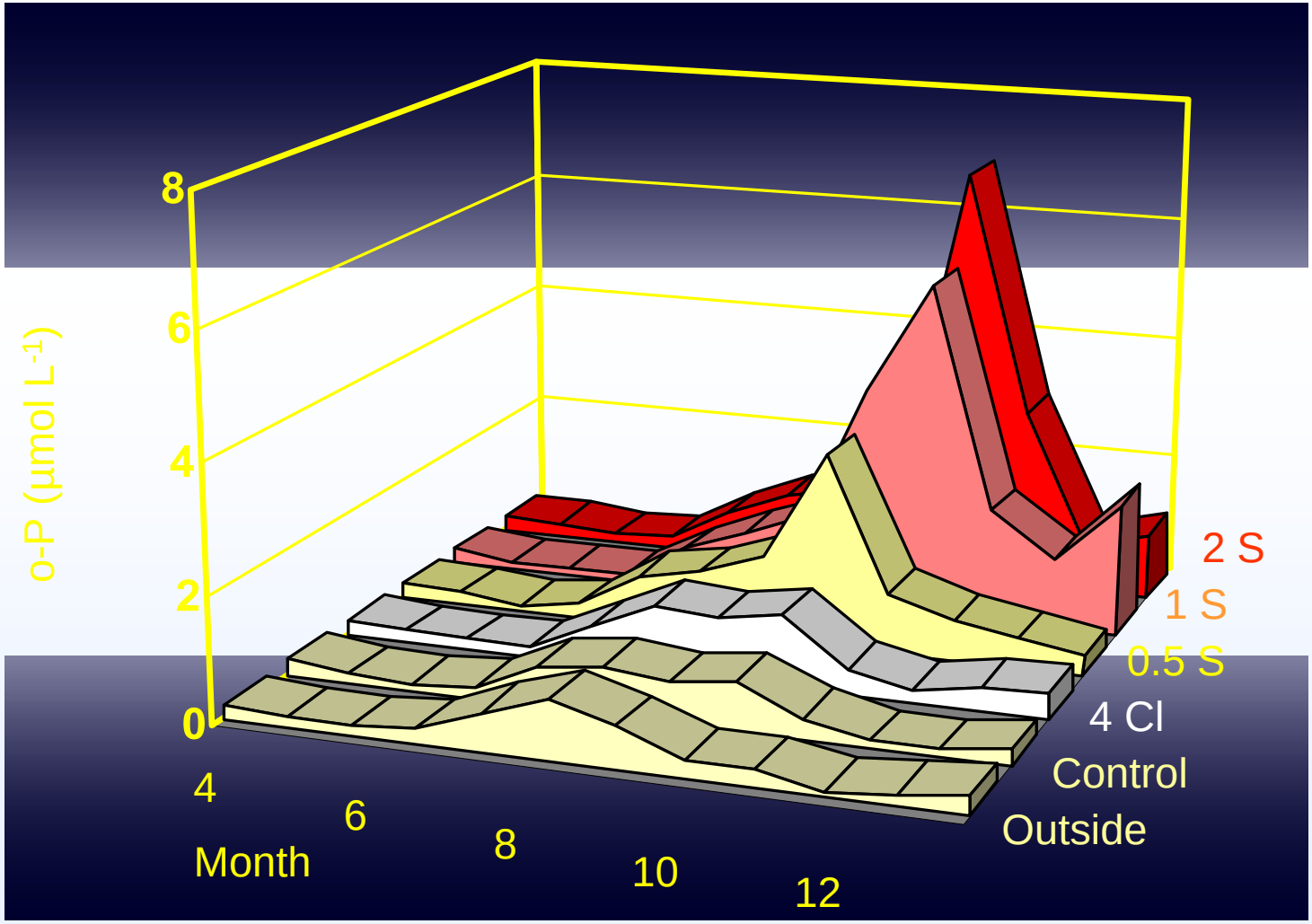

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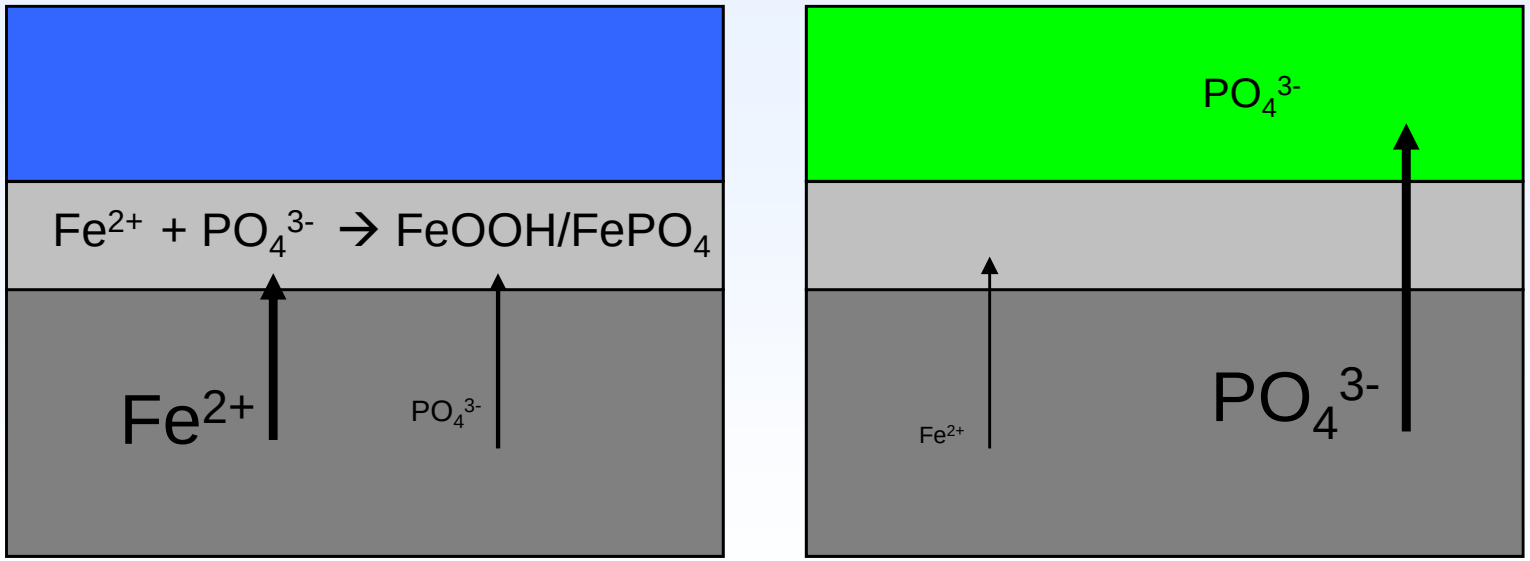
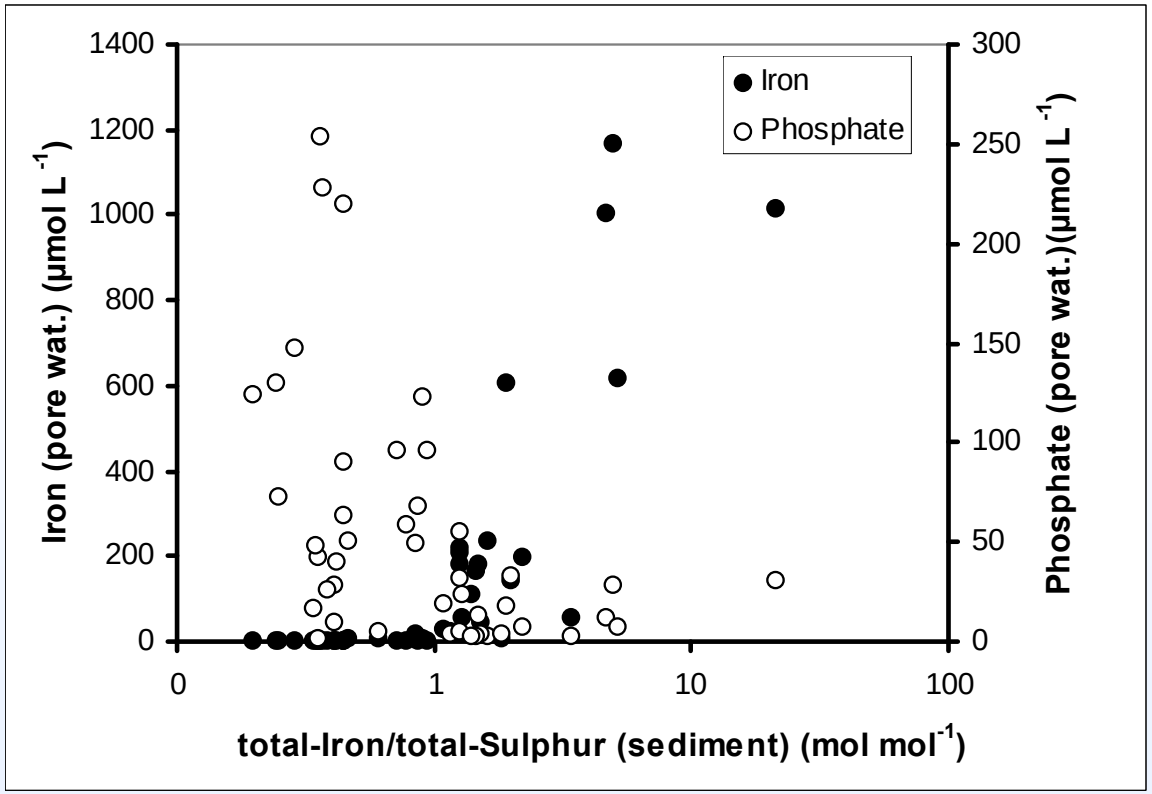
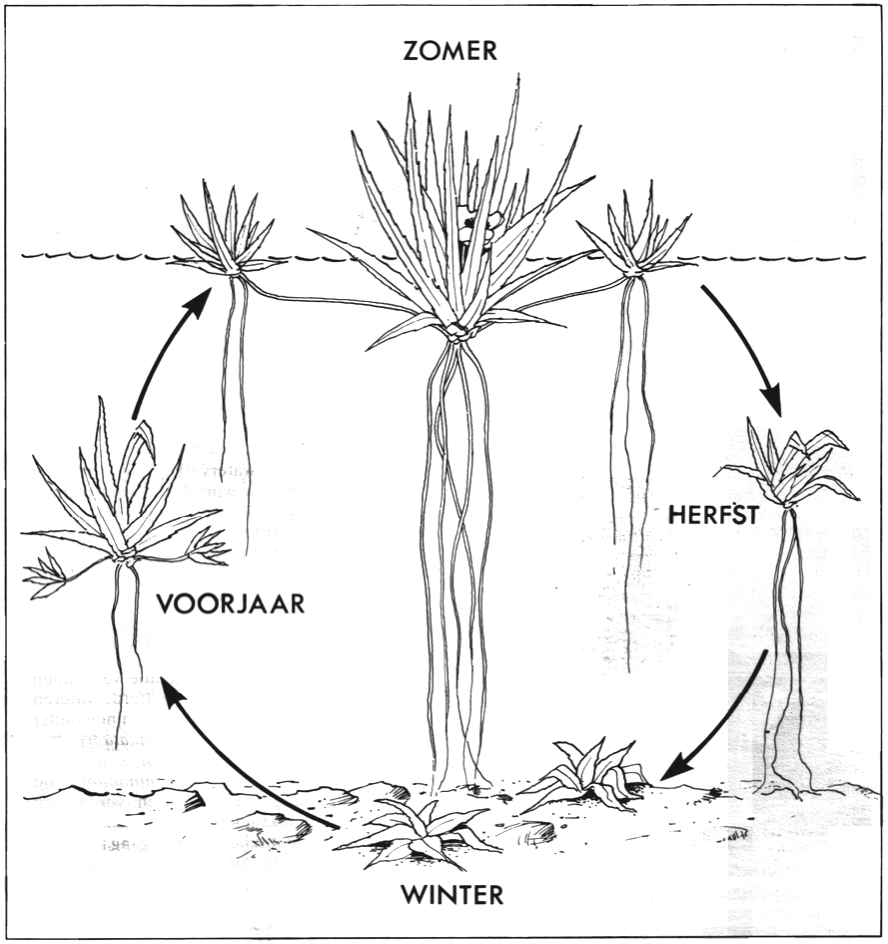
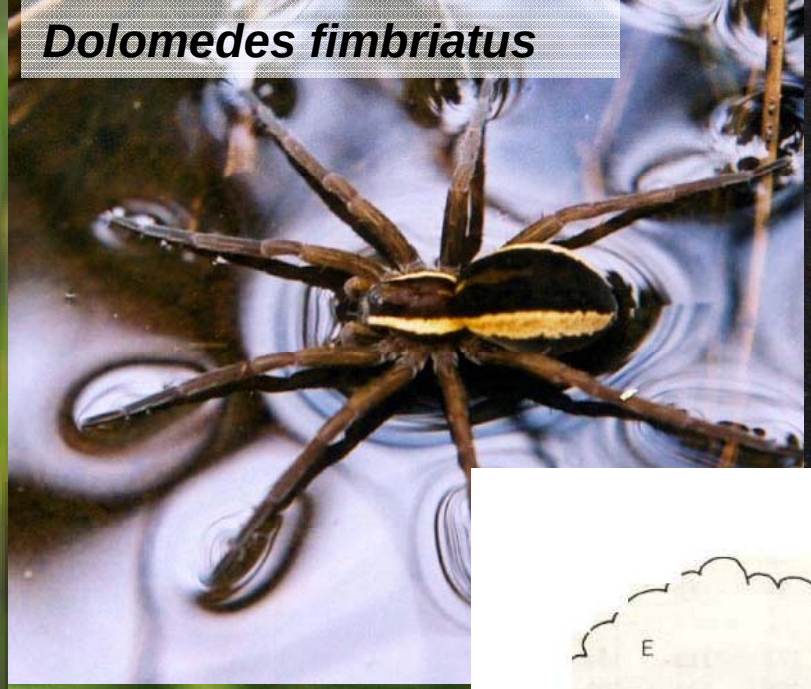

$Fe^{2+} + PO_4^{3-} \rightarrow FeOOH/FePO_4$
Fe^{2+}
PO_4^{3-}
PO_4^{3-}
Fe^{2+}
PO_4^{3-}

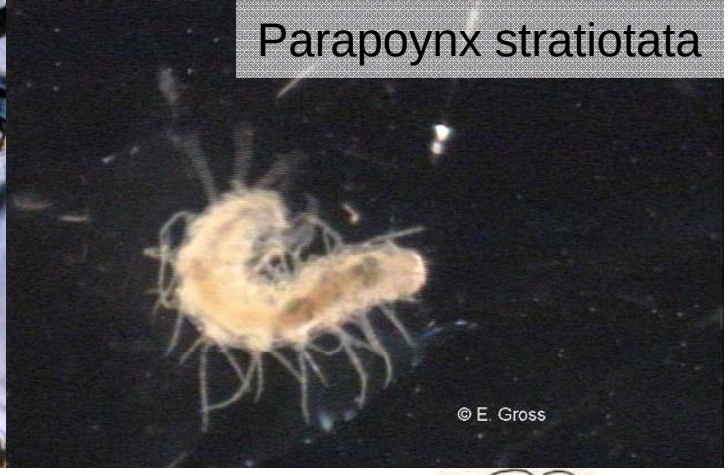

Iron
Phosphate
Iron (pore wat.) (µmol L-1)
Phosphate (pore wat.)(µmol L-1)
total-Iron/total-Sulphur (sediment) (mol mol-1)
0
200
400
600
800
1000
1200
1400
0
50
100
150
200
250
300
0
1
10
100


ZOMER
HERFST
VOORJAAR
WINTER

Aeshna viridis

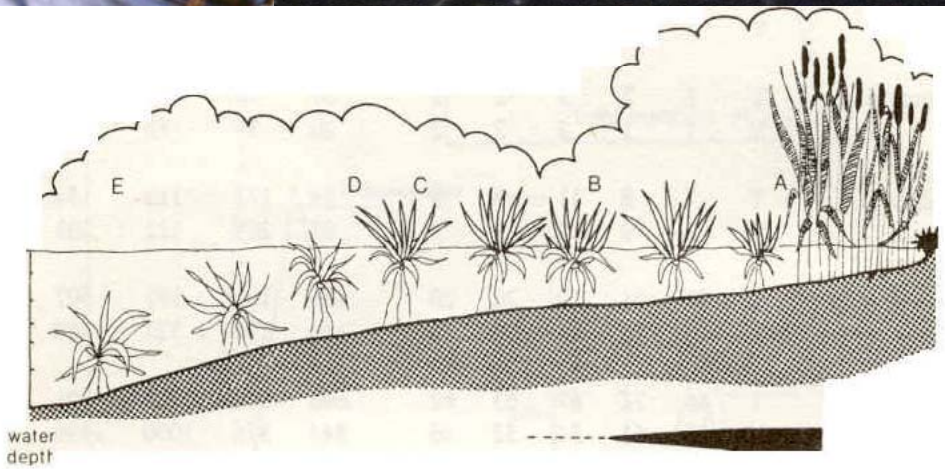


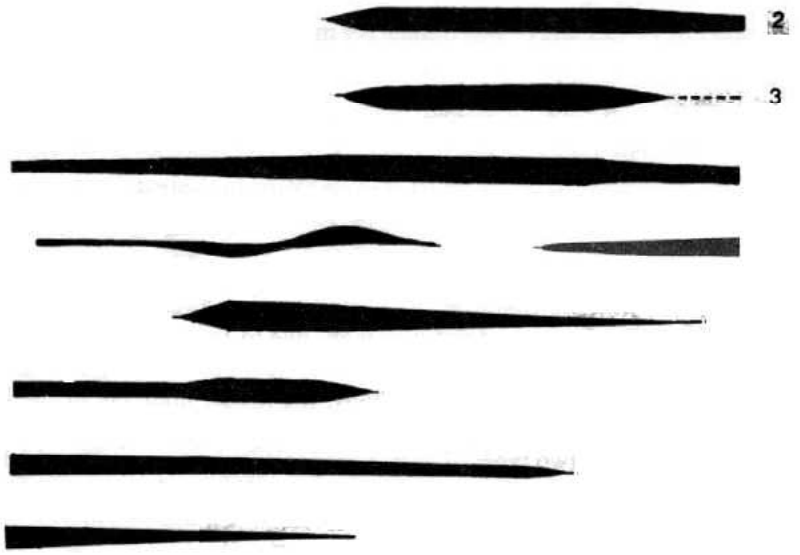
Dolomedes fimbriatus

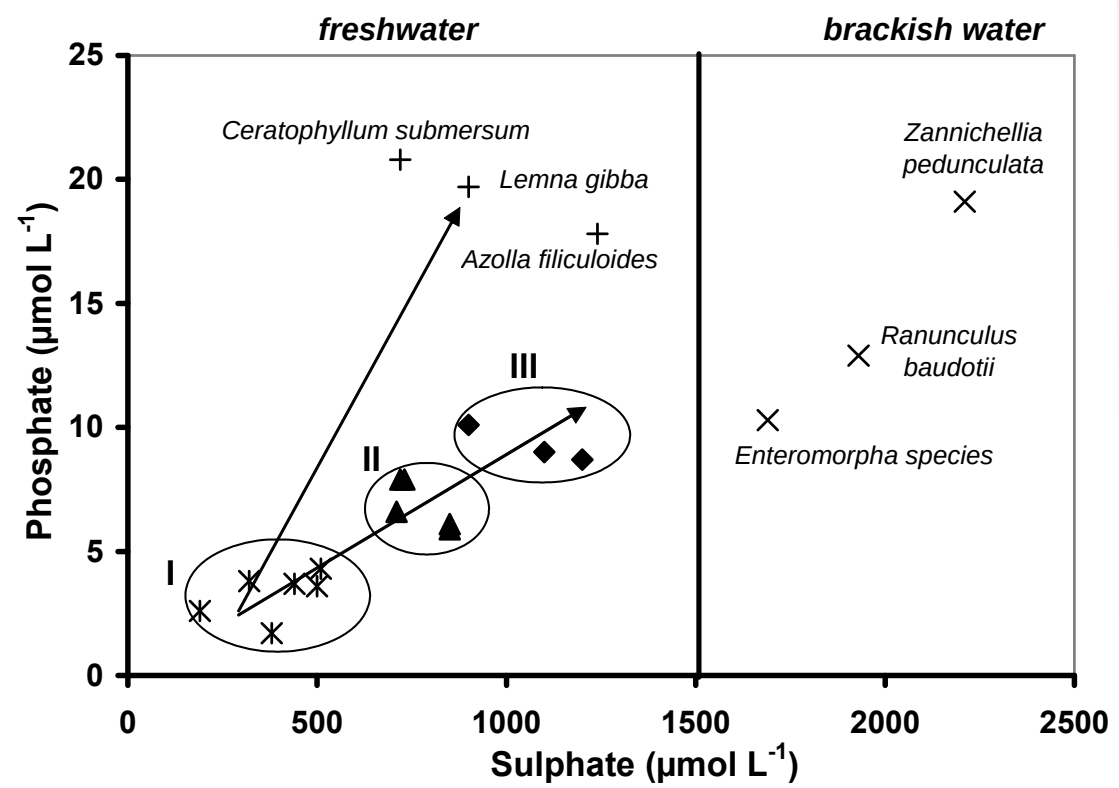


Parapoynx stratiotata

Zwarte stern







I ***Stratiotes aloides***
Hydrocharis morsus ranae
Potamogeton acutifolius
Potamogeton compressus
Potamogeton lucens
Utricularia vulgaris

II ***Nymphoides peltata***
Ranunculus circinatus
Spirodela polyrhiza
Lemna trisulca
Potamogeton mucronatus

III ***Potamogeton pectinatus***
Myriophyllum spicatum
Ceratophyllum demersum





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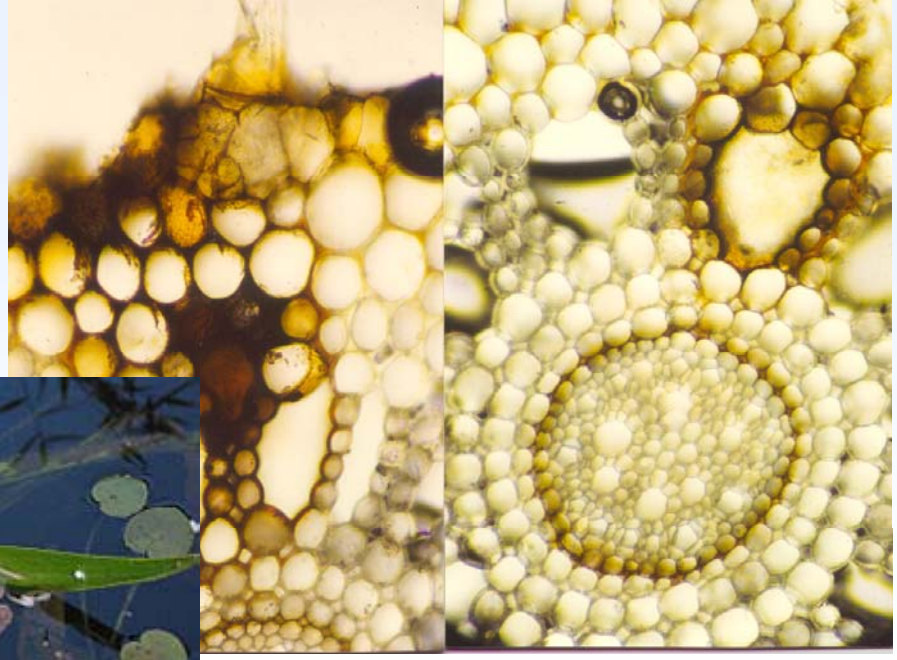
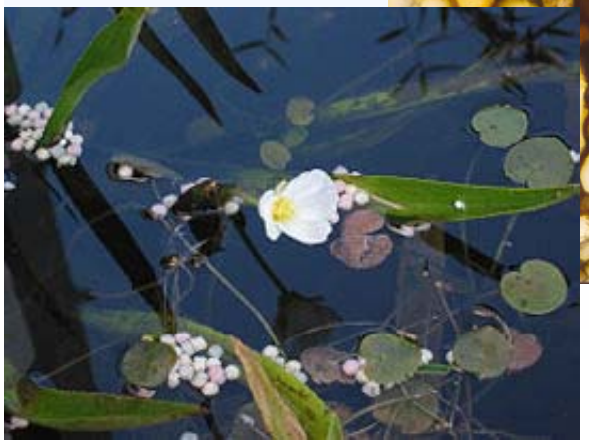
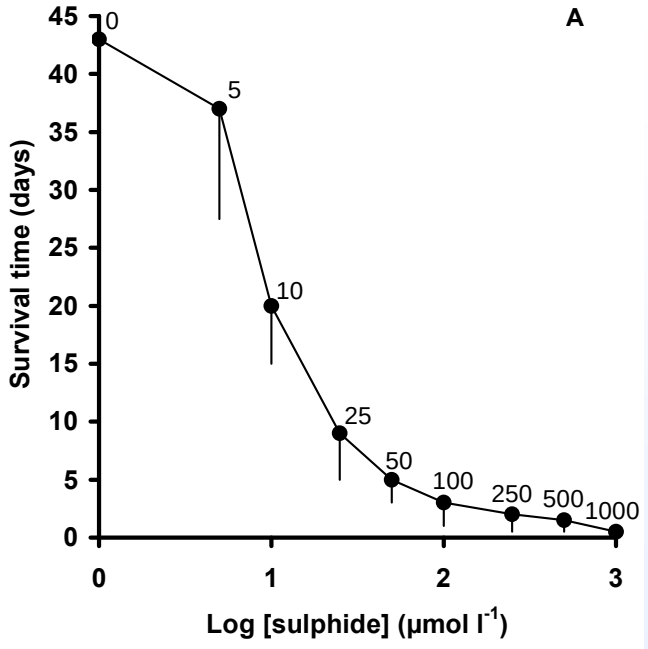




	Glimmen	*Tienhoven*	*Zegveld*
Iron content (µmol g^{-1} Dwt):			
Apoplastic iron in root (n=12)	68.1 ± 29.1	11.3 ± 10.2	0.7 ± 0.4
Iron in shoot (n=12)	21.0 ± 7.2	5.7 ± 1.0	0.1 ± 0.1
Surface water (µmol l^{-1}):			
Sulphate (n=3)	323 ± 43	254 ± 32	899 ± 101
Sediment pore water (µmol l^{-1}):			
Iron	555 ± 161	89 ± 27	1.1 ± 1.3
Sulphide (n=5)	< 0.1	< 0.1	24.7 ± 8.8
Ortho-phosphate (n=5)	4.1 ± 0.7	8.0 ± 3.0	25.1 ± 6.8
Bicarbonate (n=5)	3111 ± 551	3096 ± 620	4786 ± 712
Characteristics:	Iron rich seepage, iron precipitation in and on the roots leads to root-die-back	Healthy shoots and roots.	Root die-back due to sulphide toxicity, chlorotic iron deficient shoots



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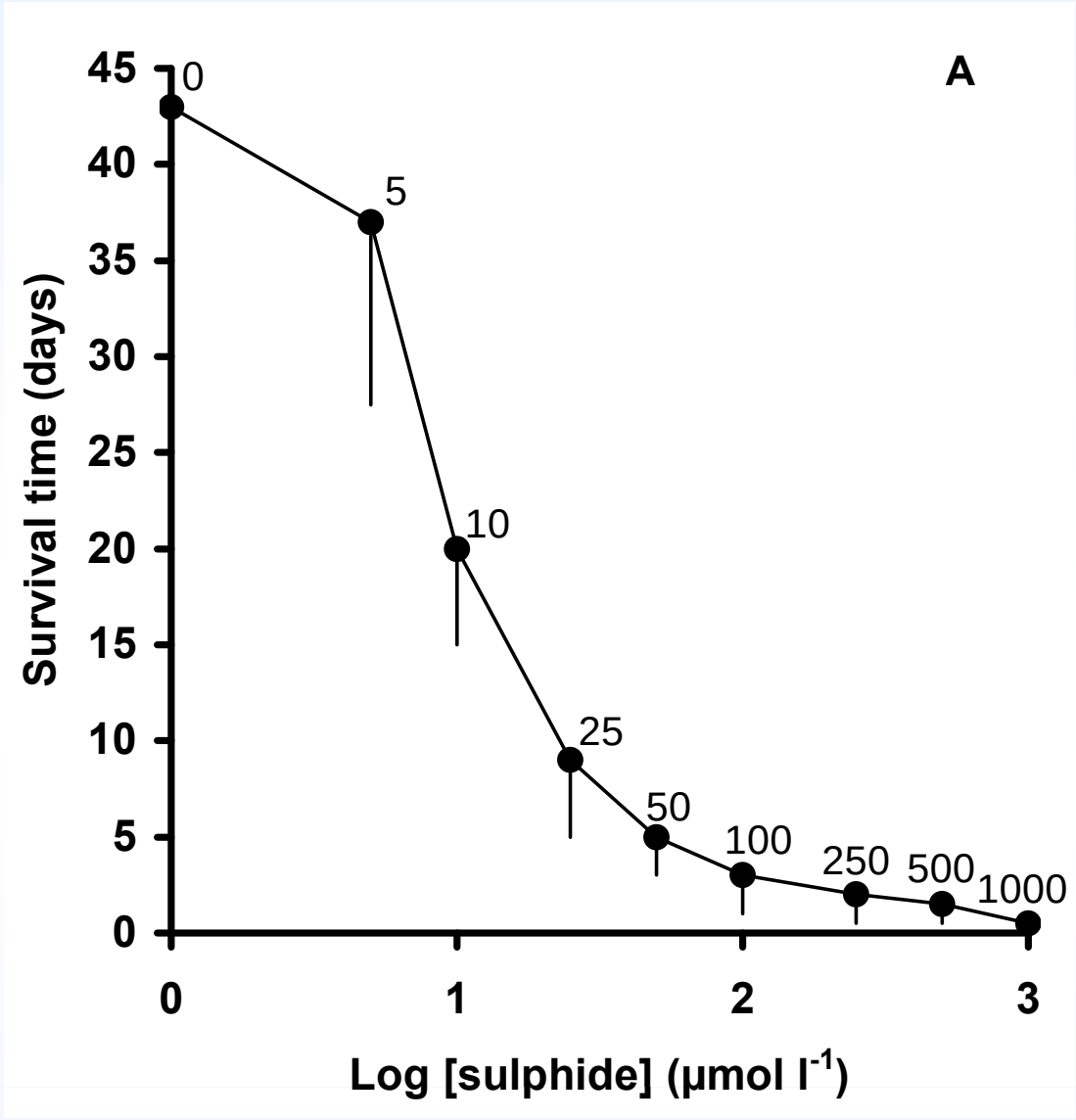
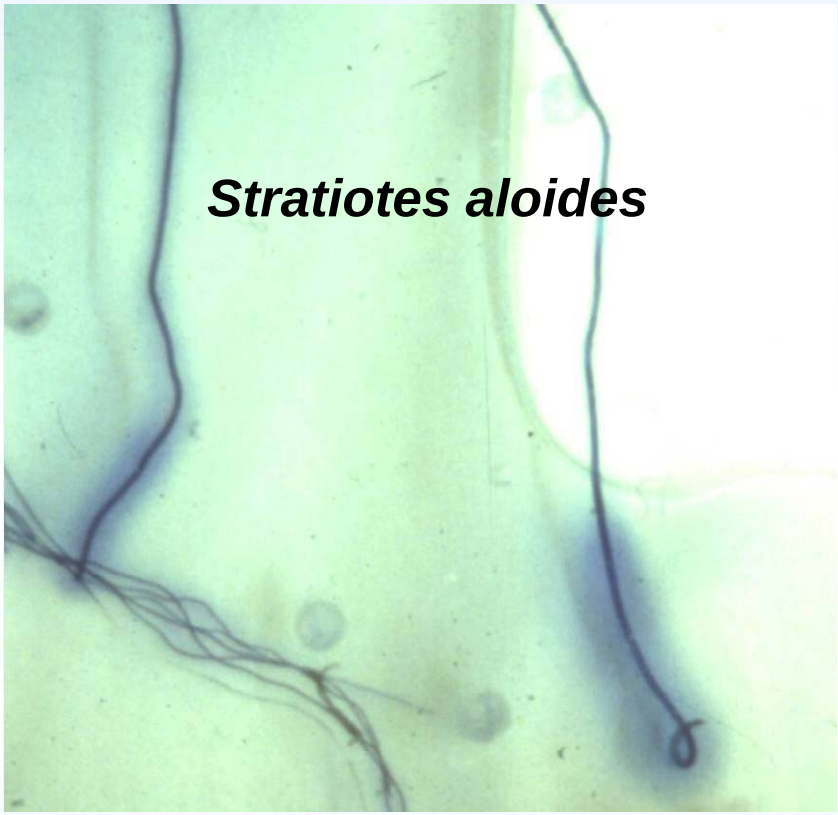
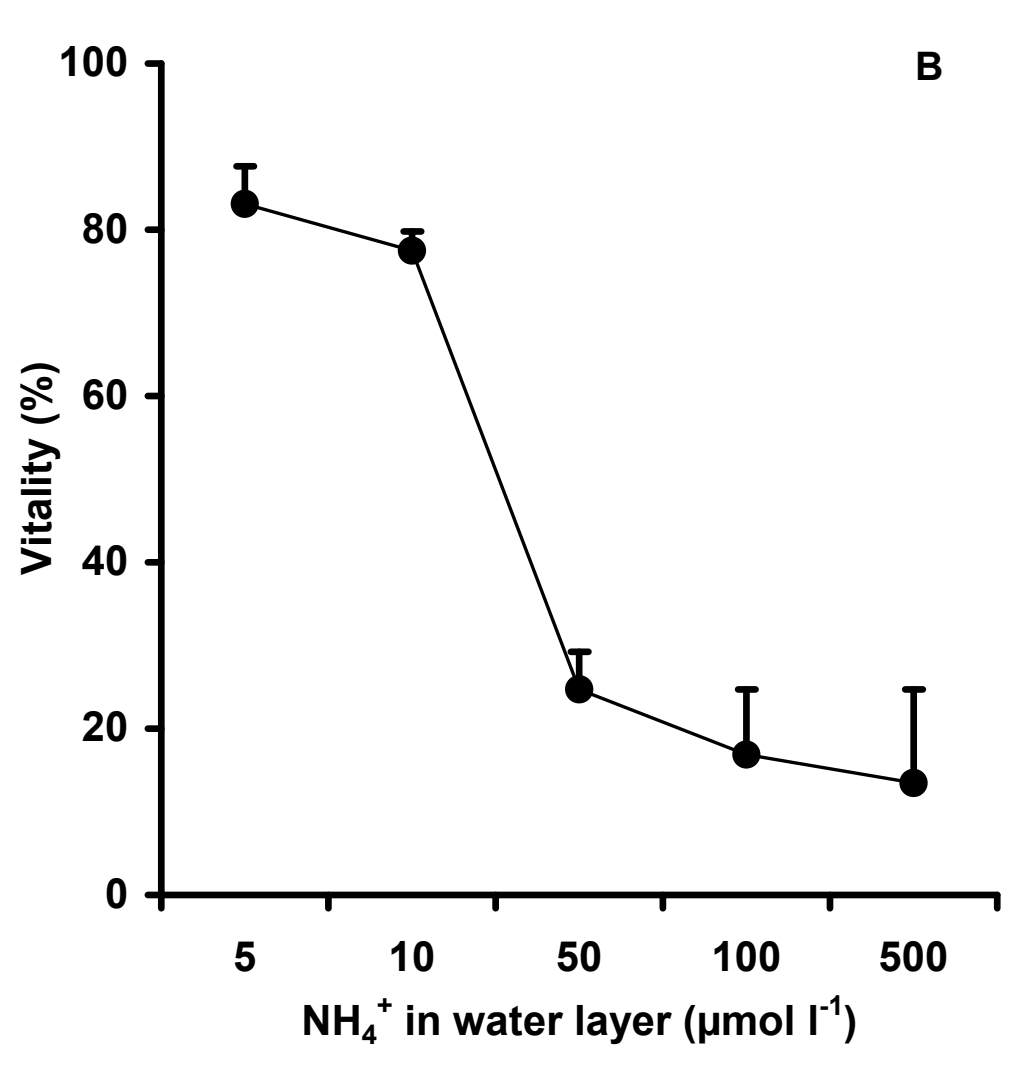
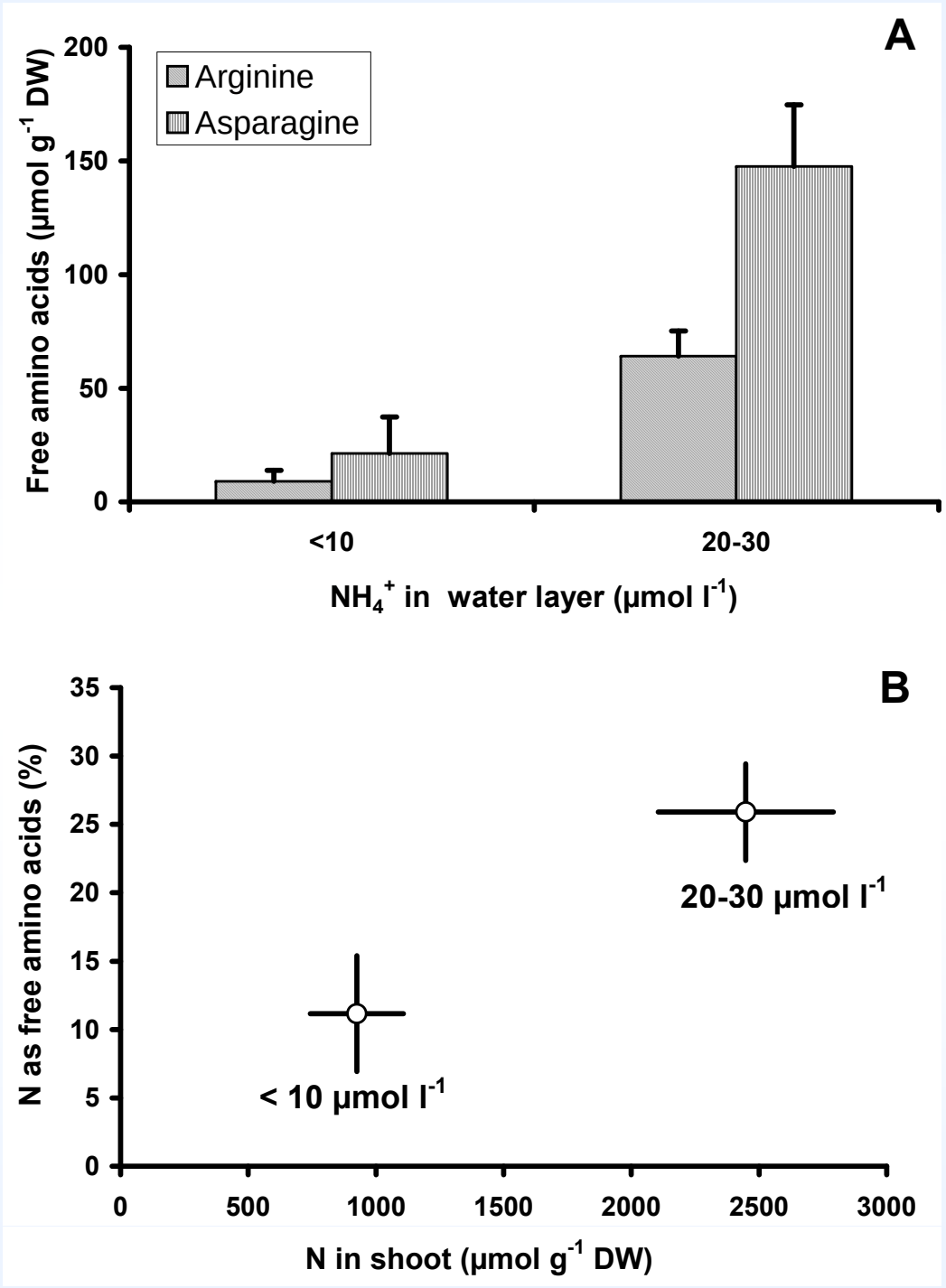

A
Survival time (days)
45
40
35
30
25
20
15
10
5
0
0
5
10
25
50
100
250
500
1000
0
1
2
3
Log [sulphide] (µmol l-1)

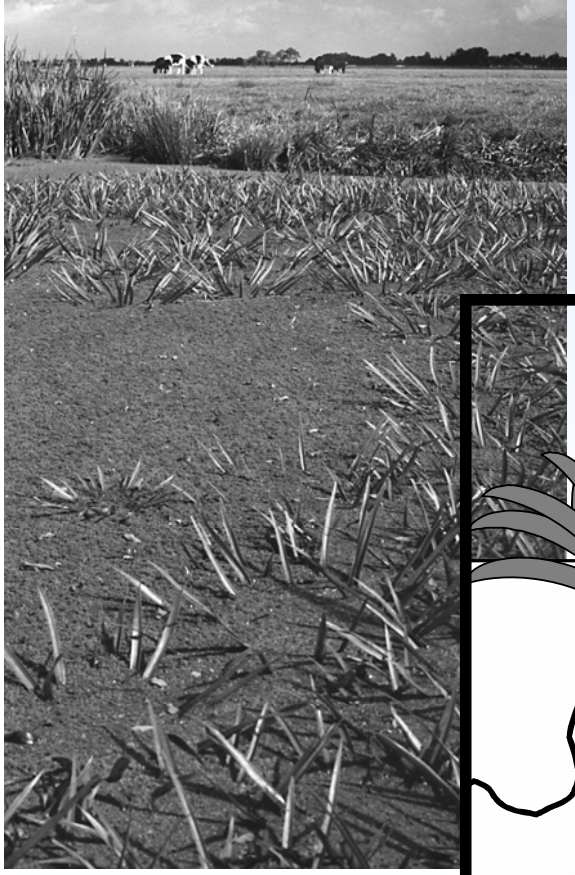
Littorella uniflora

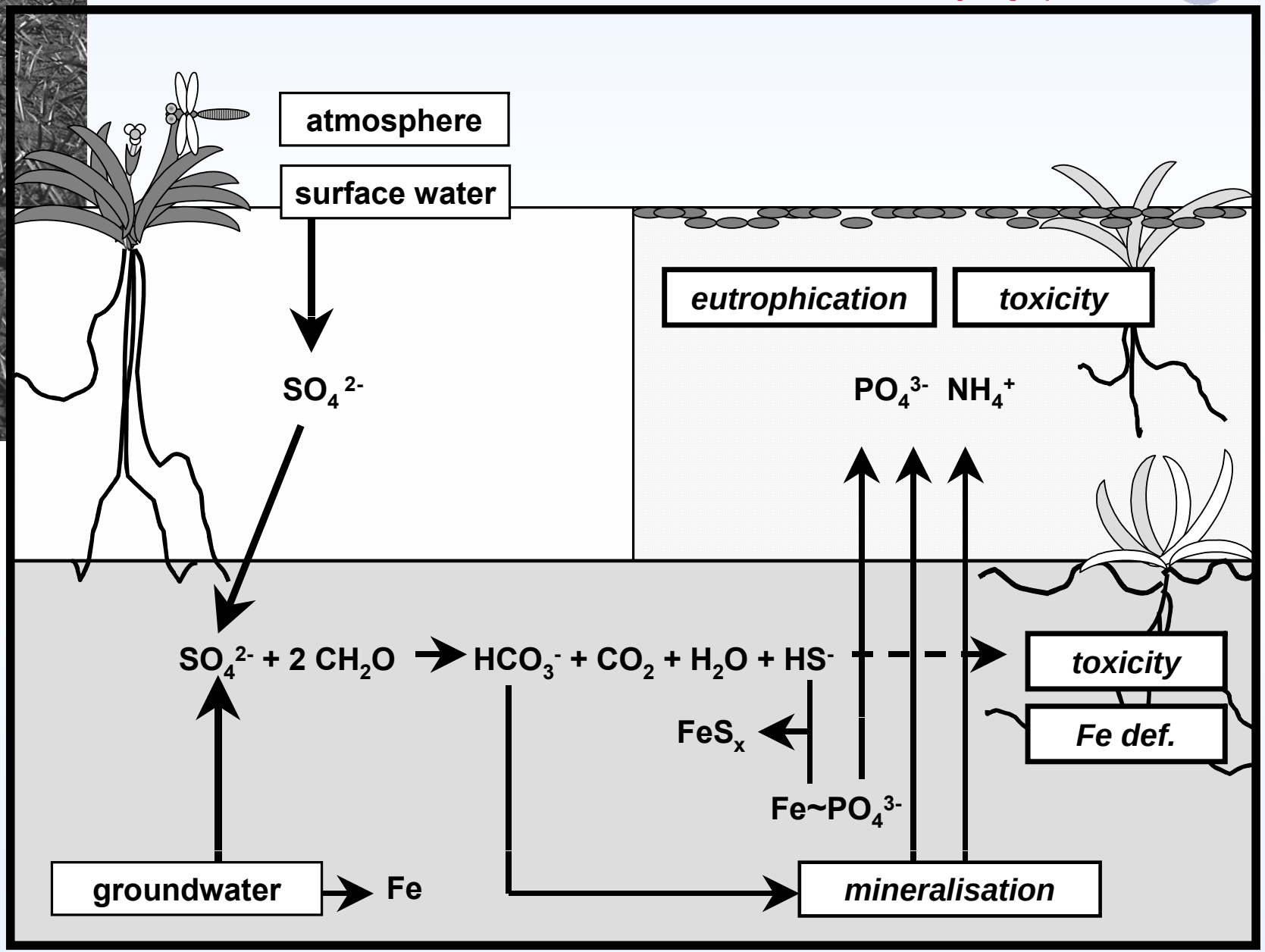


Stratiotes aloides

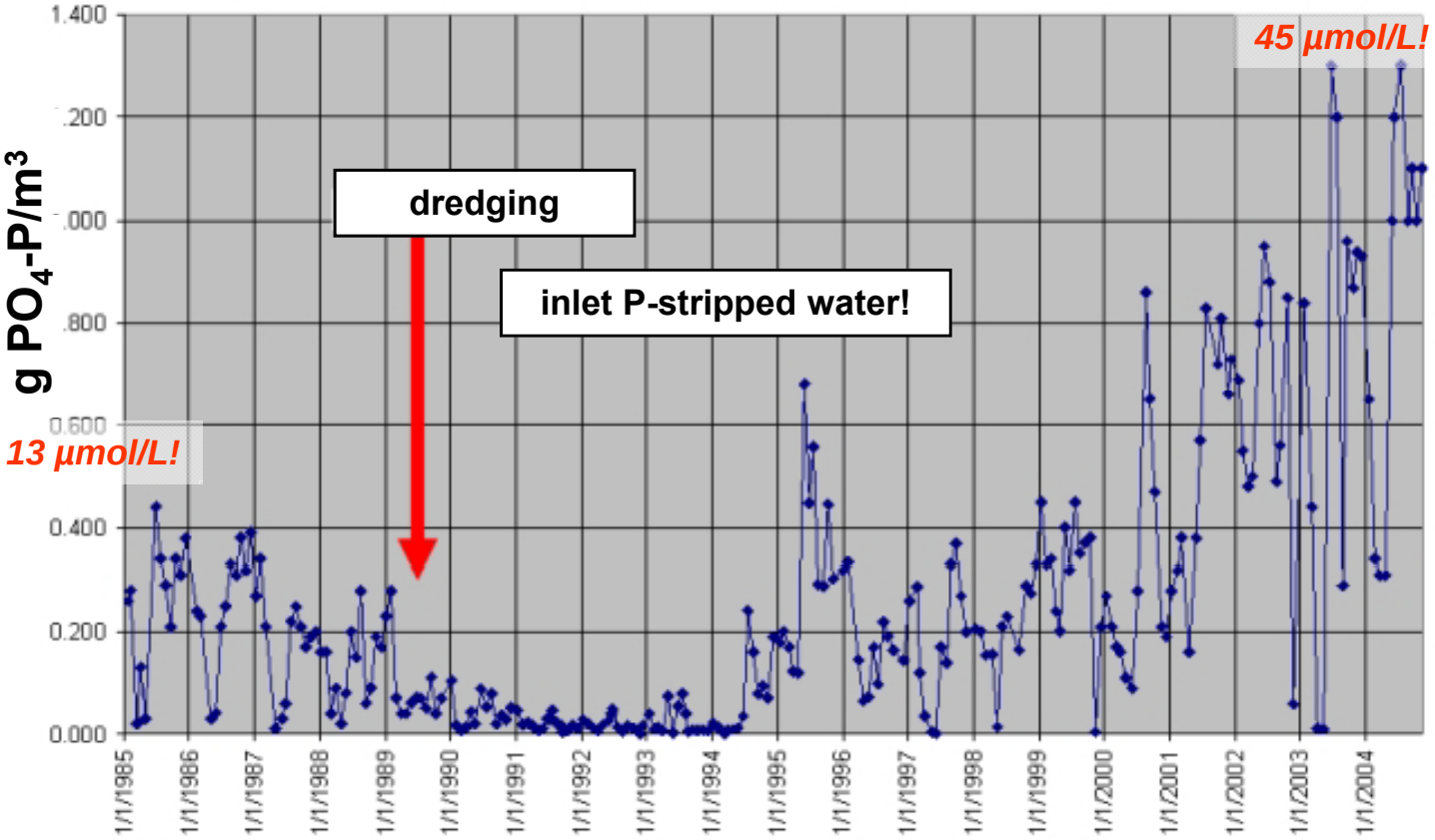

B
100
80
60
40
20
0
Vitality (%)
5
10
50
100
500
NH4+ in water layer (µmol l-1)


A
Arginine
Asparagine
Free amino acids (µmol g-1 DW)
200
150
100
50
0
<10
20-30
NH4+ in water layer (µmol l-1)
B
N as free amino acids (%)
35
30
25
20
15
10
5
0
20-30 µmol l-1
< 10 µmol l-1
0
500
1000
1500
2000
2500
3000
N in shoot (µmol g-1 DW)



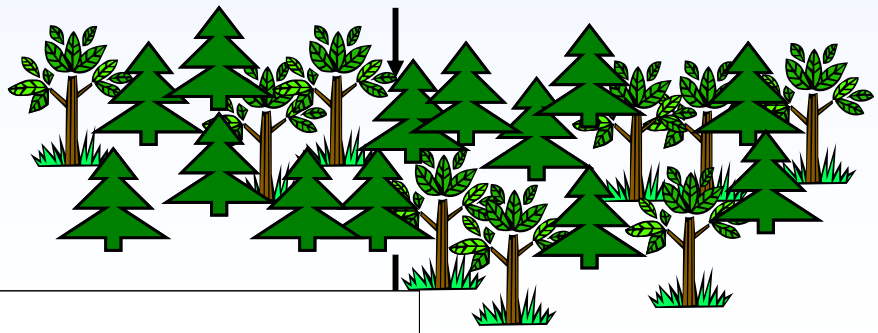

atmosphere
surface water
SO_4^{2-}
eutrophication
toxicity
PO_4^{3-} NH_4^+
$SO_4^{2-} + 2\ CH_2O \rightarrow HCO_3^- + CO_2 + H_2O + HS^-$
toxicity
Fe def.
FeS_x
$Fe{\sim}PO_4^{3-}$
groundwater
Fe
mineralisation

Shallow peat lake (Geerplas, the Netherlands)



Michielsen et al. *2008*

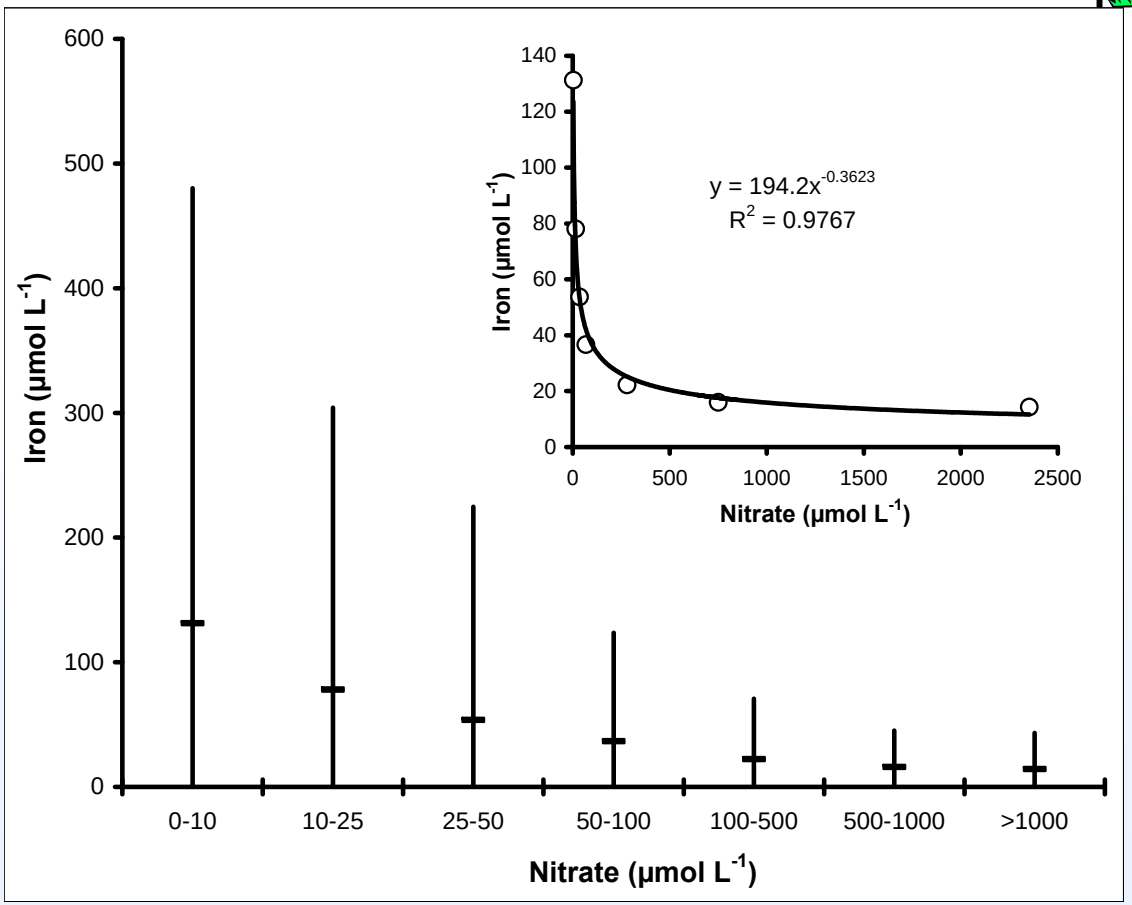
Nitrate immobilizes iron



NH_4^+

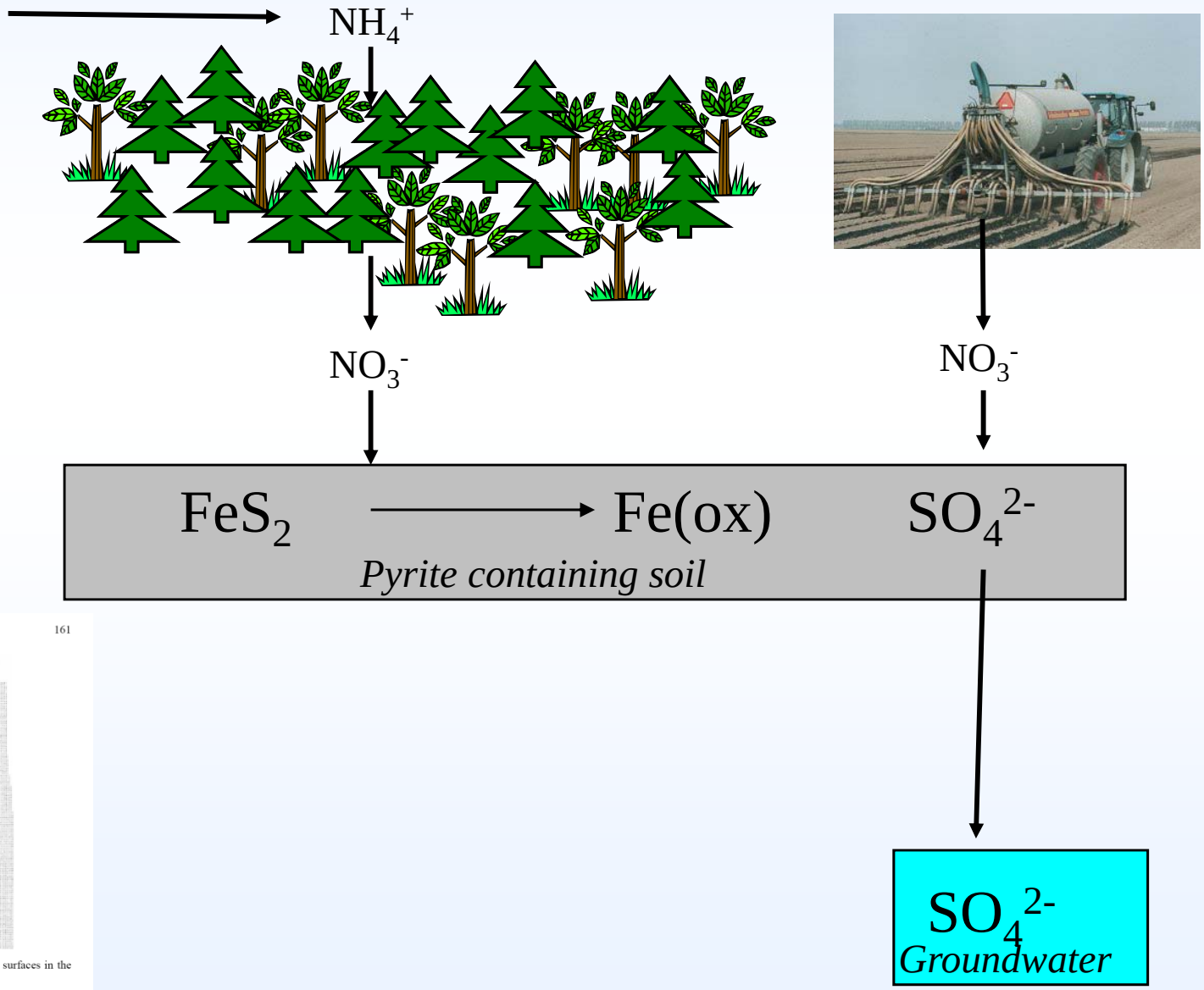
NO_3^- NO_3^-

Fe^{2+} → Fe(ox)↓



BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

$$20FeS_2 + 52NO_3^- + 5O_2 + 42H_2O \Rightarrow 20Fe(OH)_3 + 40SO_4^{2-} + 28N_2 + 24H^+$$



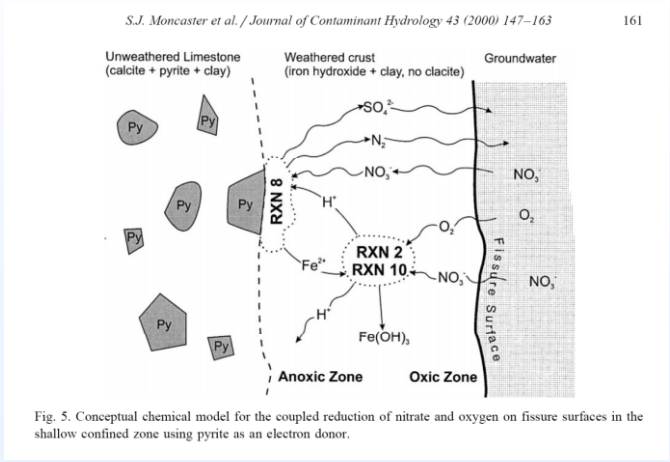
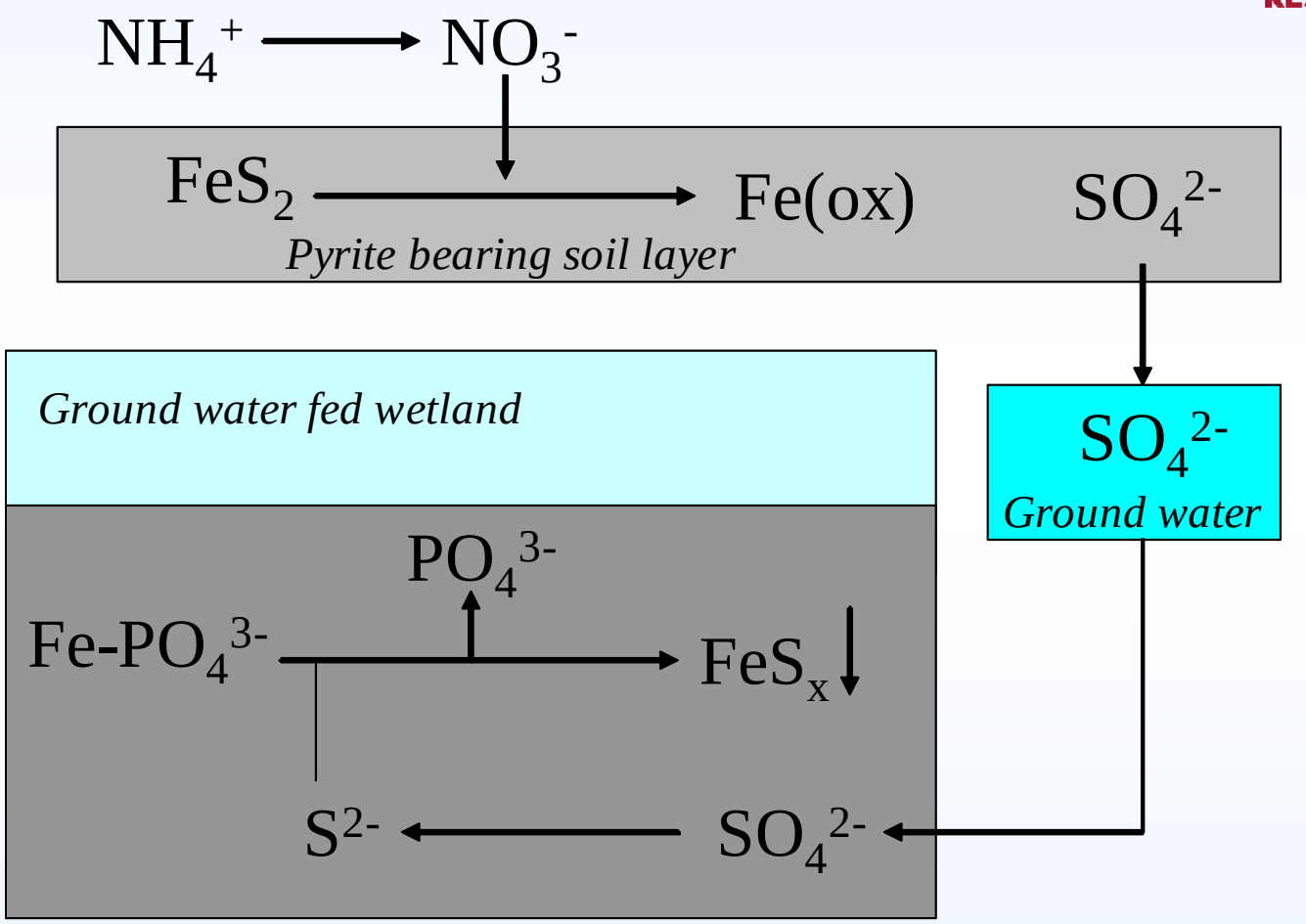
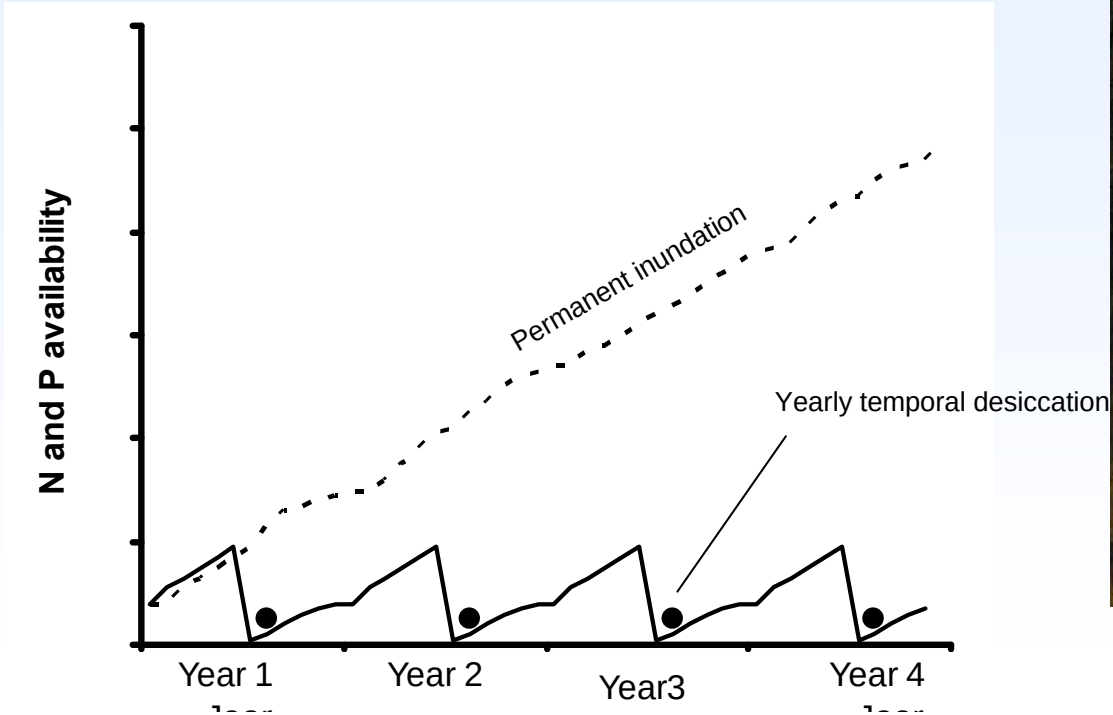


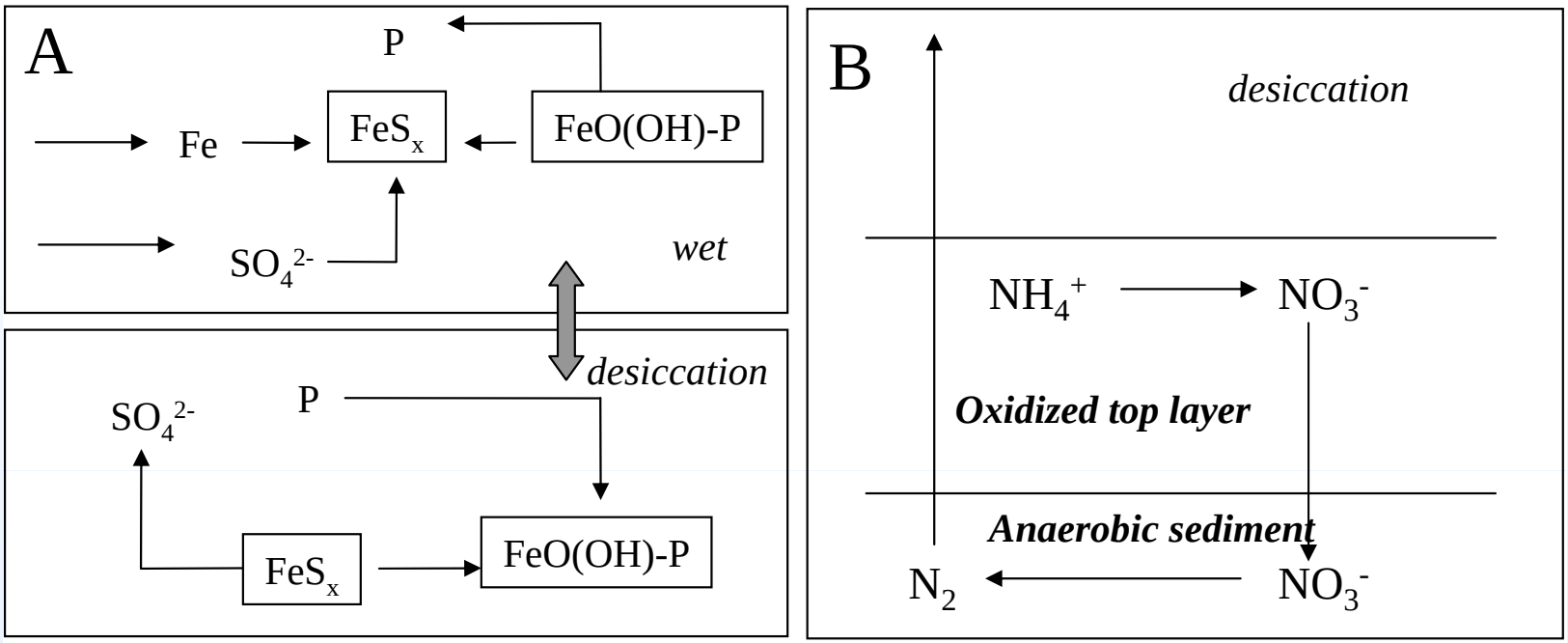
Fig. 5. Conceptual chemical model for the coupled reduction of nitrate and oxygen on fissure surfaces in the shallow confined zone using pyrite as an electron donor.

The sulphur bridge




N and P availability
Permanent inundation
Yearly temporal desiccation
Year 1
Year 2
Year3
Year 4


B ware
RESEARCH CENTRE


A
P
Fe
FeSx
FeO(OH)-P
SO4 2-
wet
desiccation
SO4 2-
P
FeSx
FeO(OH)-P
B
desiccation
NH4+
NO3-
Oxidized top layer
Anaerobic sediment
N2
NO3-

Wetland restoration !
Rewetting measures in
Alder carr woods: high summer level

before

after


B
ware
RESEARCH CENTRE

Raised bogs in the Netherlands

Janssonius 1658

BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

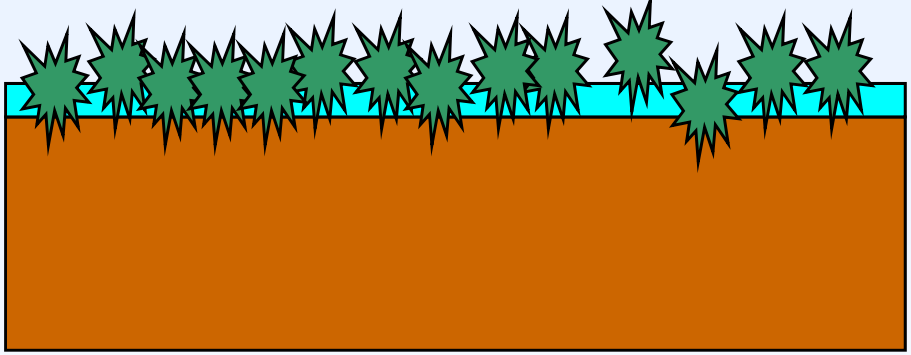
The area covered by raised bogs (1,000,000 ha) has been almost completely lost due to peat cutting activities.....

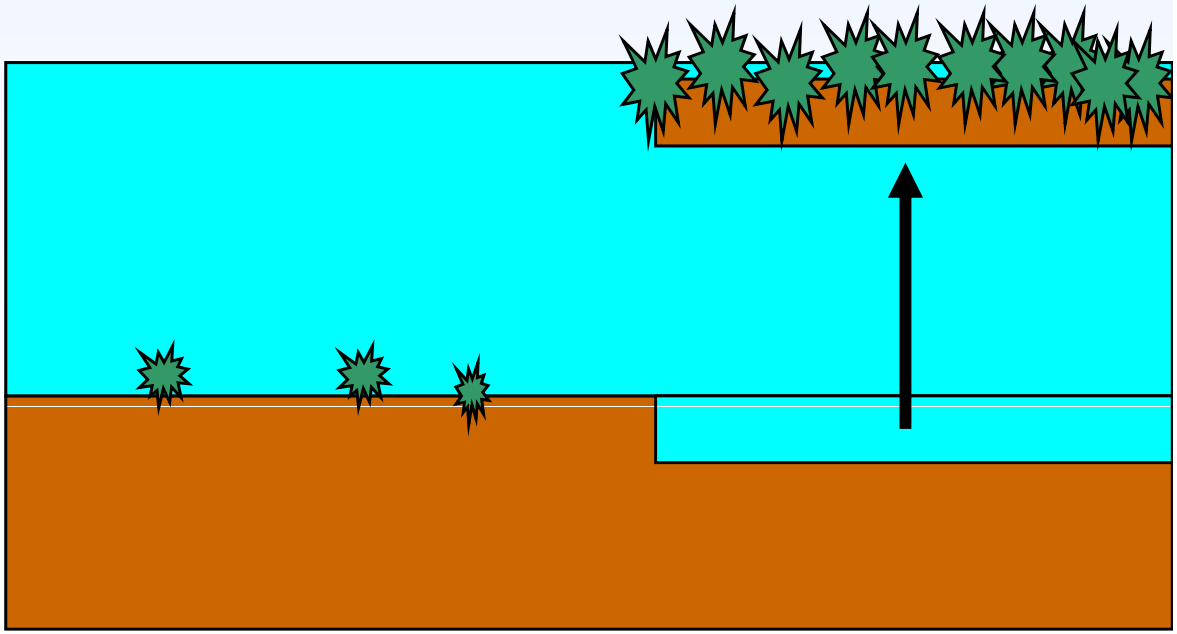
Nowadays less than 3,600 ha are covered by 'bogs'. These bog relics are often severely desiccated.....

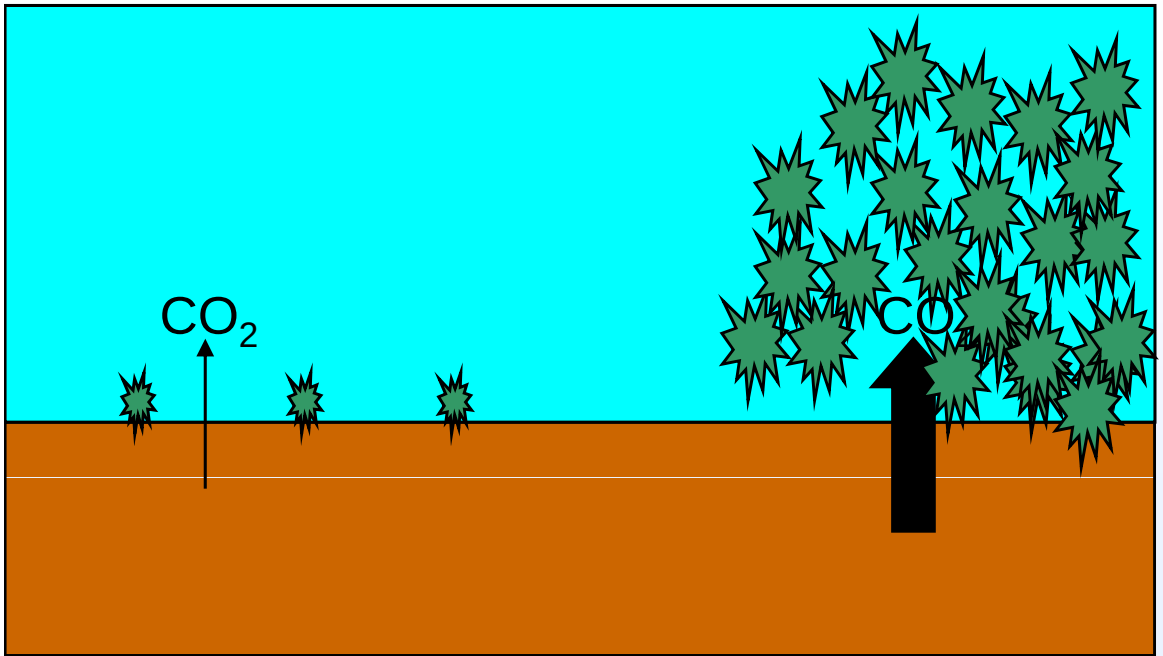
BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

Rewetting of cut-over bogs

Large areas of deeply inundated, strongly humified peat with no growth of *Sphagnum* mosses






CO_2
CO

RESEARCH CENTRE

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Development of *S. cuspidatum* carpets is usually observed in the more shallowly inundated zones

Relationship between colour of the water layer and light intensity at different depths

Depth (cm)

100
90
80
70
60
50
40
30
20
10
0

0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500

Colour density (E_{450})

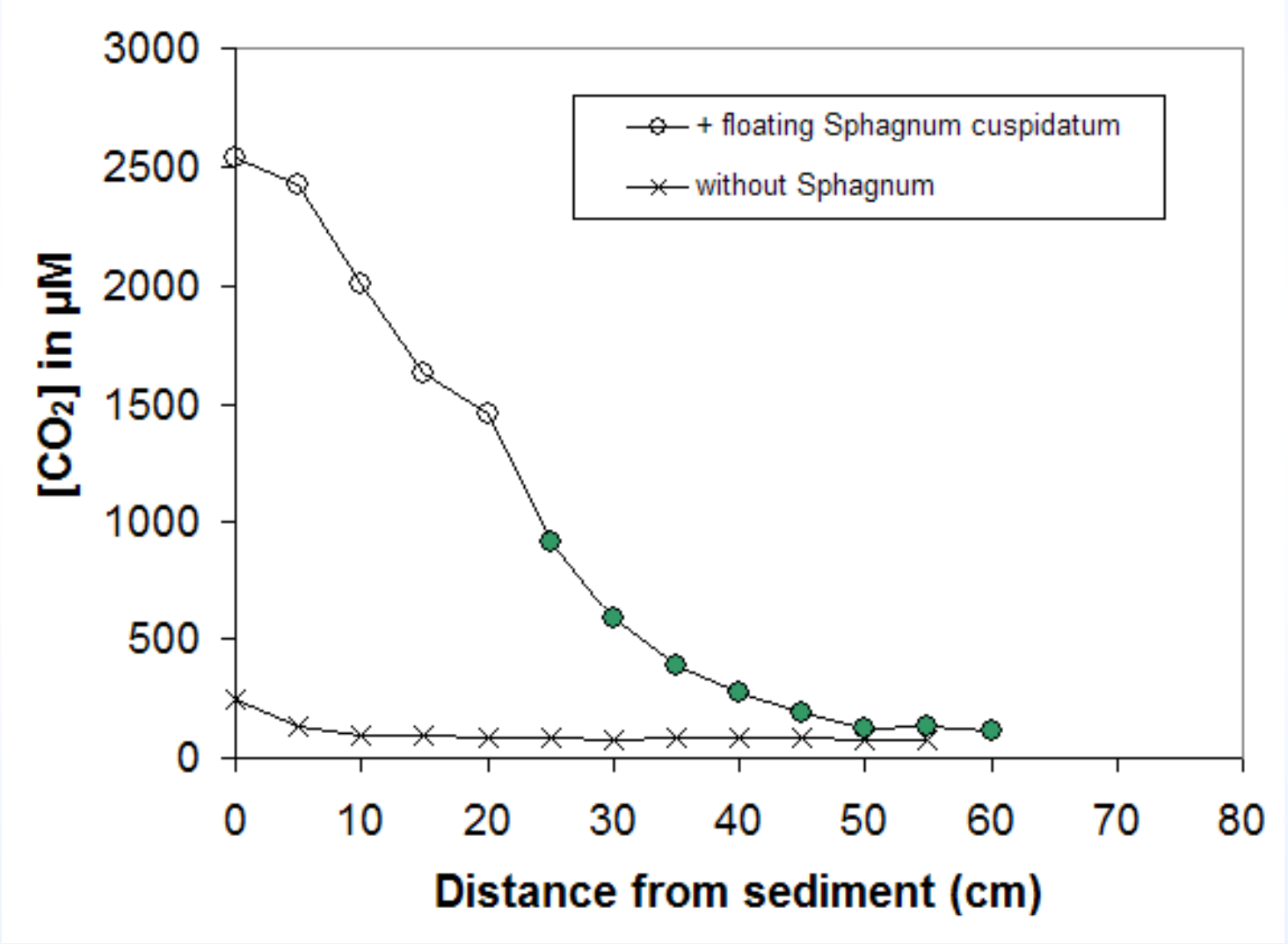
5 %

Light intensity

Smolders *et al.* 2003
Wetlands Ecology & Management

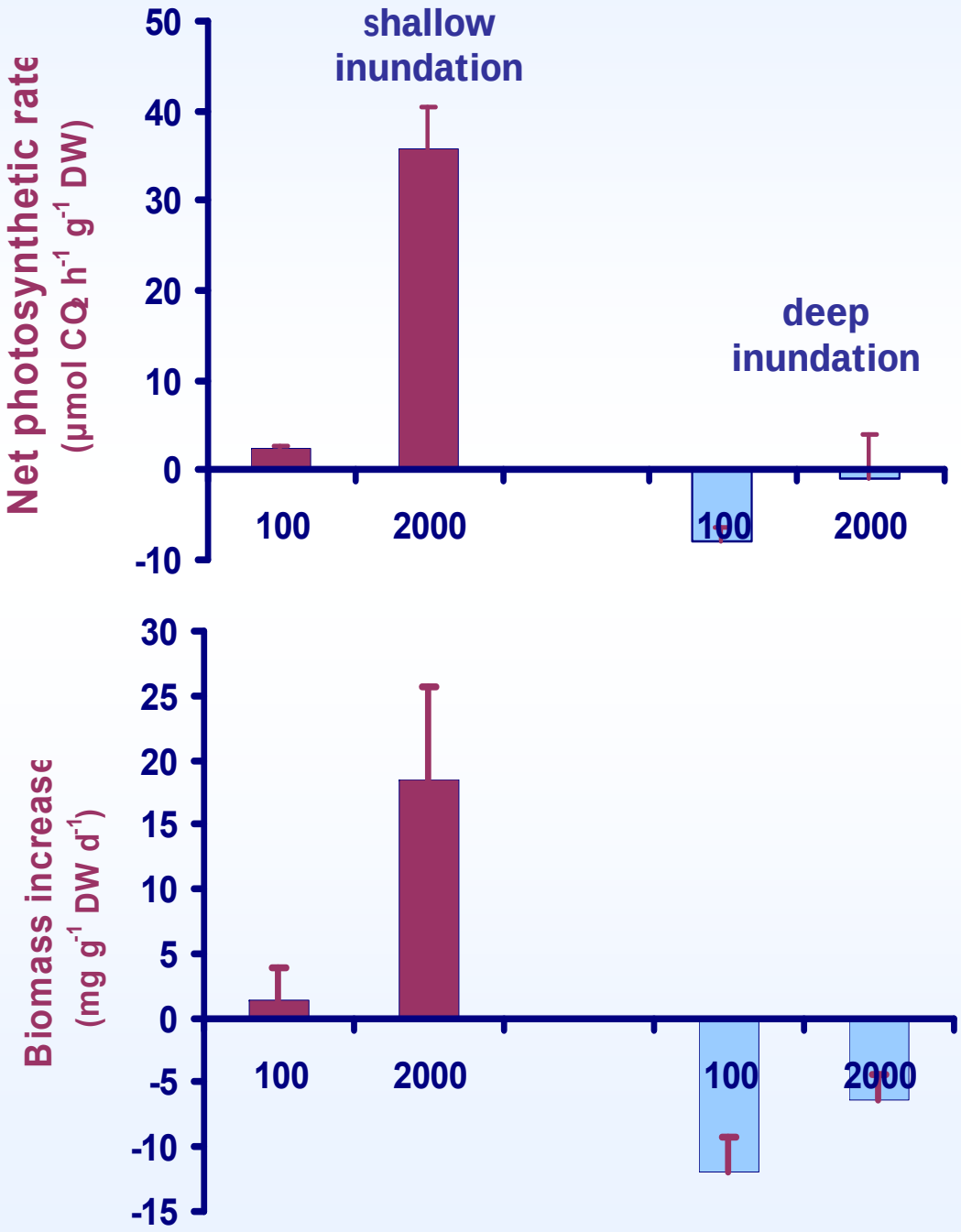
BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

Submerged *Sphagnum* needs substrate derived CO_2 for growth

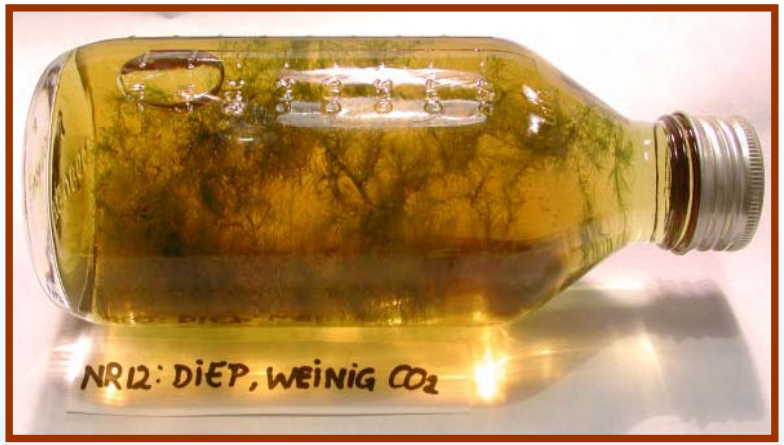


BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

Growth of *S. cuspidatum* at different light conditions and CO_2 concentrations



Shallow inundation & 2000 µmol l^{-1} CO_2

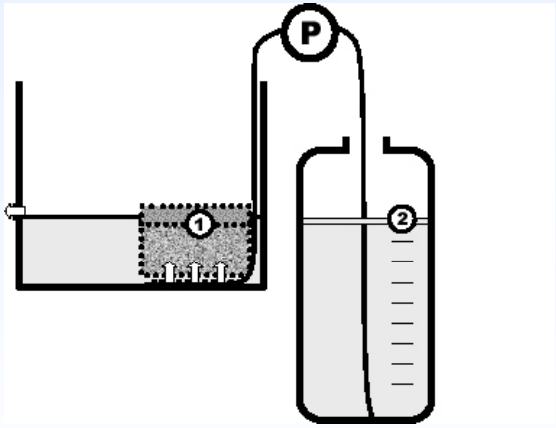


Deep inundation & 100 µmol l^{-1} CO_2

Smolders *et al.* 2003
Wetlands Ecology & Management

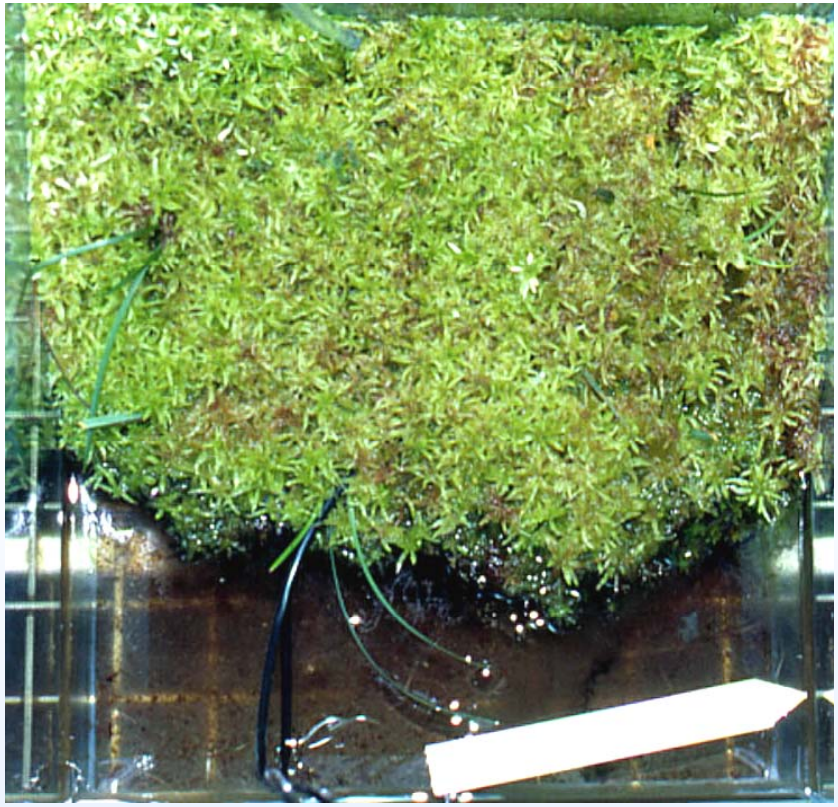
BIOGEOCHEMICAL WATER-MANAGEMENT & APPLIED RESEARCH ON ECOSYSTEMS

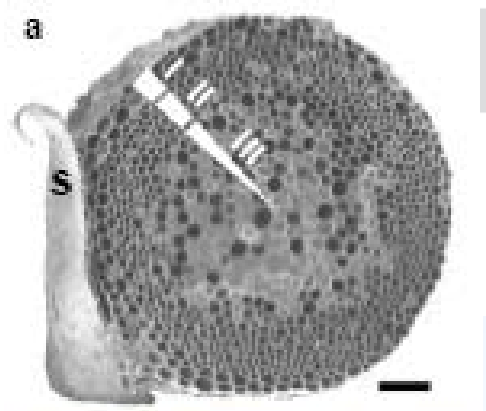
Growth of *Sphagnum magellanicum* at different CO_2 concentrations

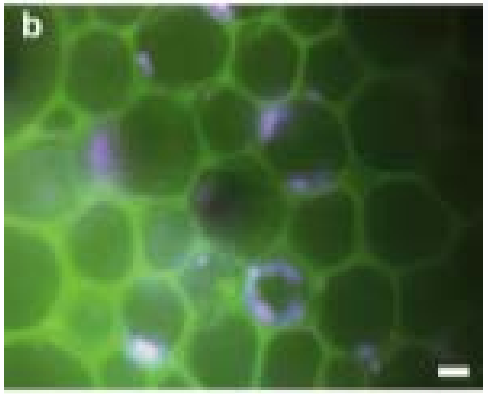


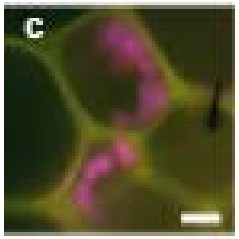
20 µmol l^{-1} CO_2

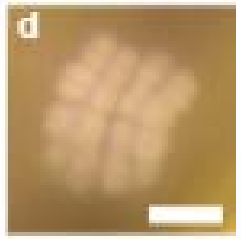
2000 µmol l^{-1} CO_2

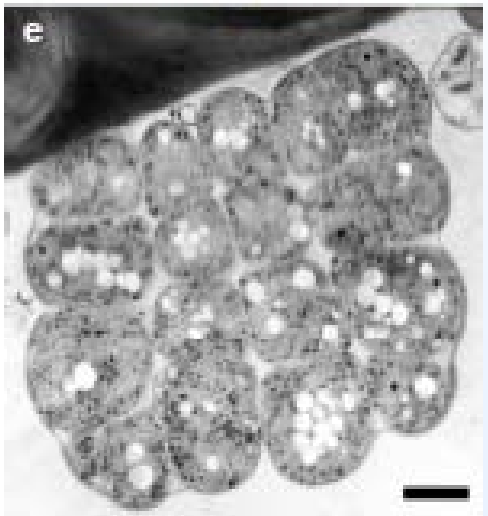








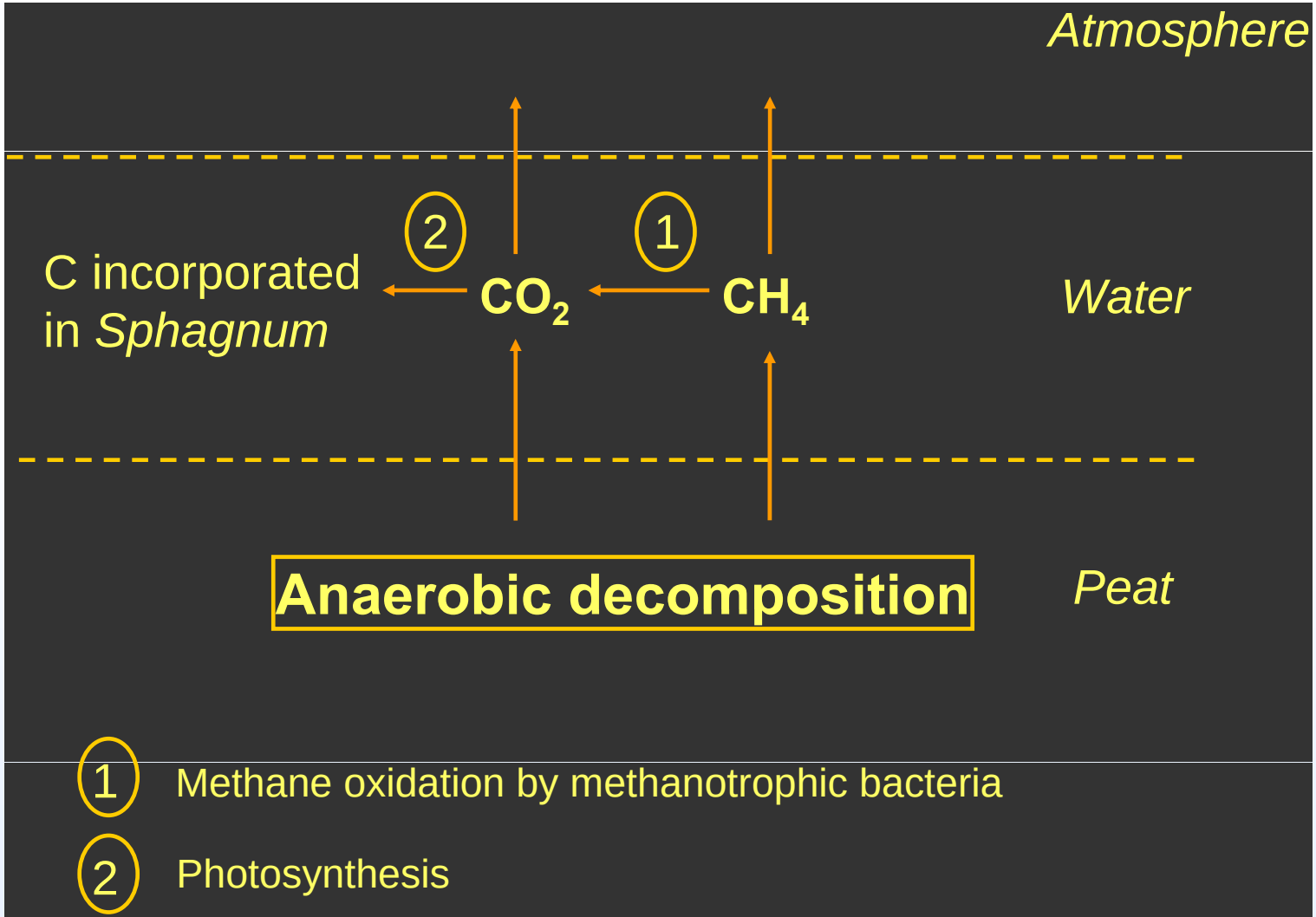


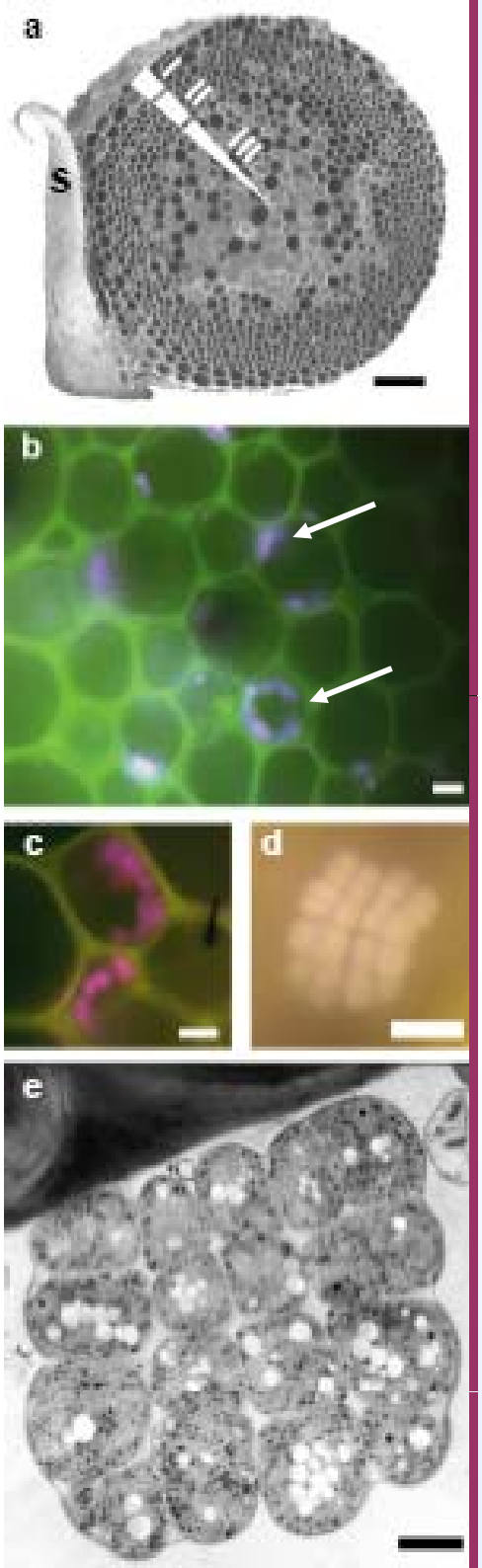


Vol 436|25 August 2005|doi:10.1038/nature03802 nature

Methanotrophic symbionts provide carbon for photosynthesis in peat bogs

Ashna A. Raghoebarsing[1], Alfons J. P. Smolders[2], Markus C. Schmid[1], W. Irene C. Rijpstra[4], Mieke Wolters-Arts[3], Jan Derksen[3], Mike S. M. Jetten[1], Stefan Schouten[4], Jaap S. Sinninghe Damsté[4], Leon P. M. Lamers[2], Jan G. M. Roelofs[2], Huub J. M. Op den Camp[1] & Marc Strous[1]





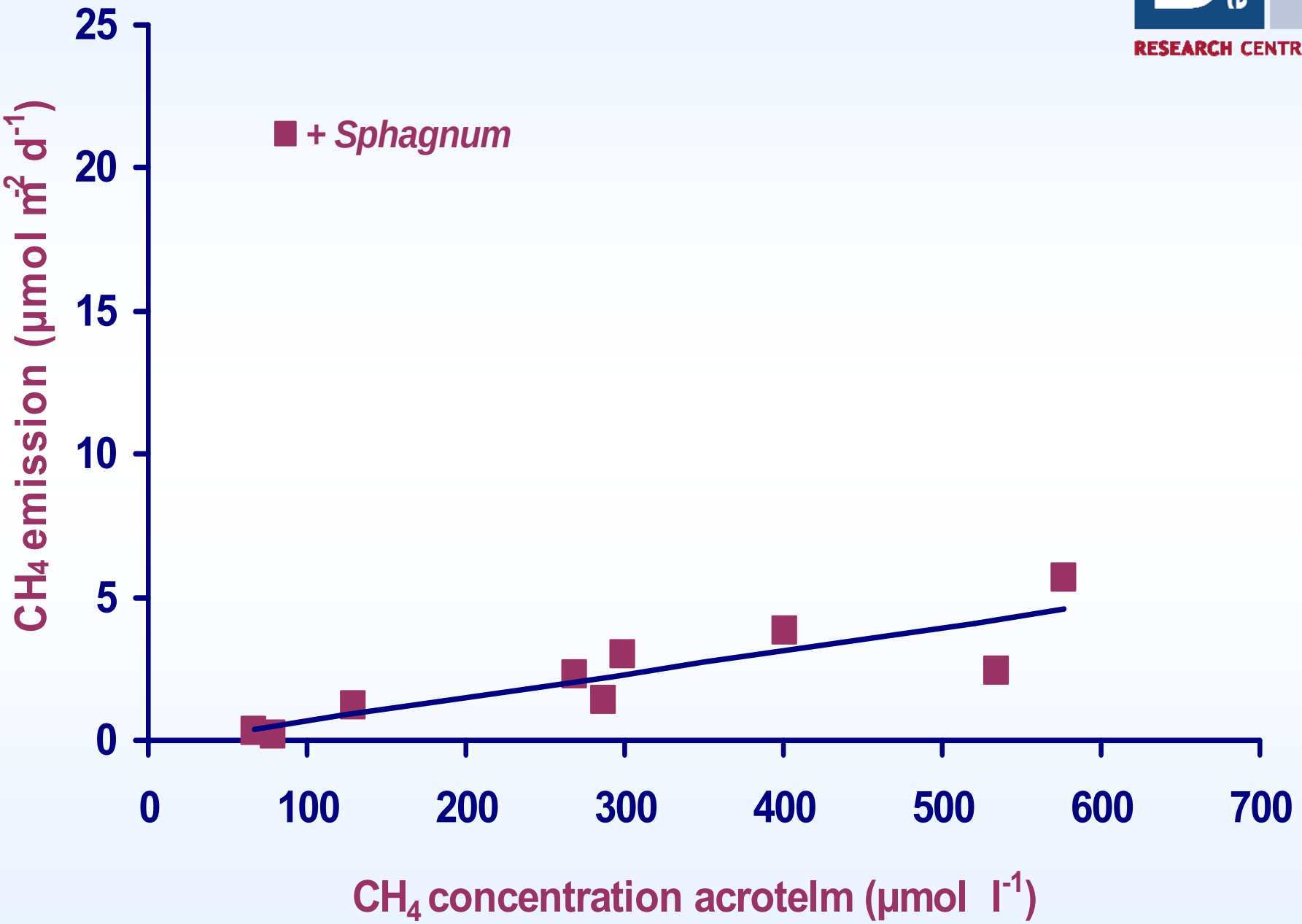
With the aid of FISH (Fluorescence *In Situ* Hybridisation) methanotrophic bacteria have been found in the hyaline cells of *S. cuspidatum* and on stem leaves

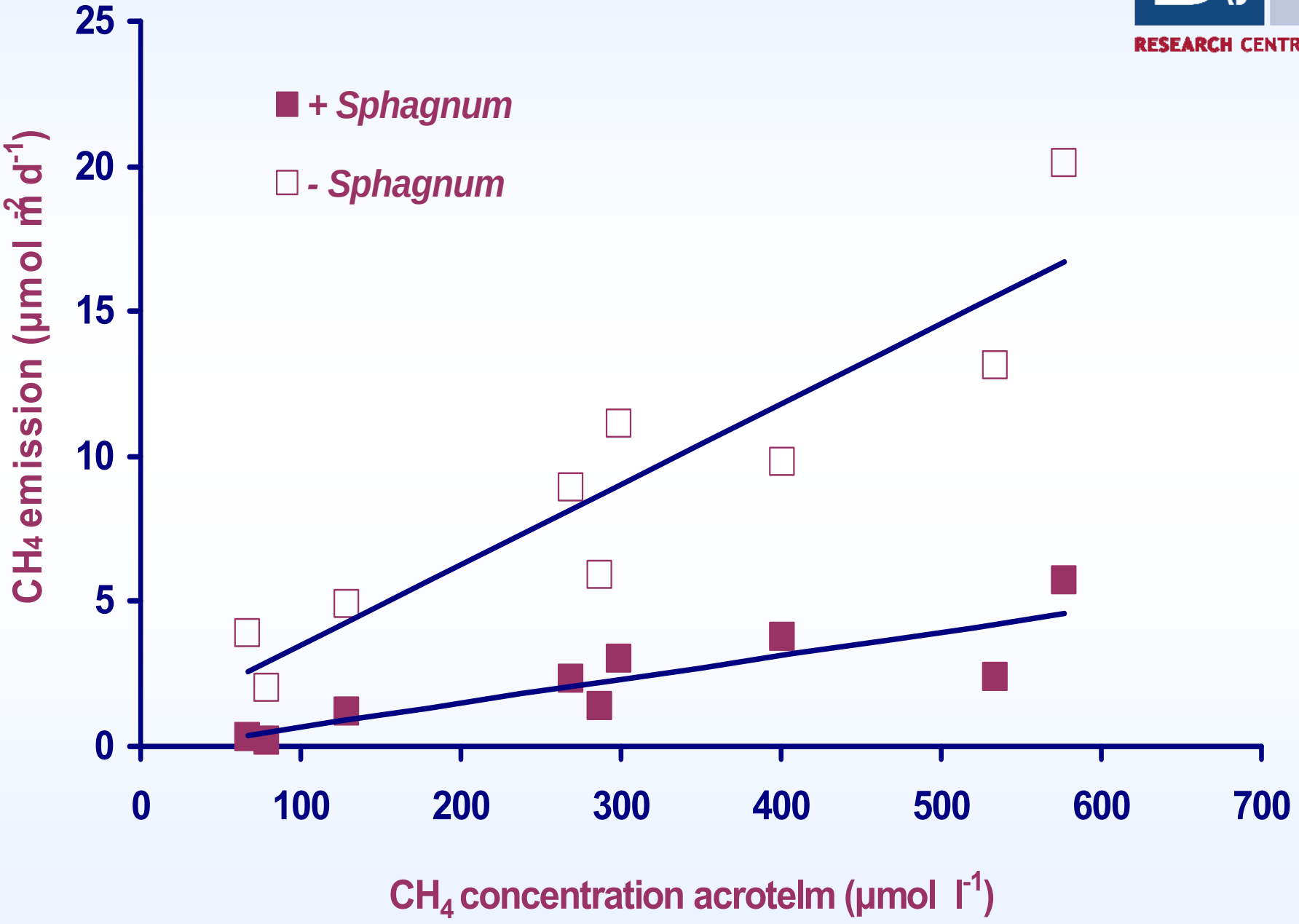
16S rRNA sequence shows highest similarity with uncultured α-Proteobacteria/type II methanotrophic bacteria

Isotopic mass balance calculation: methane contributed between 5 and 20% of the total carbon fixated by *S. cuspidatum* (field measurements)

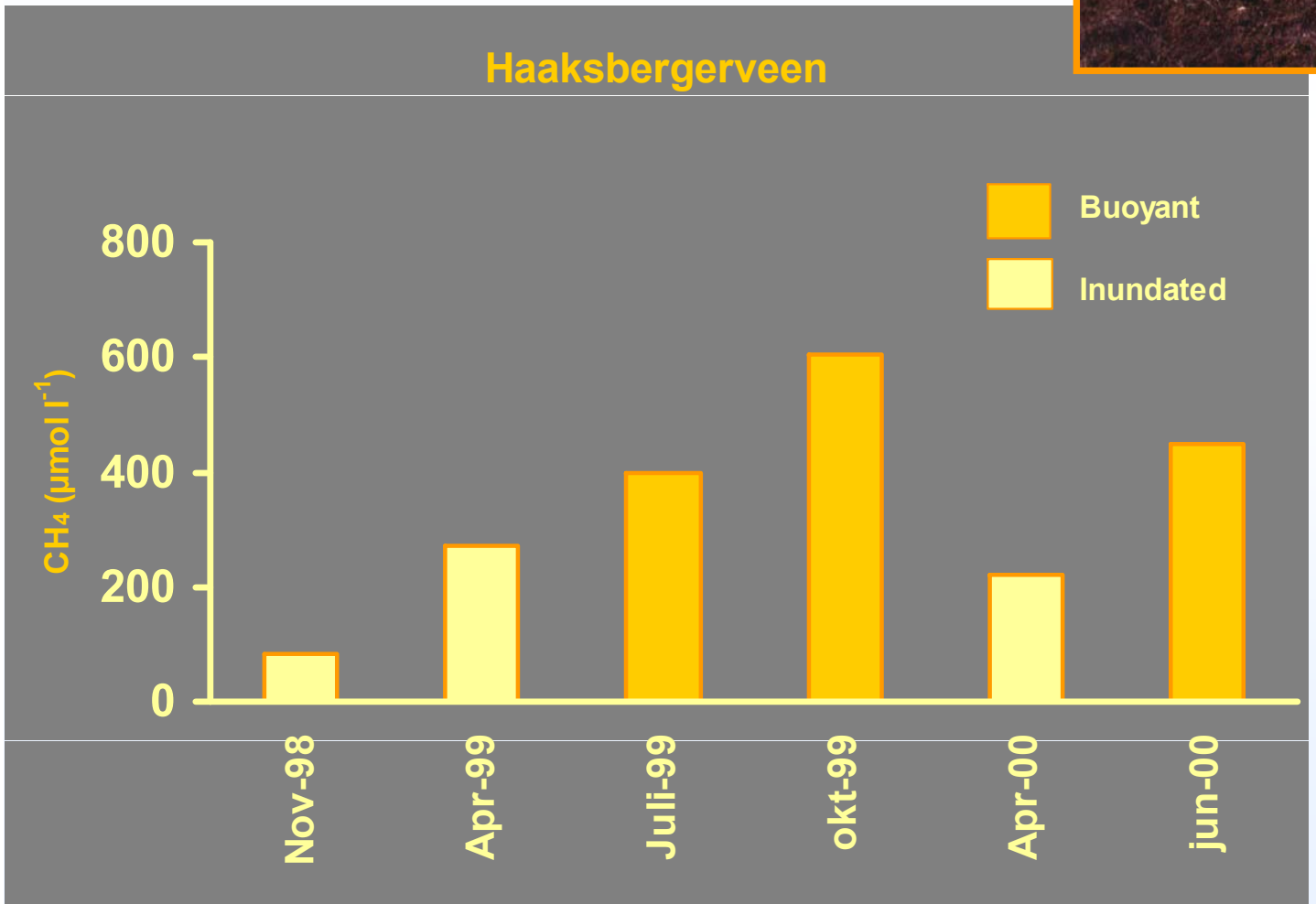
This symbiosis is important in the view of global change (efficient recycling of methane)

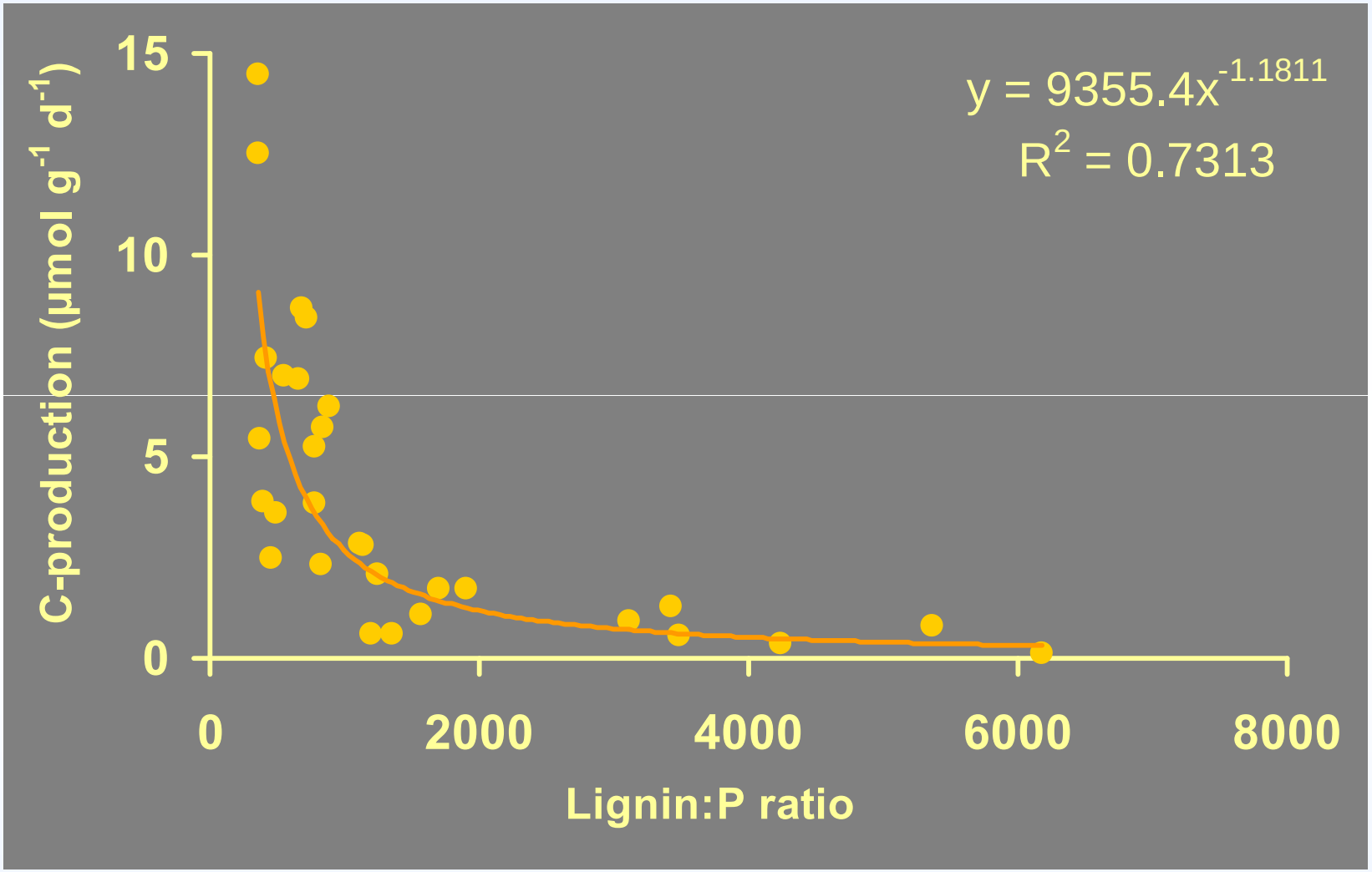
Raghoebarsing, Smolders et al. Nature (2005)

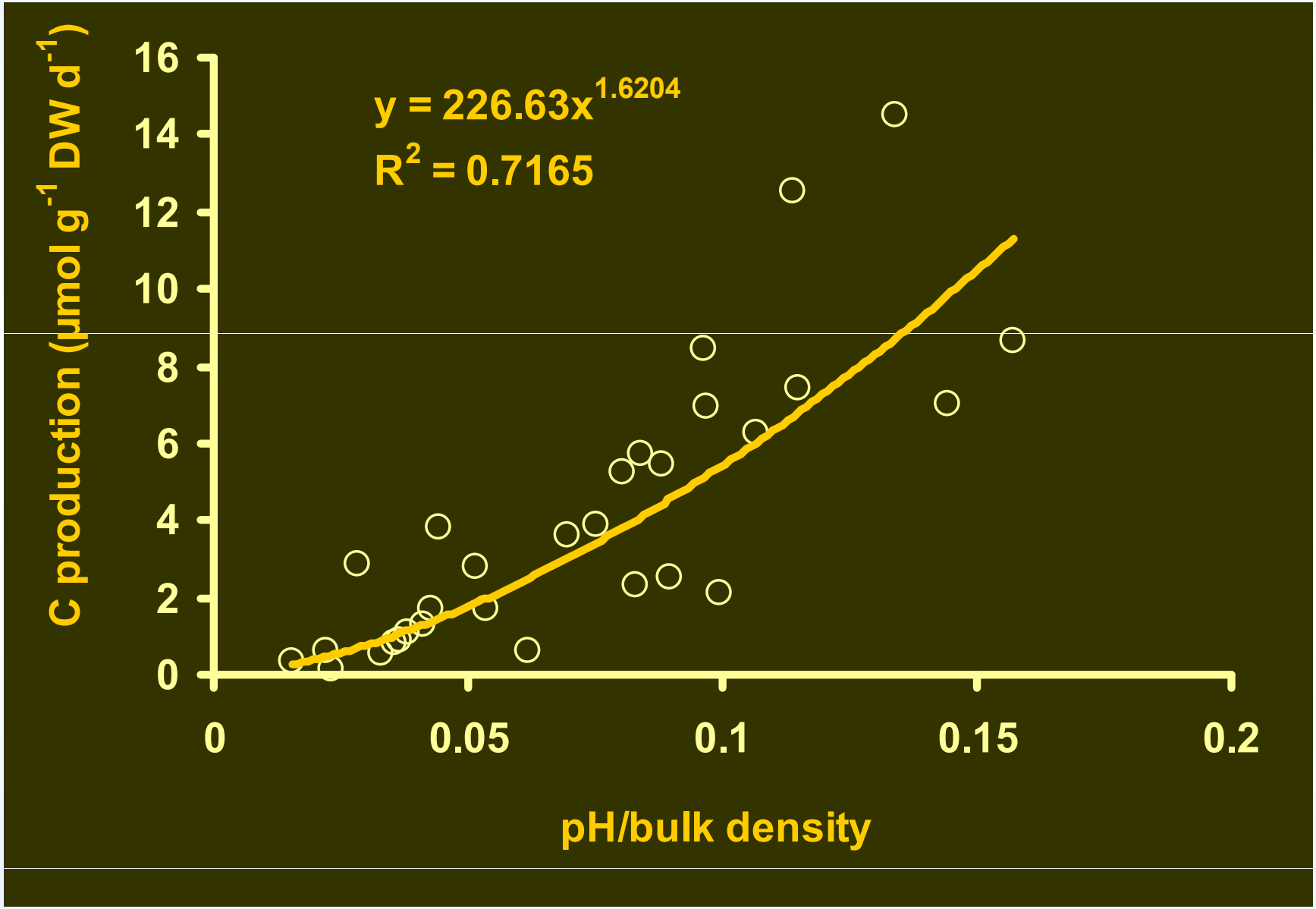

+ Sphagnum
CH4 emission (µmol m-2 d-1)
25
20
15
10
5
0
0
100
200
300
400
500
600
700
CH4 concentration acrotelm (µmol l-1)


+ Sphagnum
- Sphagnum
CH4 emission (µmol m-2 d-1)
0
5
10
15
20
25
0
100
200
300
400
500
600
700
CH4 concentration acrotelm (µmol l-1)

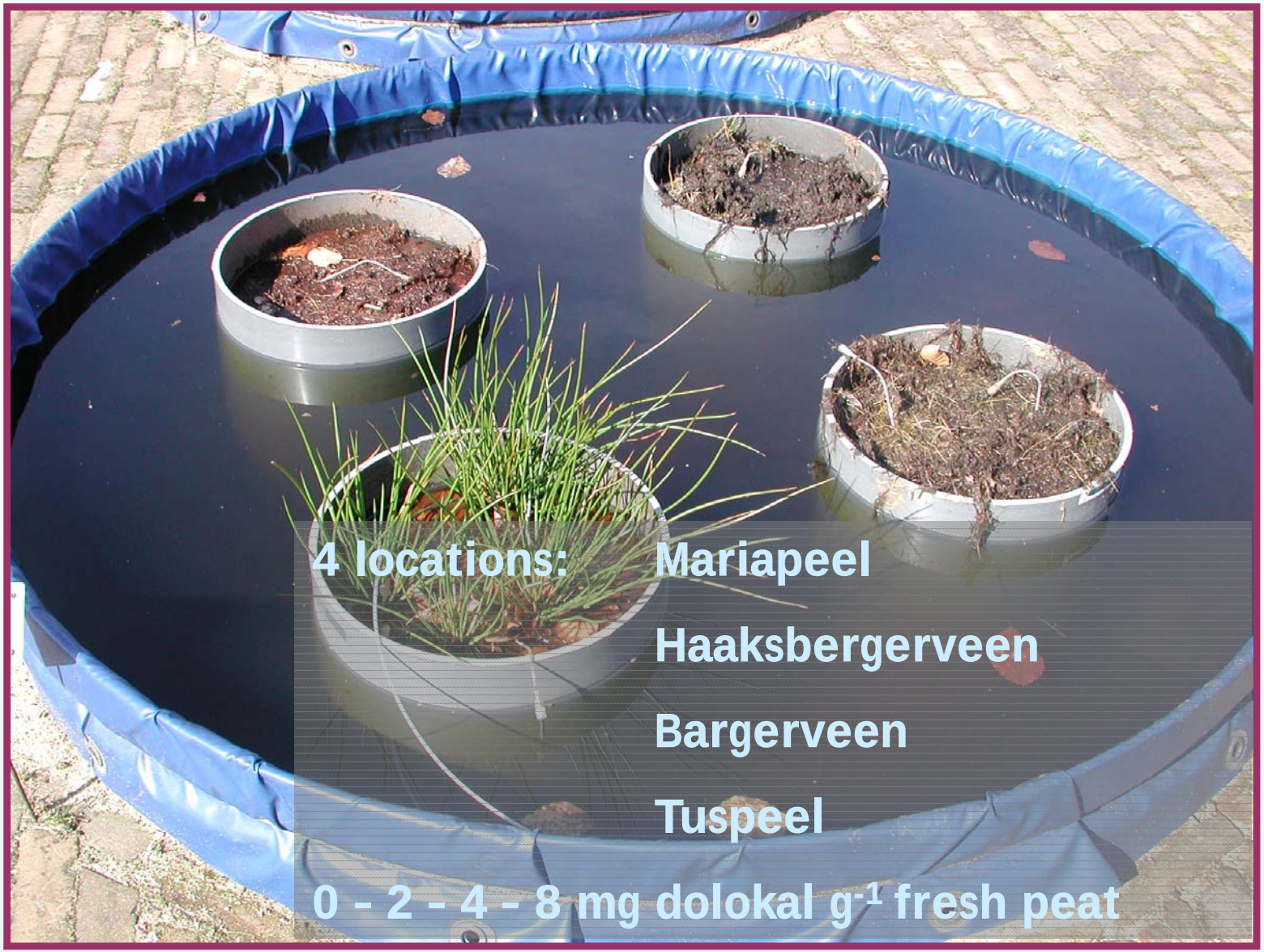
Spontaneous development of floating rafts

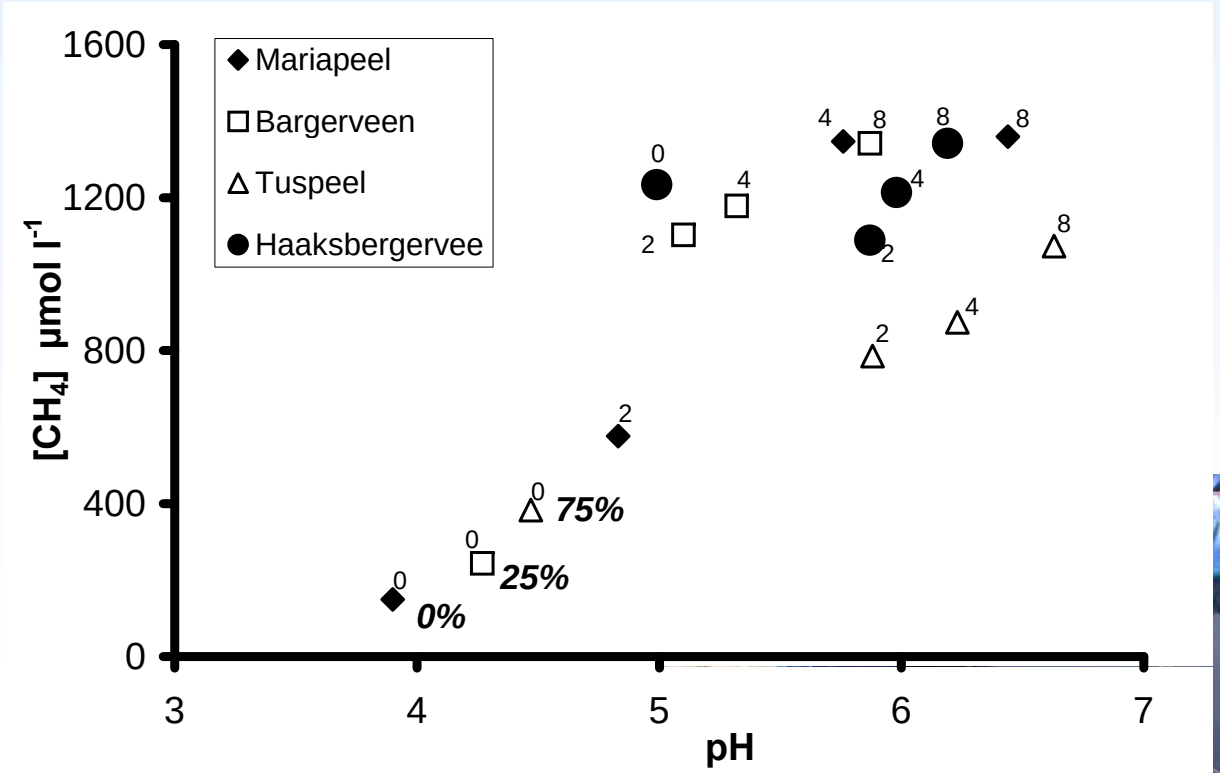

Haaksbergerveen
Buoyant
Inundated
800
600
400
200
0
CH4 (µmol l-1)
Nov-98
Apr-99
Juli-99
okt-99
Apr-00
jun-00

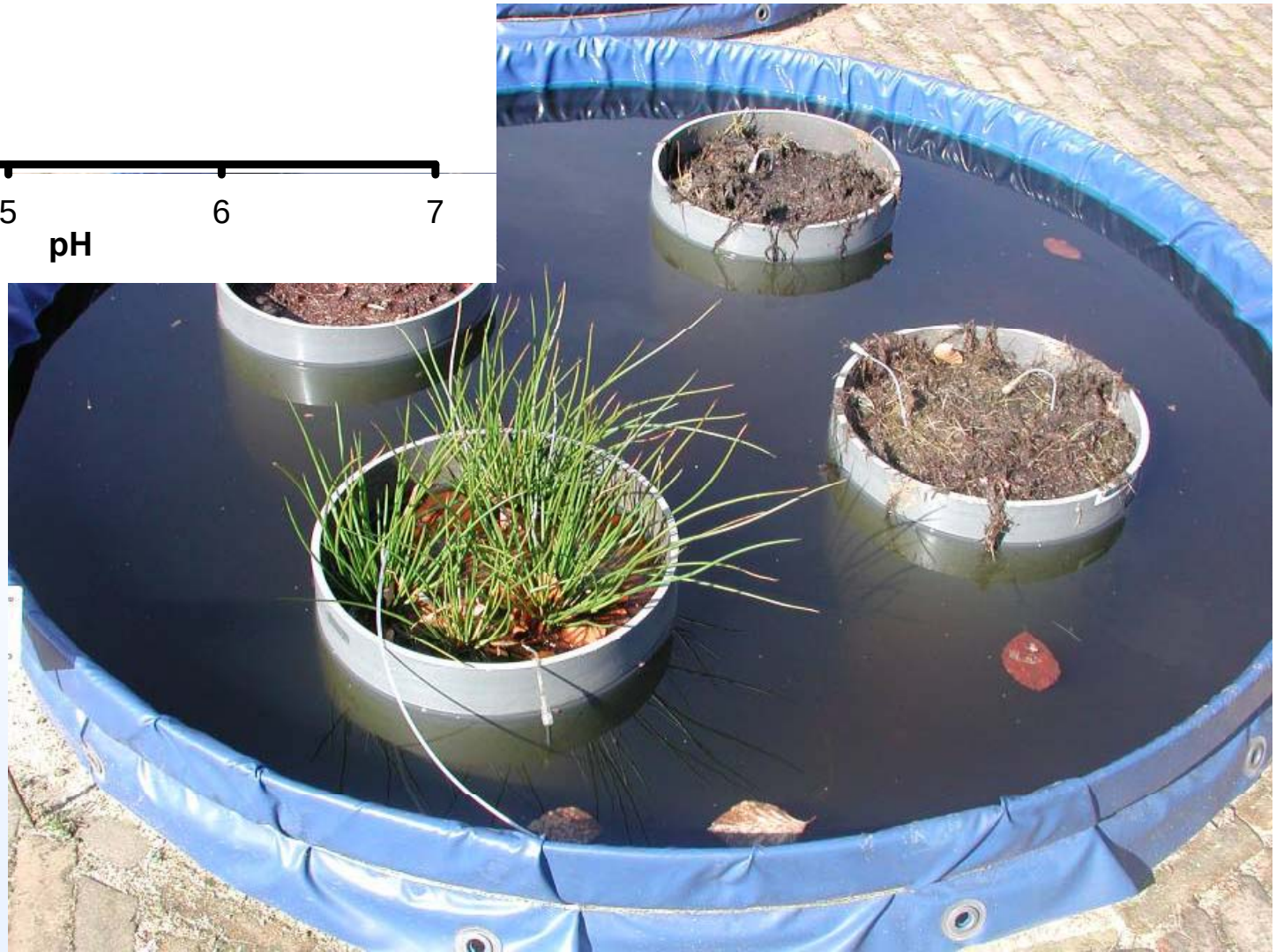

y = 9355.4x-1.1811
R2 = 0.7313
C-production (µmol g-1 d-1)
15
10
5
0
0
2000
4000
6000
8000
Lignin:P ratio


C production (µmol g-1 DW d-1)
y = 226.63x1.6204
R2 = 0.7165
16
14
12
10
8
6
4
2
0
0
0.05
0.1
0.15
0.2
pH/bulk density

Introduction of suitable substrates with different amounts of lime added



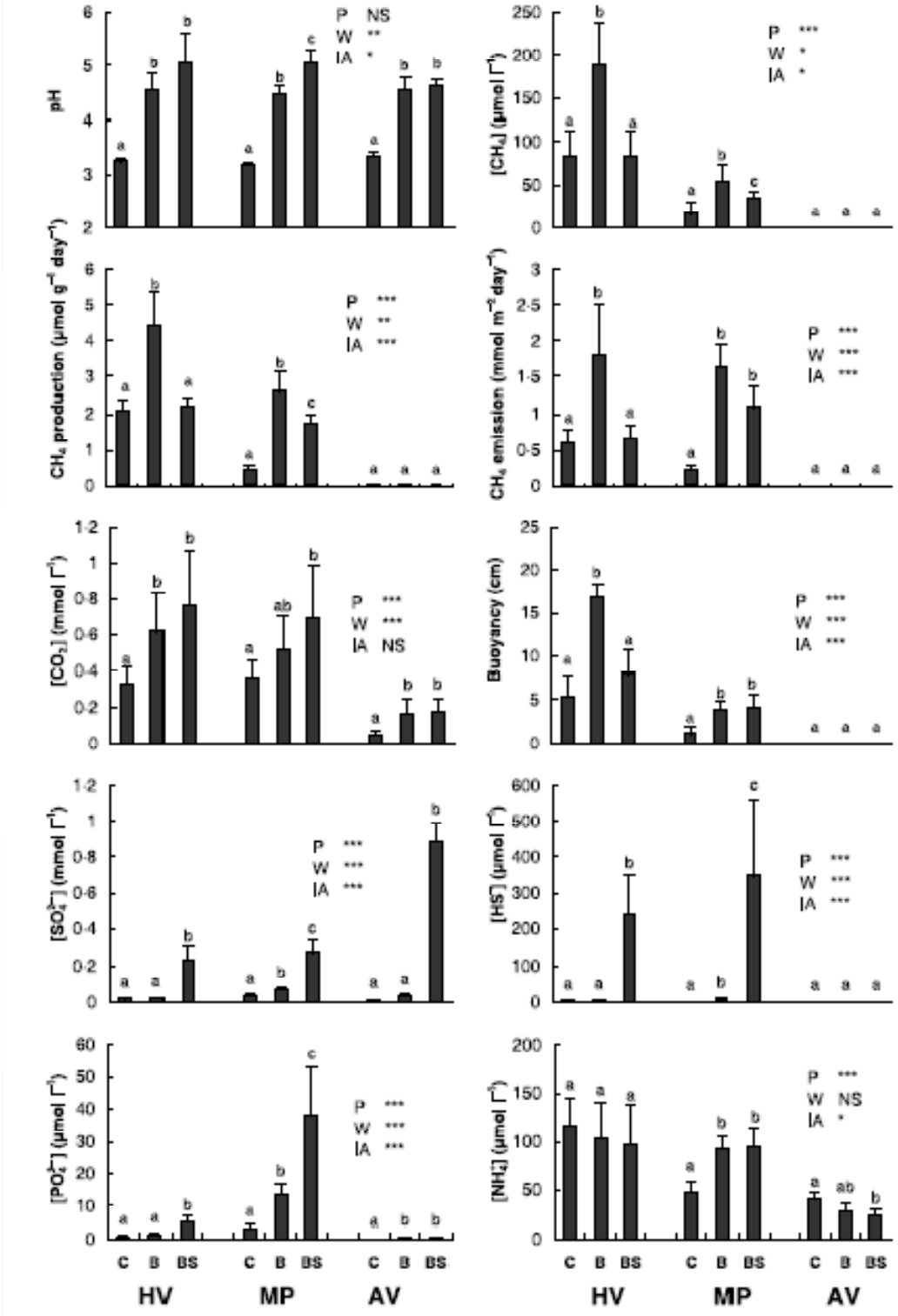

1600
1200
800
400
0
3
4
5
6
7
pH
[CH4] µmol l-1
Mariapeel
Bargerveen
Tuspeel
Haaksbergervee
0%
25%
75%

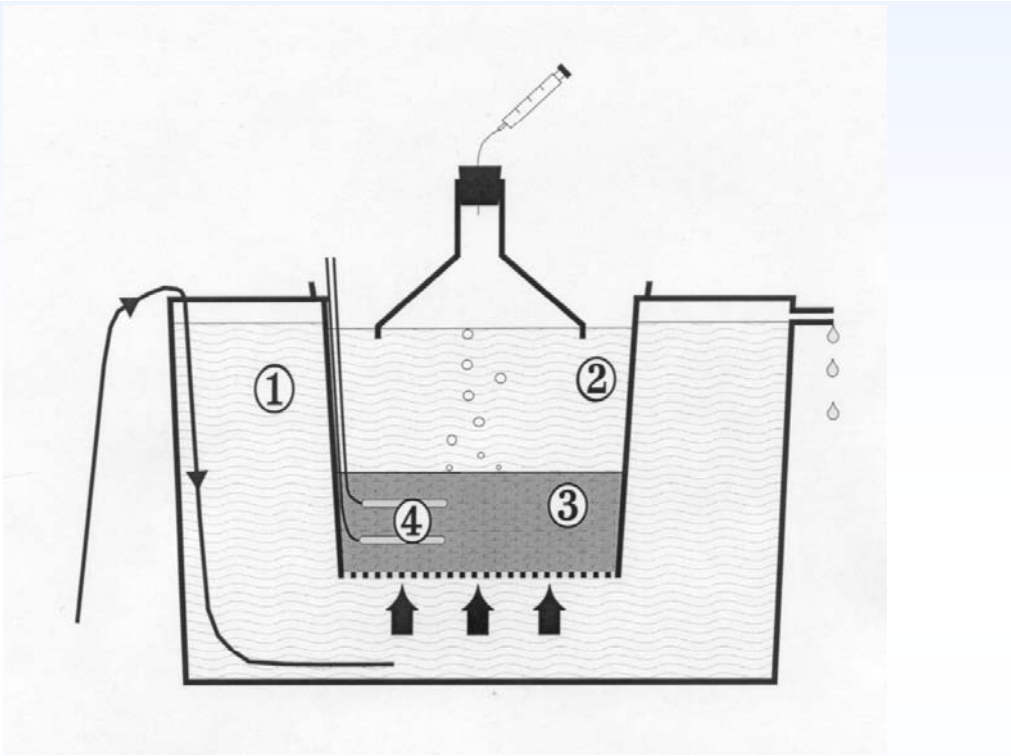


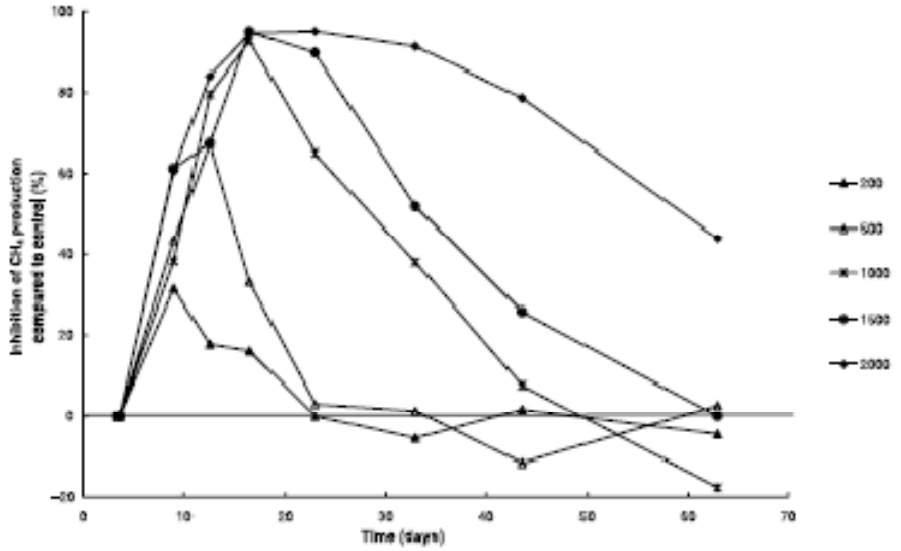
Journal of Applied Ecology 2002
39, 391–401

Peat bog restoration by floating raft formation: the effects of groundwater and peat quality

ALFONS J. P. SMOLDERS, HILDE B. M. TOMASSEN, LEON P. M. LAMERS, BART P. LOMANS* and JAN G. M. ROELOFS
*Department of Aquatic Ecology and Environmental Biology and *Department of Microbiology, University of Nijmegen, Toernooiveld 1, 6525 ED Nijmegen, the Netherlands*







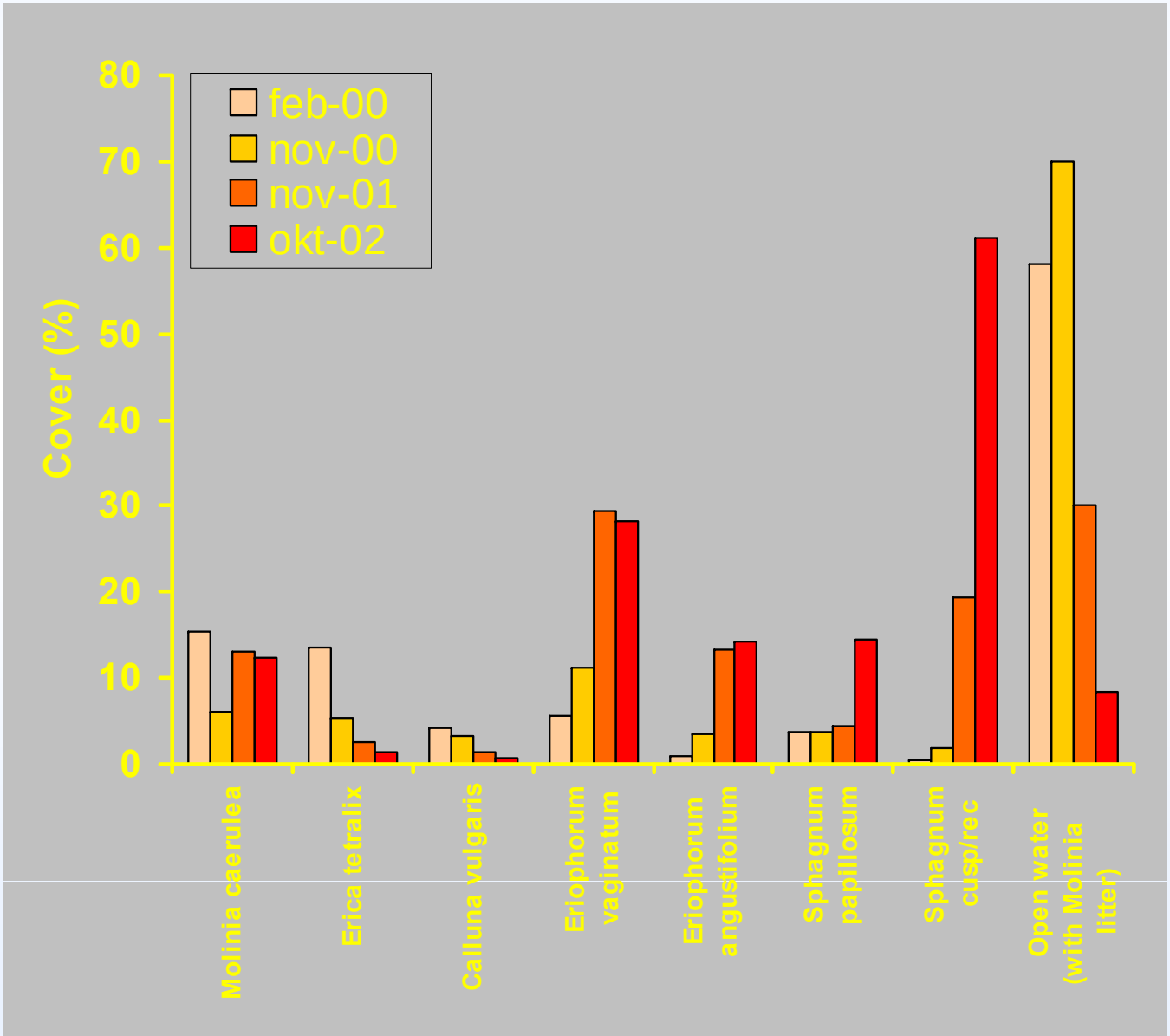
Black peat “Inundated”

Black peat “Dry”

Black peat “Waterlogged”

Inundation of desiccated sites with ‘white’ peat

Fochteloerveen


feb-00
nov-00
nov-01
okt-02
Cover (%)
0
10
20
30
40
50
60
70
80
Molinia caerulea
Erica tetralix
Calluna vulgaris
Eriophorum vaginatum
Eriophorum angustifolium
Sphagnum papillosum
Sphagnum cusp/rec
Open water (with Molinia litter)

Conclusions