Managing eutrophication and controlling cyanobacteria blooms

Miquel Lürling, Maíra Mucci, Natalia Noyma, Leonardo Magalhães, Lisette de Senerpont Domis, Vera Huszar, Guido Waajen, Frank van Oosterhout, Marcelo Manzi

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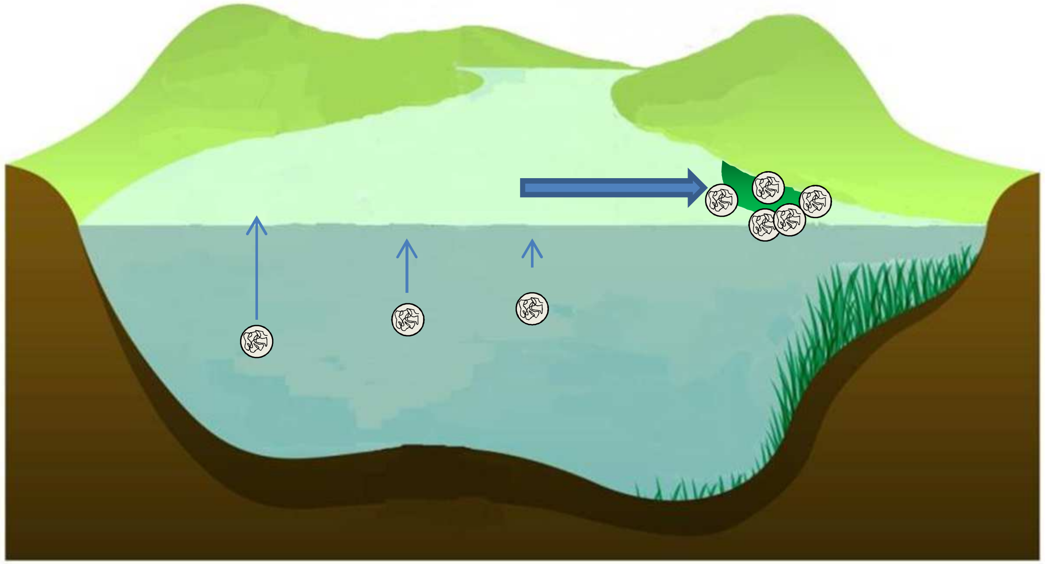
akwa


KLM
C15
C13
C13
C11


What is a bloom?

Not all cyanobacteria nuisance is because of eutrophication

Scenario 1: clear water, low cyanobacteria, but local problem



Buoyant low cyanobacteria biomass blown to leeside shore giving locally nuisance

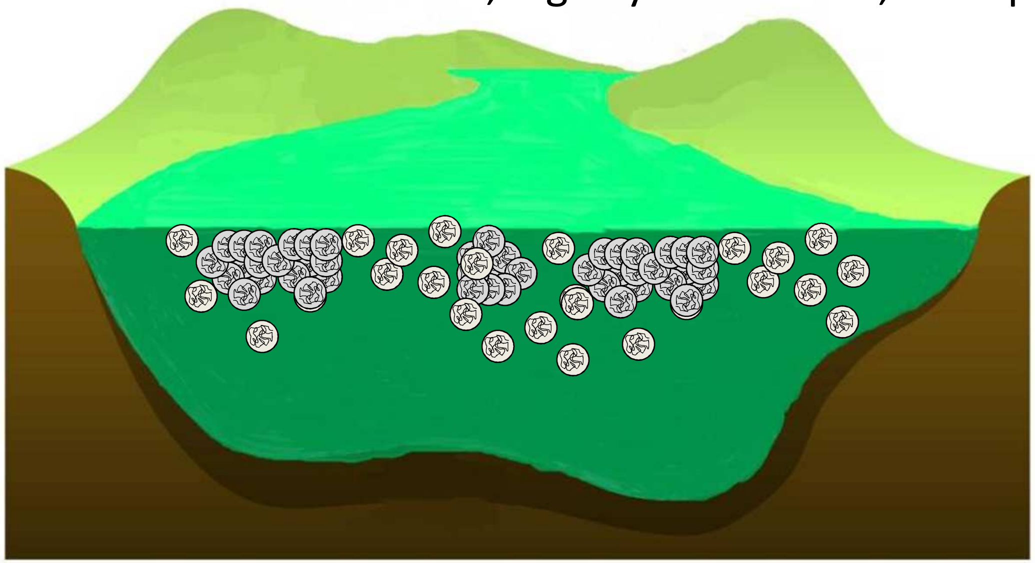
Accumulation:

- Physically driven

Management:

- Target cyanobacteria

Scenario 2: turbid water, high cyanobacteria, wide problem



High cyanobacteria biomass giving widespread nuisance

Proliferation:

- Nutrient driven

Management:

- Target nutrients (+ cyano's)

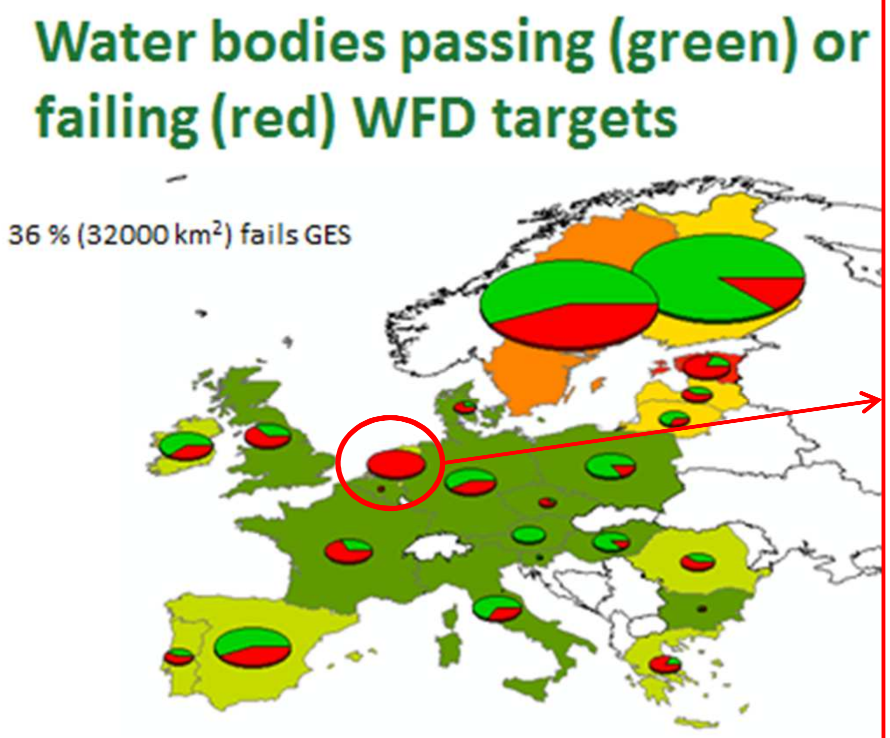
“Eutrophication has become the primary water quality issue for most of the freshwater and coastal marine ecosystems in the world”

Smith & Schindler 2009 TREE 24: 201-207.

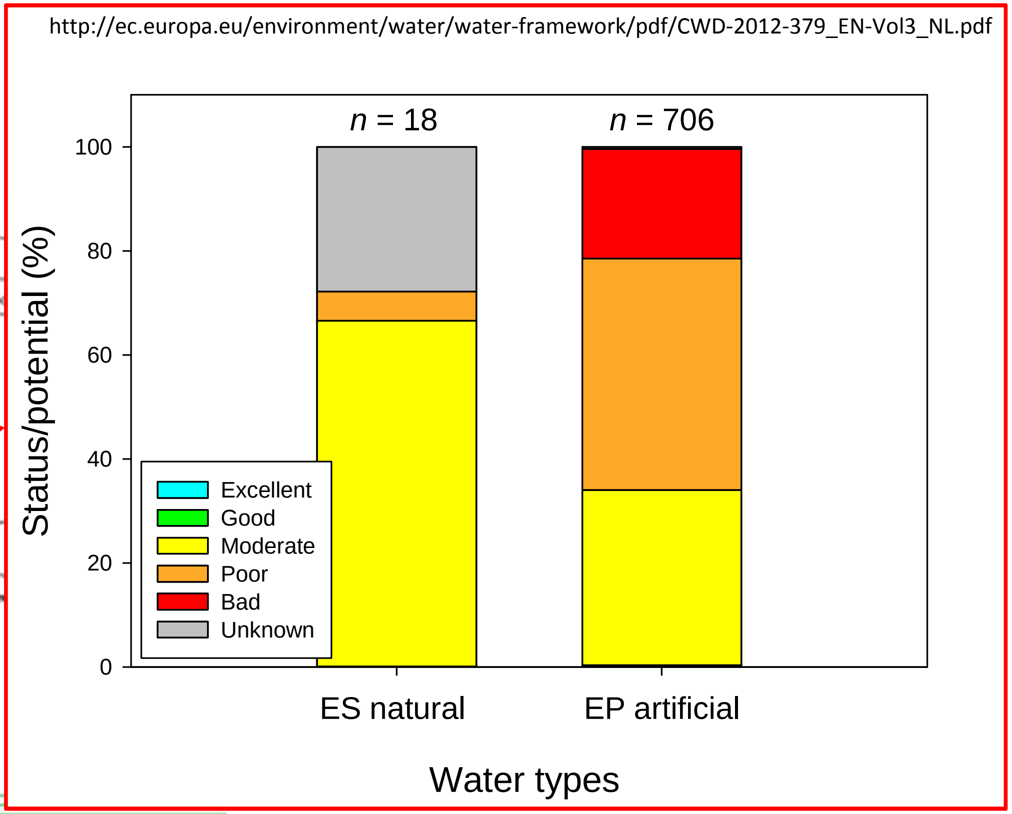
Table 5. The top-10 problems faced by limnology today and in the future, according to an email survey of top limnologists. The survey was selective because I consulted people whose work I respect and who have broad interests. It was not a survey of all the people I know who fit those criteria. The list is ordered by the problems mentioned the most frequently by those responding to my survey.

	2013		2023
1.	Eutrophication and other water pollution	1.	Eutrophication and other pollution
2.	Aquatic invasive species	2.	Aquatic invasive species - global biotic homogenization
3.	Effects of altered hydrology (human and climatic)	3.	Agricultural impact
4.	Habitat destruction	4.	Climate change impacts on water quantity and quality
5.	Climate change on water quantity and quality	5.	Novel chemicals, xenobiotics (toxins, drugs, etc.)
6.	Novel chemicals, xenobiotics (toxins, drugs, etc.)	6.	Effects of altered hydrology (human and climatic)
7.	Lost biodiversity and endangered species	7.	Sustainable freshwater supply
8.	Water quantity demand and management	8.	Habitat destruction
9.	Overexploitation and overuse (e.g., fishing)	9.	Mine pollution
10.	Agricultural impact	10.	Inland waters' effects on marine eutrophication

Downing 2014 Inland Waters 4: 215-232



Courtesy of Dr Kasper Reitzel, Univ. Southern Denmark



4.3 Delineation of surface water bodies

The Netherlands does not have a specific methodology for small water body delineation and therefore the water bodies for which the drainage basin is less than 10 km^2 long for rivers or 50 ha for lakes have not been included.

http://ec.europa.eu/environment/water/water-framework/pdf/CWD-2012-379_EN-Vol3_NL.pdf

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2014GL060641

Key Points:

- Earth has 117 million lakes > 0.002 km^2
- Large and intermediate lakes dominate the total surface area of lakes
- Power law-based extrapolations do not adequately estimate lake abundance

A global inventory of lakes based on high-resolution satellite imagery

Charles Verpoorter[1,2], Tiit Kutser[2,3], David A. Seekell[4,5], and Lars J. Tranvik[2]

[1]INSU-CNRS, UMR 8187, LOG, Laboratoire d'Océanologie et des Géosciences, Université du Littoral Cote d'Opale, ULCO, Wimereux, France, [2]Department of Ecology and Genetics/Limnology, Uppsala University, Uppsala, Sweden, [3]Estonian Marine Institute, University of Tartu, Tallinn, Estonia, [4]Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, USA, [5]Now at Department of Ecology and Environmental Sciences, Umeå University, Umeå, Sweden

117 million lakes on Earth

↓

90 million lakes of 0.2 – 1 ha
23 million lakes of 1 – 10 ha
2 million lakes of 10 – 100 ha

} Lakes > 50 ha: leaves out > 97.5% of lakes

Many small lakes in urban areas → intense contact citizens

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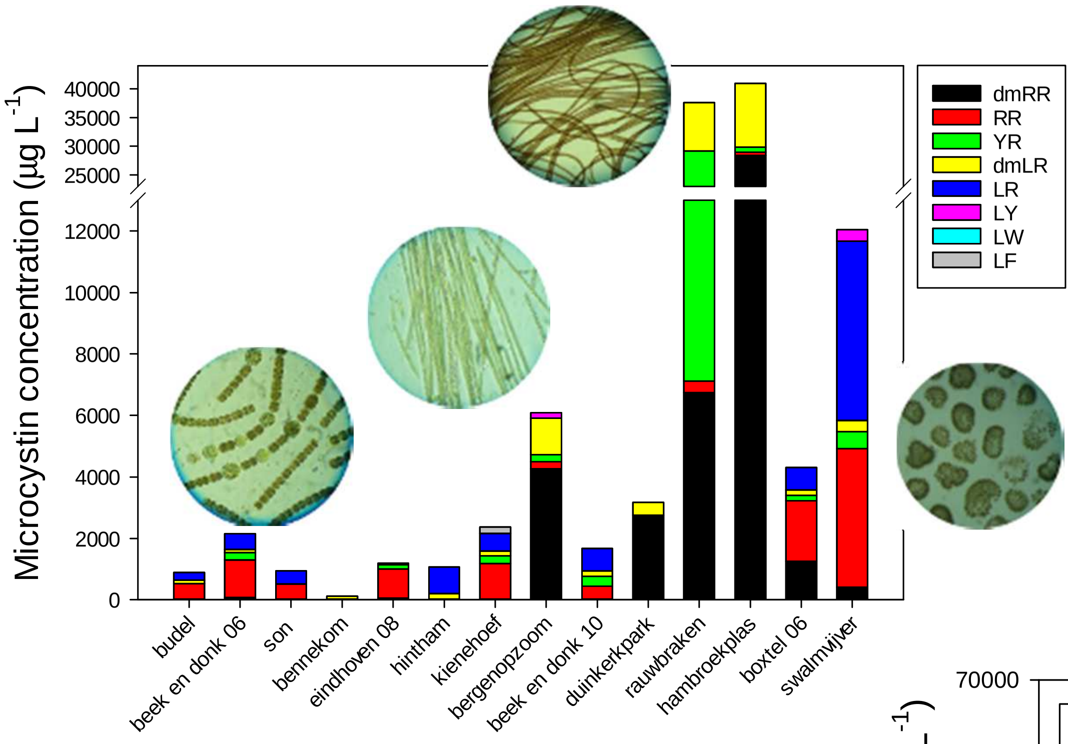
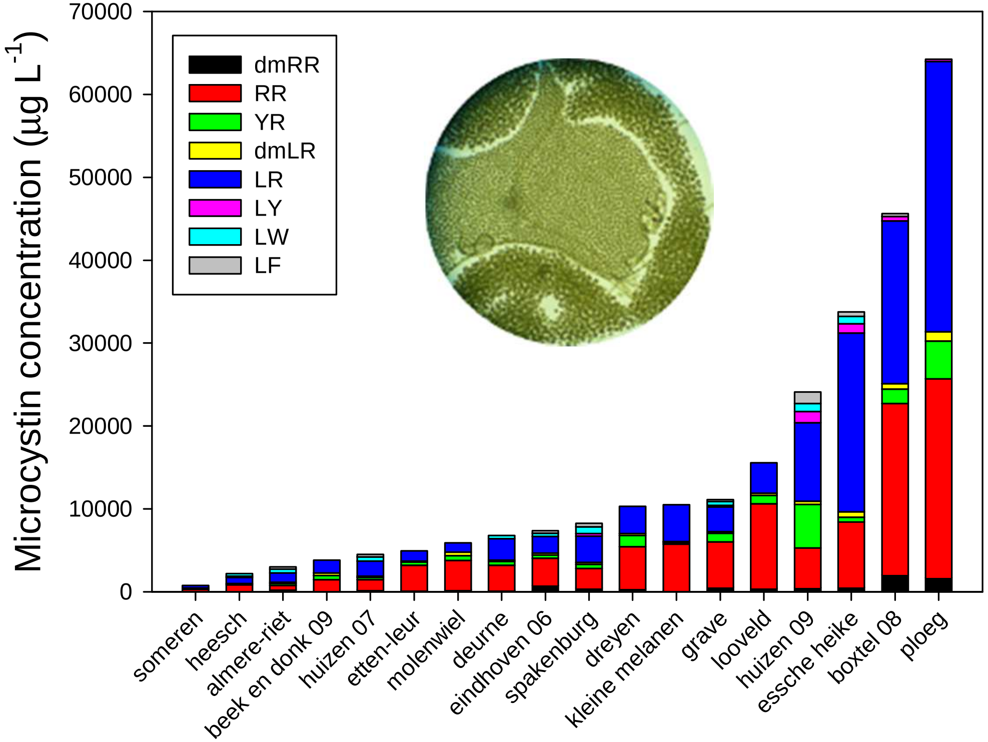
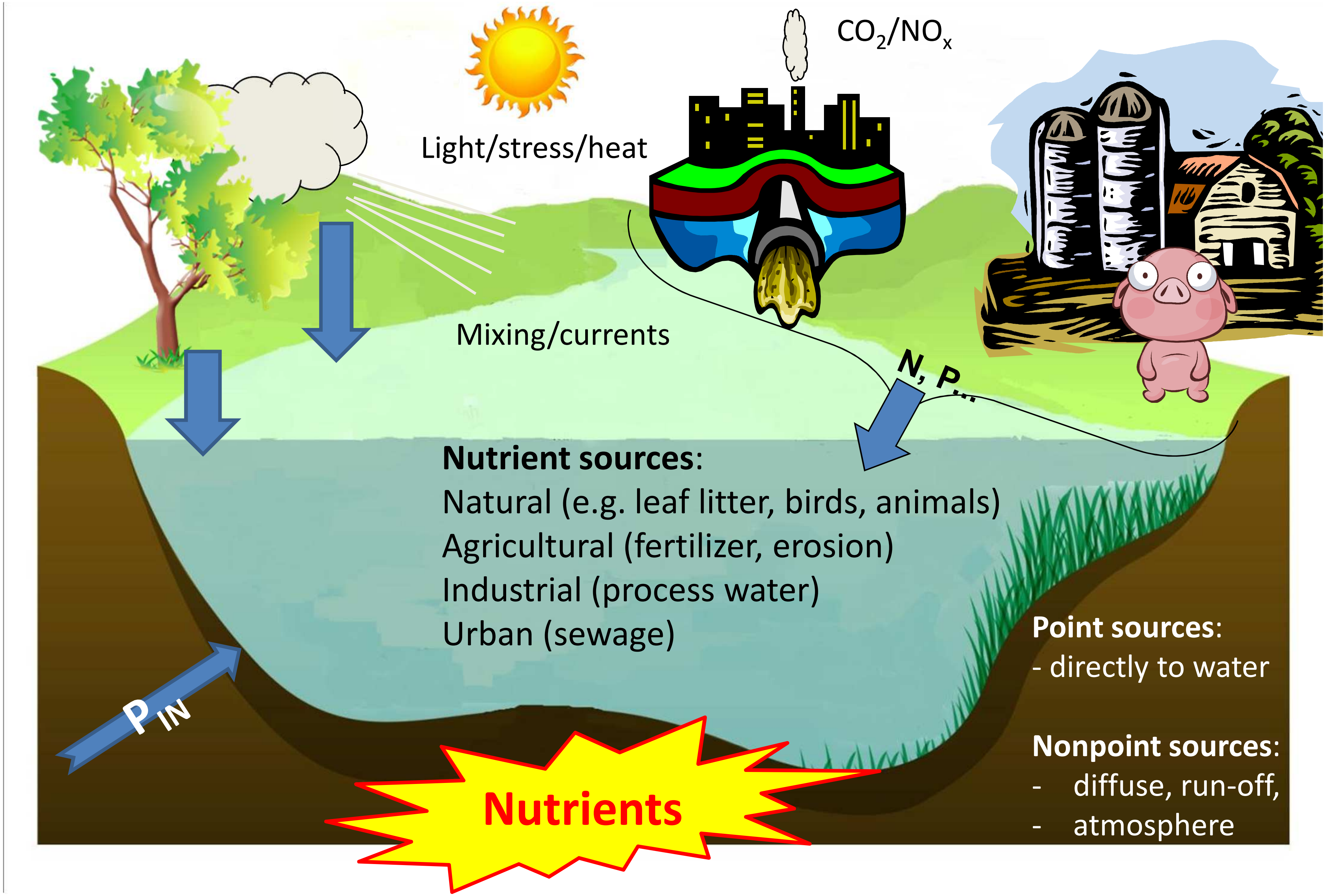
AQWA Aquatische ecologie, Waterkwaliteitsbeheer



Closing of bathing site when

MC > 20 µg L^{-1}





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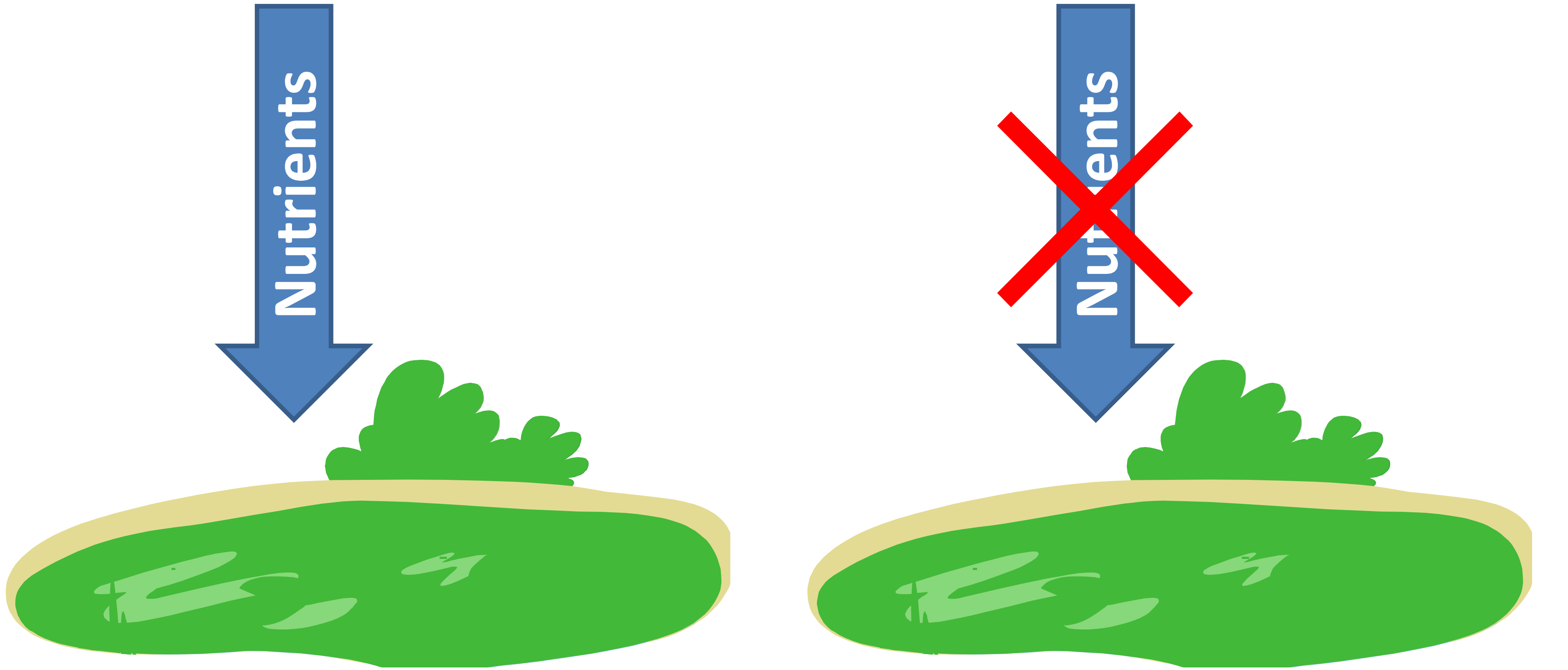
AQWA
Aquatische ecologie
Waterkwaliteitsbeheer



In general, the achievements of restoration work in the Dutch lakes, especially those using biomanipulation measures, are questionable: there are probably more examples of failures than of successes.

Hydrobiologia **478:** 73–106, 2002.
P.H. Nienhuis & R.D. Gulati (eds), Ecological Restoration of Aquatic and Semi-Aquatic Ecosystems in the Netherlands (NW Europe).

Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-the-art review*

Ramesh D. Gulati & Ellen van Donk

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Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-the-art review*

Ramesh D. Gulati & Ellen van Donk

To sum up, the results of the Dutch biomanipulation studies (see Meijer, 2000) are ambiguous, with more long-term failures than successes recorded. The failures are, by and large, related to insufficient or no decrease in the in-lake nutrient loading

Mitigation:

1) Reduce external load

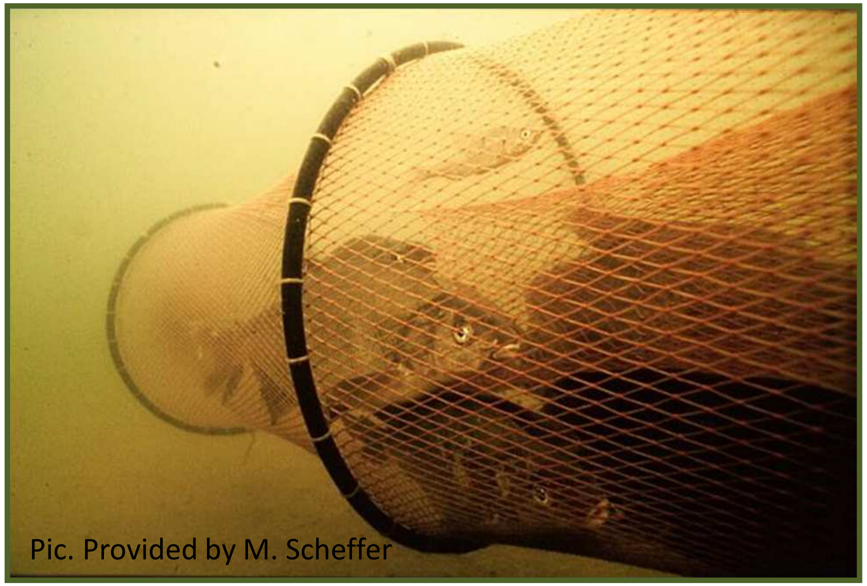
2) Reduce carps/bream if applicable

→ **Target in-lake nutrient (P) load**

3) Reduce water column P

4) Block sediment P-release

→ P-adsorbents


Pic. Provided by M. Scheffer

Science of the Total Environment 442 (2013) 103–110

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Comparison of phosphorus (P) removal properties of materials proposed for the control of sediment p release in UK lakes

Bryan M. Spears *, Sebastian Meis, Amy Anderson, Myriam Kellou

P-sorbent	Adsorption (mg g^{-1})	Reference
Red mud	114	Li et al., 2006
Calcite ($CaCO_3$)	25	Brix et al., 2001
Calcite ($CaCO_3$)	31	Xu et al., 2014
Dolomite ($CaMg(CO_3)_2$)	38	Xu et al., 2014
Half-burned dolomite	10	Roques et al., 1991
Iron impregnated coir pith	71	Krishnan & Haridas, 2008
Mesoporous ZrO2	30	Liu et al., 2008
Ceramic biomaterial	14	Chen et al., 2014
Iron ox		
Steel sl		
Steel sl		
La-mod		
Zero-V		
Black o		
Red oc		
Phoslo		
Phoslo		
Phoslo		
Phoslo		
Phoslo		
Phoslo		
Vermic		
Vermic		
Serpen		
Fe–Zr b		
La doped mesoporous SiO_2	23	Ou et al., 2007
Fe–Ti bimetal oxide	35	Lu et al., 2015
Fe–Cu binary oxides	35	Li et al., 2014
Porous $Pr(OH)_3$ nanowires	129	Tang et al., 2014
Mag dust	59	Spears et al., 2013
Sander dust	63	Spears et al., 2013
Ceramic biomaterials	14	Chen et al., 2014
Ca-Al - LDH	67	Jiang & Ashekuzaman, 2014
Ca-Fe - LDH	47	Jiang & Ashekuzaman, 2014
MgCa-Al - LDH	71	Jiang & Ashekuzaman, 2014

P-sorbent	Adsorption (mg g^{-1})	Reference
Iron oxide tailings	13	Zeng et al., 2004
Modified bentonite Bephos	27	Zamparas et al., 2013
Red mud	<1	Huang et al., 2008
Blast furnace slag	<1	Johansson & Gustafsson, 2000
Blast furnace slag	3-19	Kostura et al., 2005
Layered double hydroxides (LDH)	28-54	Das et al., 2006
Mg/Fe - LDH	16	Seida & Nakano, 2002
		ou,
Bentonite	4	Zamparas et al., 2012
Fe modified bentonite	11	Zamparas et al., 2012
Bentonite	2	Shanableh & Elsergany, 2013
Fe modified bentonite	9-10	Shanableh & Elsergany, 2013
Al modified bentonite	9-11	Shanableh & Elsergany, 2013
Al/Fe modified bentonite	14	Shanableh & Elsergany, 2013
Fe–Al–Mn trimetal oxide	48	Lǚ et al., 2013
Activated aluminum oxide	21	Xie et al., 2015
Lanthanum oxide	47	Xie et al., 2015
Al-pillared smectites	5-7	Kasama et al., 2004

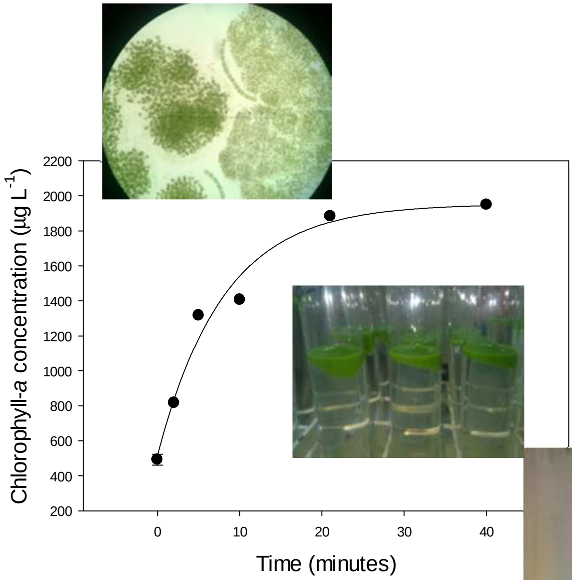
There are many P adsorbents in the literature...

...but applicable?

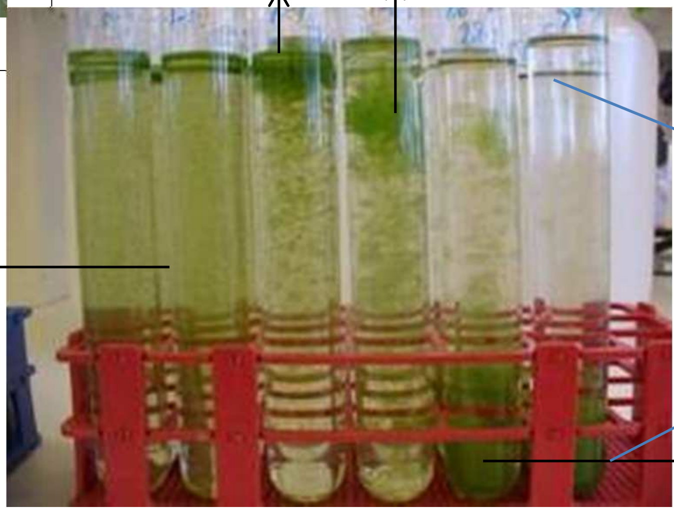
- Cheap
- Easy
- Fast & effective
- Safe

P-sorbents only bind SRP; not particulate P
During bloom most P in cyanobacteria

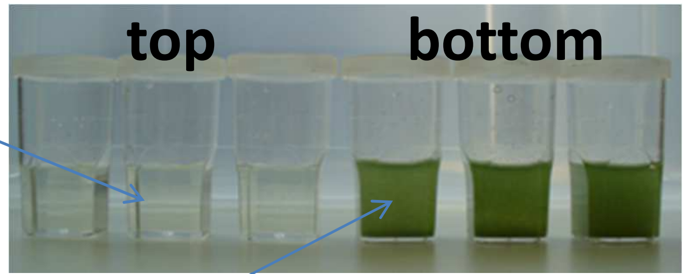
Low dose flocculent + ballast to flock and sink the cyanobacteria
Solid phase P-sorbent as ballast and capping to prevent sediment P release



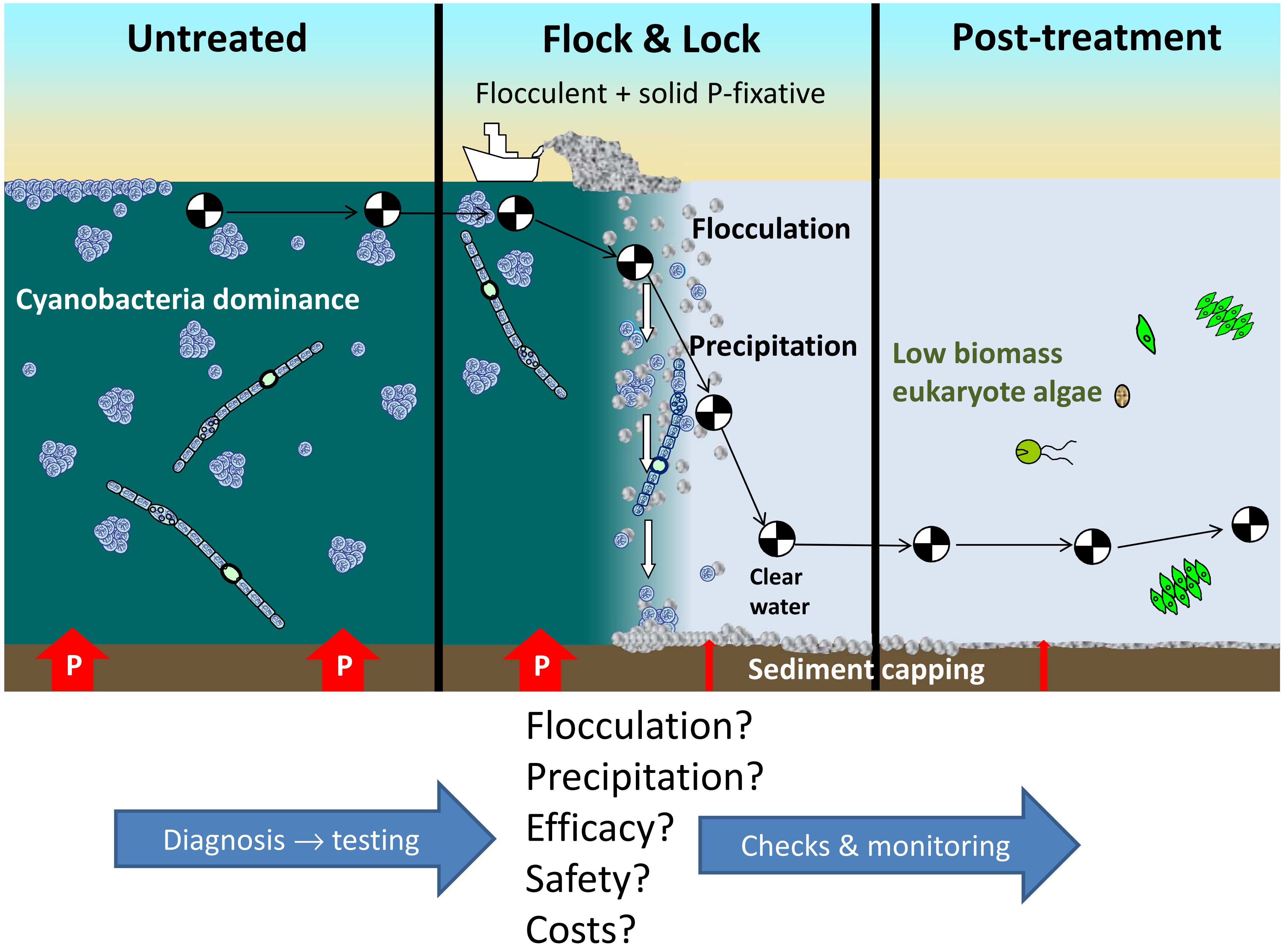
Nothing added:
Cyanobacteria will gradually go to surface



Flocculent added:
Cyanobacteria will Fast accumulate at surface



Flocculent + ballast added:
Cyanobacteria will rapidly settle at bottom


Untreated
Flock & Lock
Post-treatment
Flocculent + solid P-fixative
Cyanobacteria dominance
Flocculation
Precipitation
Low biomass
eukaryote algae
Clear
water
P
P
P
Sediment capping
Flocculation?
Precipitation?
Efficacy?
Safety?
Costs?
Diagnosis ⟶ testing
Checks & monitoring

Flocculants (Flock):

chemicals that cause aggregation of suspended par... ...ocs:

- Aluminium salts (alum, PAC)
- Iron salts - Fe(III)Cl_3
- Chitosan
- *Moringa oleifera* seed extract
- Cationic starch

P sorbents (Lock):

chemicals tha... ...ns; P is no longer bioavailable:

- Alumi... ...alts
- Ir... ...ts (red mud, gypsum...) - Safety ??

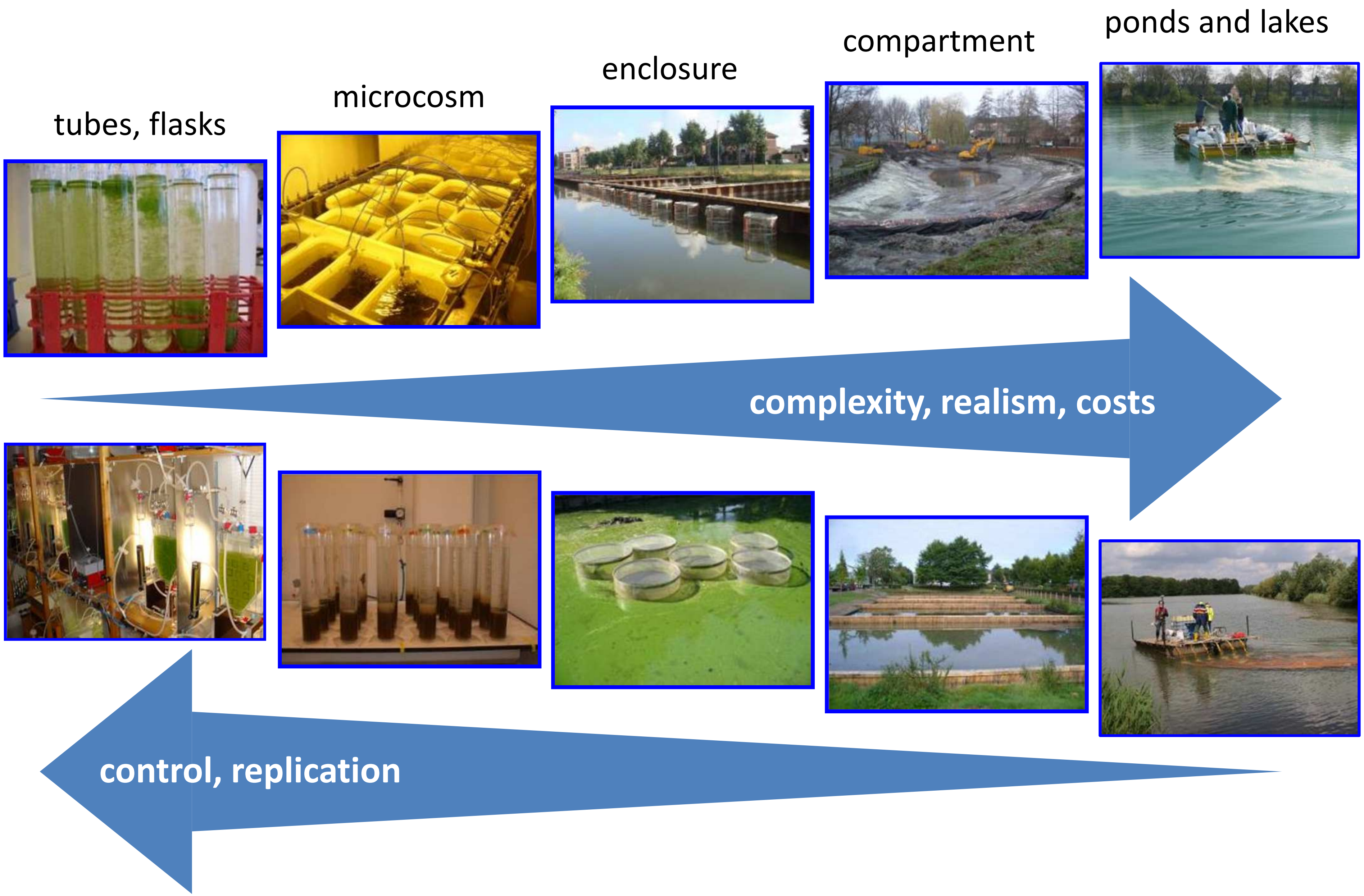
...nanoparticles

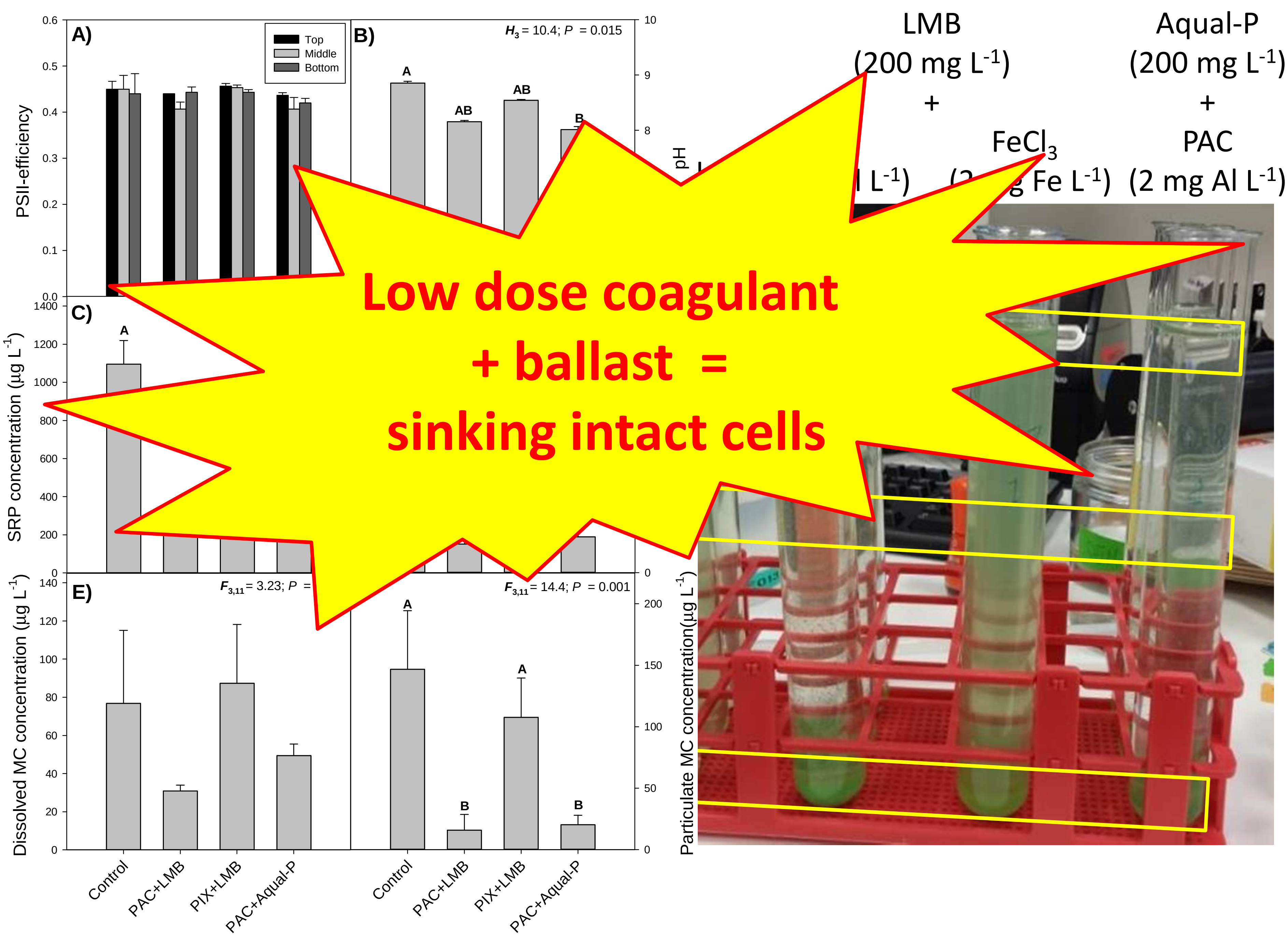
...y oxides/hydrotalcites

Costs, ease to apply ??

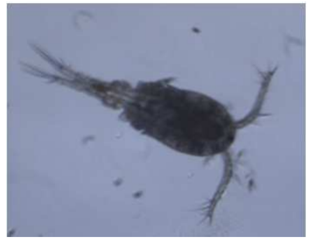
Thorough testing and dose estimates required

Experiments on various scales are needed

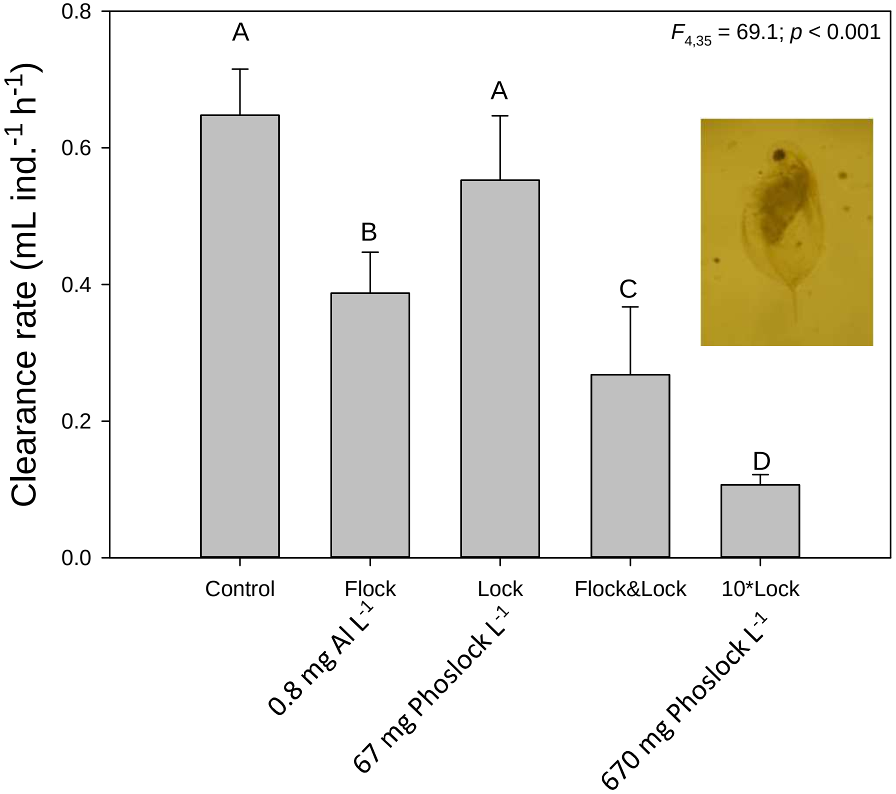




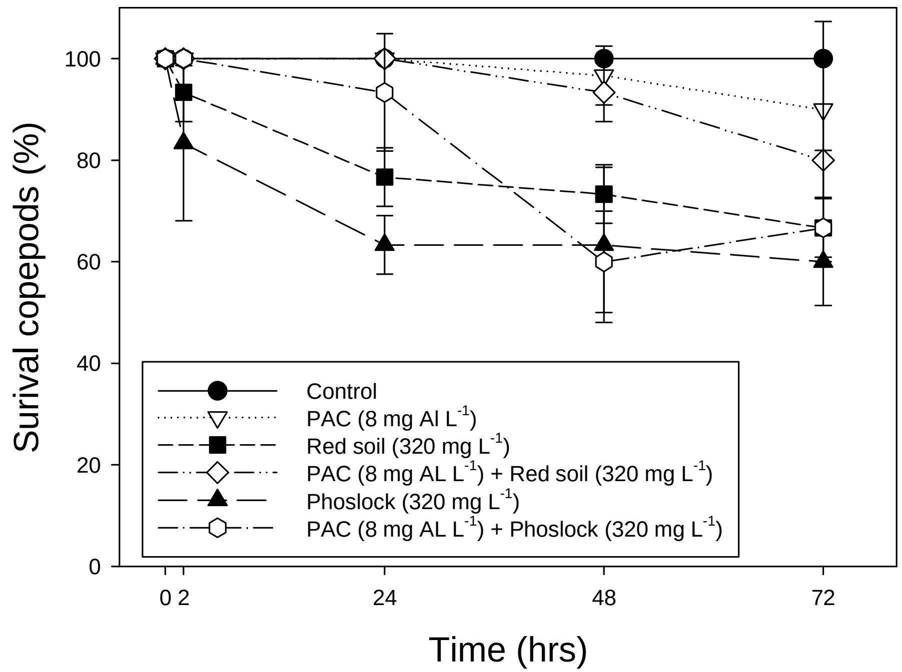
Low dose coagulant
+ ballast =
sinking intact cells
LMB
(200 mg L-1)
+
Aqual-P
(200 mg L-1)
+
FeCl3
PAC
(2 mg Al L-1)
A)
Top
Middle
Bottom
PSII-efficiency
B)
H3 = 10.4; P = 0.015
pH
C)
SRP concentration (µg L-1)
E)
F3,11 = 3.23; P =
Dissolved MC concentration (µg L-1)
F3,11 = 14.4; P = 0.001
Particulate MC concentration(µg L-1)
Control
PAC+LMB
PIX+LMB
PAC+Aqual-P

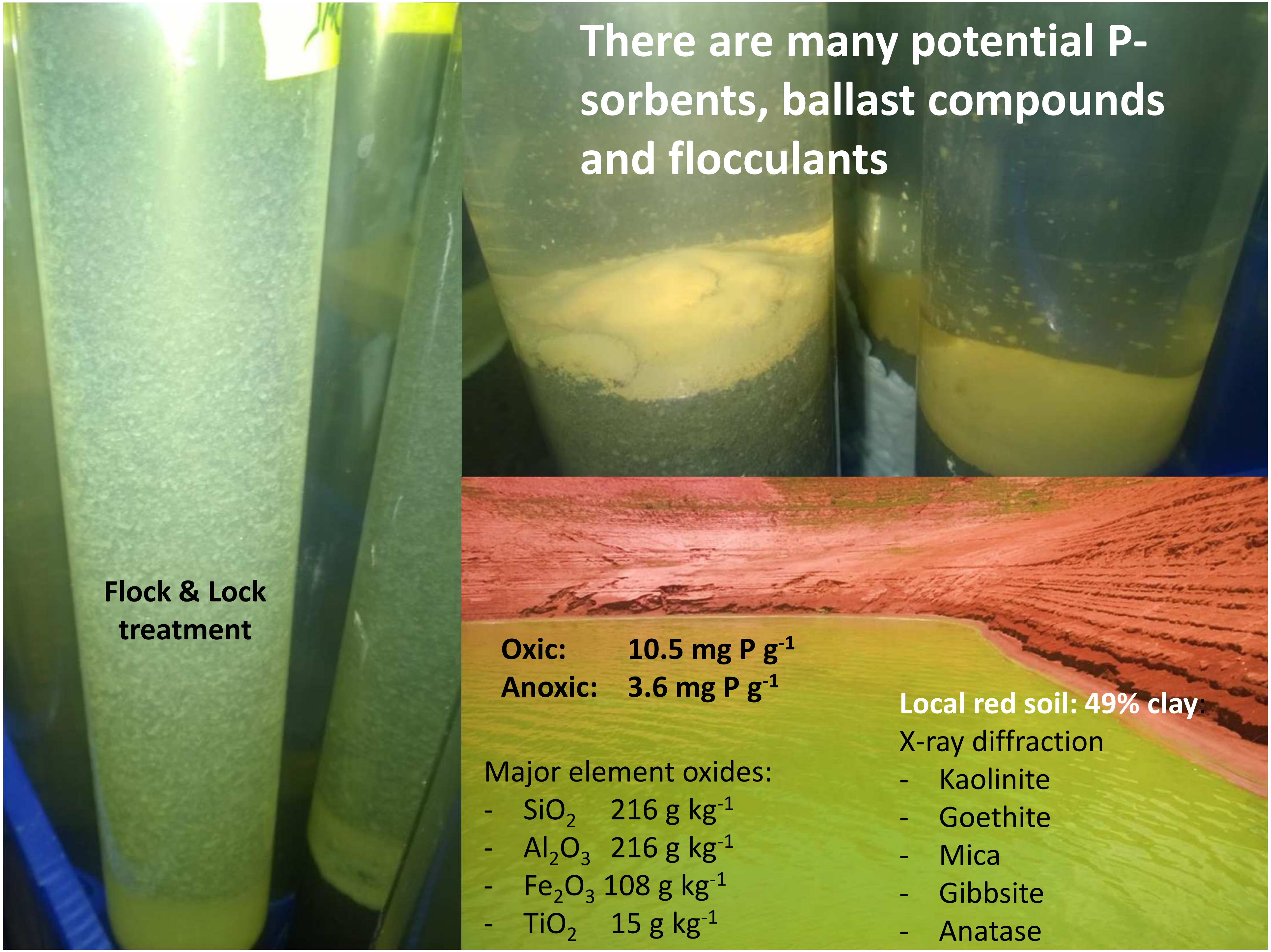


Daphnia from Rauwbraken



Copepods from Jacarepagua




There are many potential P-sorbents, ballast compounds and flocculants
Flock & Lock treatment
Oxic: 10.5 mg P g^{-1}
Anoxic: 3.6 mg P g^{-1}
Major element oxides:
- SiO_2 216 g kg^{-1}
- Al_2O_3 216 g kg^{-1}
- Fe_2O_3 108 g kg^{-1}
- TiO_2 15 g kg^{-1}
Local red soil: 49% clay.
X-ray diffraction
- Kaolinite
- Goethite
- Mica
- Gibbsite
- Anatase

PHOSLOCK®
Phoslock Europe GmbH

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Developed by Australian Government
CSIRO Land and Water, Centre for Environment and Life Sciences

Available commercially in EU since 2006

Welcome to the website of Phoslock Europe GmbH, the licensee for Phoslock in 19 countries in Western Europe. This website provides information on Phoslock, an innovative technology from Australia for the reduction of phosphorus in water systems and the prevention and control of blue green algae.

Product Information

+ *About Phoslock*
+ *Ecotox*
+ *Publications*

Applications

+ *Case Studies*
+ *Applying Phoslock*
+ *Approvals*

In The Media

Polish Project awarded Best LIFE Environment Project Award by EU

Applications in Hyde Park and Kensington Gardens, London, UK

September 2011 - Video Clip - BBC, UK

+ *Archive*

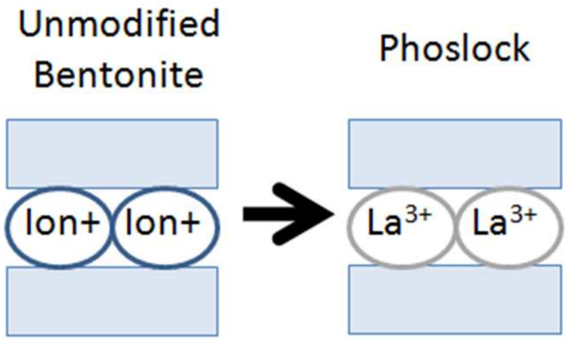
New Information

Newsletter June 2012

Phoslock for Ponds and small lakes

Newsletter December 2011

+ *Archive*



http://www.phoslock.eu/en/phoslock/about-phoslock/

What is Phoslock?
Bentonite enriched with lanthanum
(Atomic number: 57; 138.9 g/mol)

pH = 7

- 85.83 % La^{3+}
- 13.39 % $LaCl^{2+}$
- 0.60 % $La(OH)^{2+}$
- 0.17 % $LaCl_2^{+}$

$LaCl_3$ = 245.26 g/mol

0.1 M ≡ 24.5 g/l = 24.5‰ salt

(12) **United States Patent**
Douglas

(10) **Patent No.:** **US 6,350,383 B1**
(45) **Date of Patent:** **Feb. 26, 2002**

(54) **REMEDIATION MATERIAL AND REMEDIATION PROCESS FOR SEDIMENTS**

(75) Inventor: **Grant Brian Douglas**, Parkerville (AU)

(73) Assignee: **Commonwealth Scientific and Industrial Research Organisation,** Austrialian Capitol Terriroty (AU)

JP	4-215900	8/1992
JP	06-218 365	8/1994

OTHER PUBLICATIONS

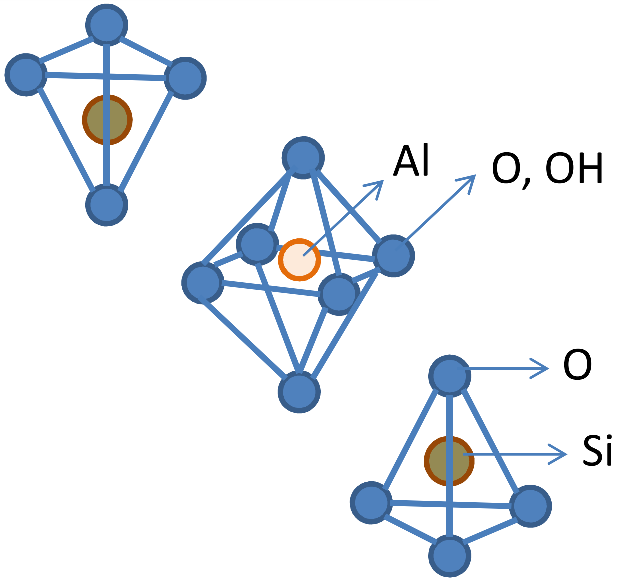
Water Environment Research vol. 68 No. 3 May/Jun. 1996; pp. 295–300; "Adsorption of Fluoride, Phosphate, and Arsenate Ions Lanthanum—Impregnated Silica Gel"; Wasay et al.

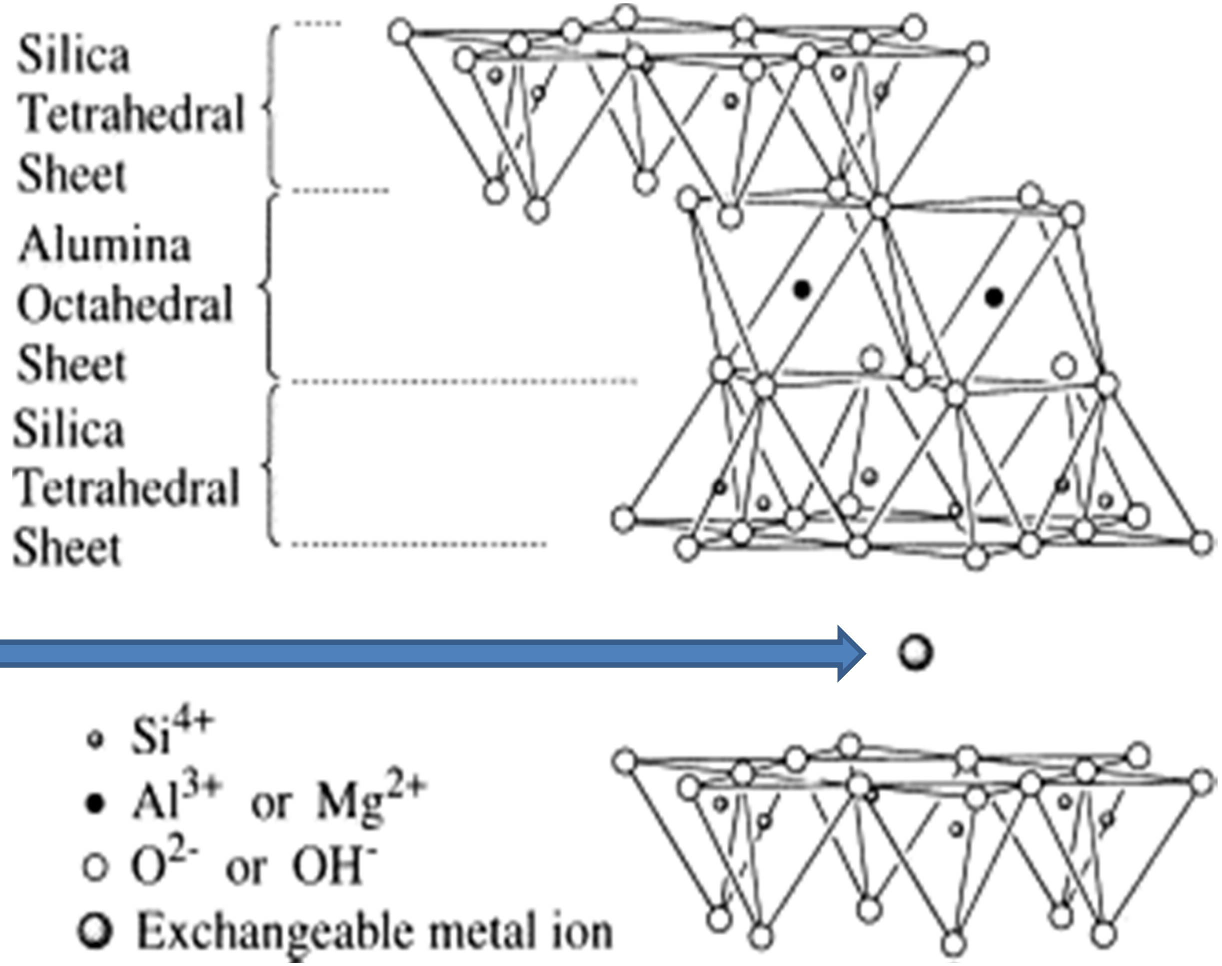
Generally the procedure involves the mixing of a solution of 0.1M $LaCl_3$ with high purity bentonite (e.g. Commercial Minerals CE150 —ca. 90% bentonite), in the ratio 100:1 solution: solid ratio (so that a large excess of La was available for ion-exchange), in an acid-washed plastic container. For laboratory scale production, the $LaCl_3$ solution and bentonite were mixed on a bottle roller for approximately 24 hours, although it will be understood that the mixing apparatus, solid/solution ratios and/or solute concentration and physico-chemical conditions may be varied to take into account requirements for scaling up.

On completion of the mixing, the product is centrifuged (10,000 rpm, 10 minutes) and the supernatant liquid decanted. A second eliquot of 0.1M $LaCl_3$ was added in the same solution: solid ratio and the mixing (ion-exchange) process repeated. The cation- exchanged sediment remediation material is then washed with distilled water and centrifuged. This process if repeated a minimum of three times to ensure removal of excess, unexchanged La. The washed cation-exchanged samples are then dried overnight in an oven at ca. 60° C. and stored under airtight conditions for later use.

Bentonite is a clay type,
ore containing mostly the mineral **montmorillonite**

Montmorillonite is a three-layer mineral consisting of two tetrahedral silica (SiO_2) layers sandwiched around a central octahedral alumina (Al_2O_3) layer

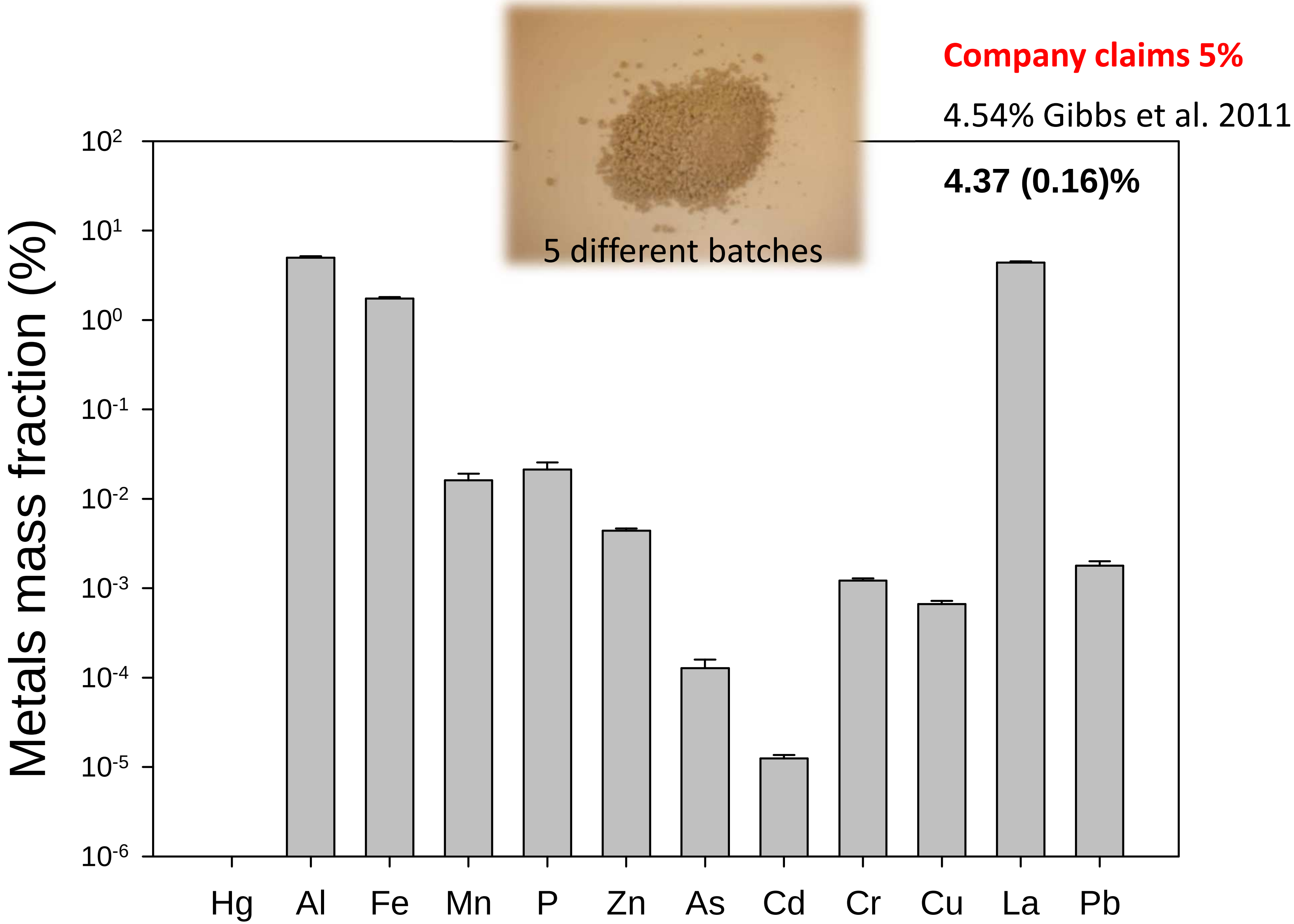




The Si- and Al ion often undergo substitutions by lower valence metals (Mg, Fe).
These substitutions lead to a charge imbalance, compensated by exchangeable cations,

Zhang et al 2003 Materials Letters 57: 1858-1862

Metals in Phoslock®

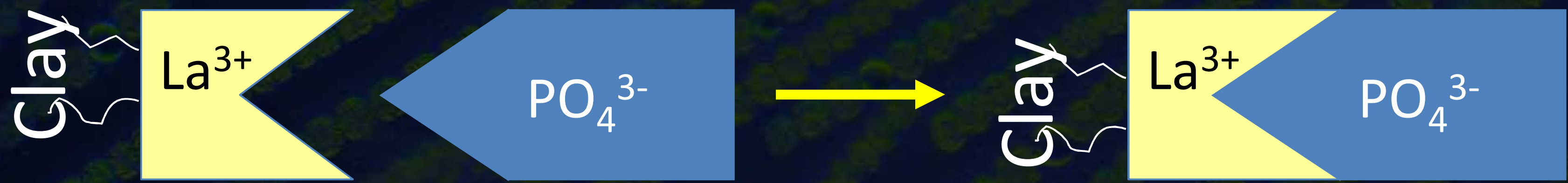


Extremely low solubility lanthanum – orthophosphate (rhabdophane):

Ksp = $10^{-24.7}$ to $10^{-25.7}$ $mol^2\ L^{-2}$ at 25°C (Johanneson & Lyons 1994; Liu & Byrne 1997)

$$La(OH)^{2+} + HPO_4^{2-} \rightarrow LaPO_4 \cdot H_2O$$

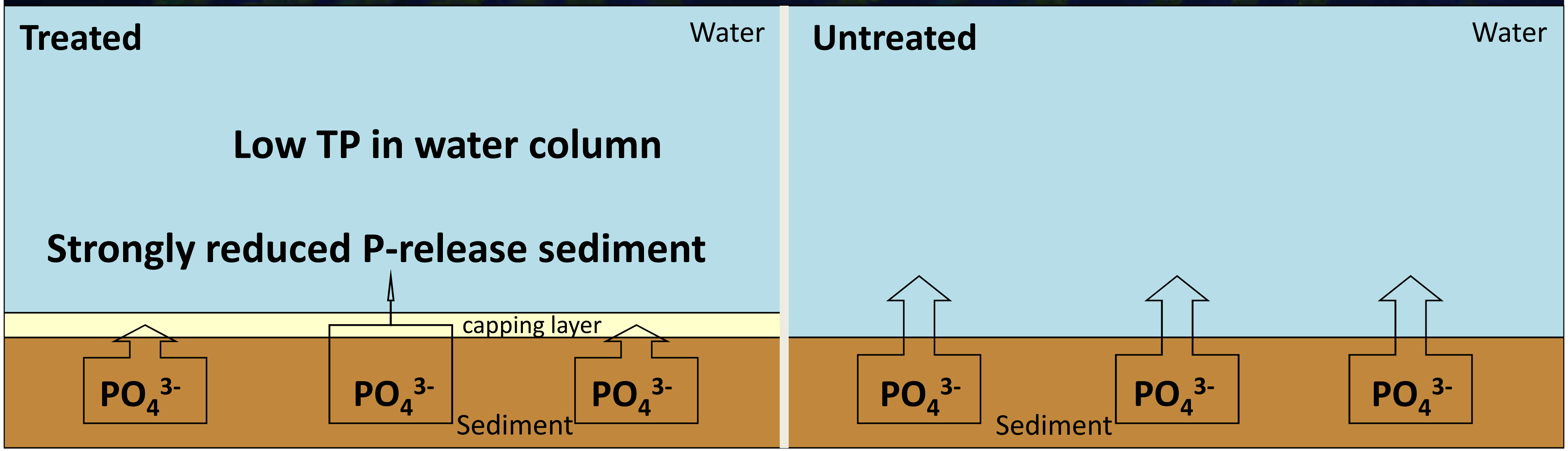
$$La^{3+} + PO_4^{3-} \rightarrow LaPO_4$$



PHOSLOCK®

$LaPO_4 \cdot nH_2O$ = rhabdophane

$LaPO_4$ = monazite

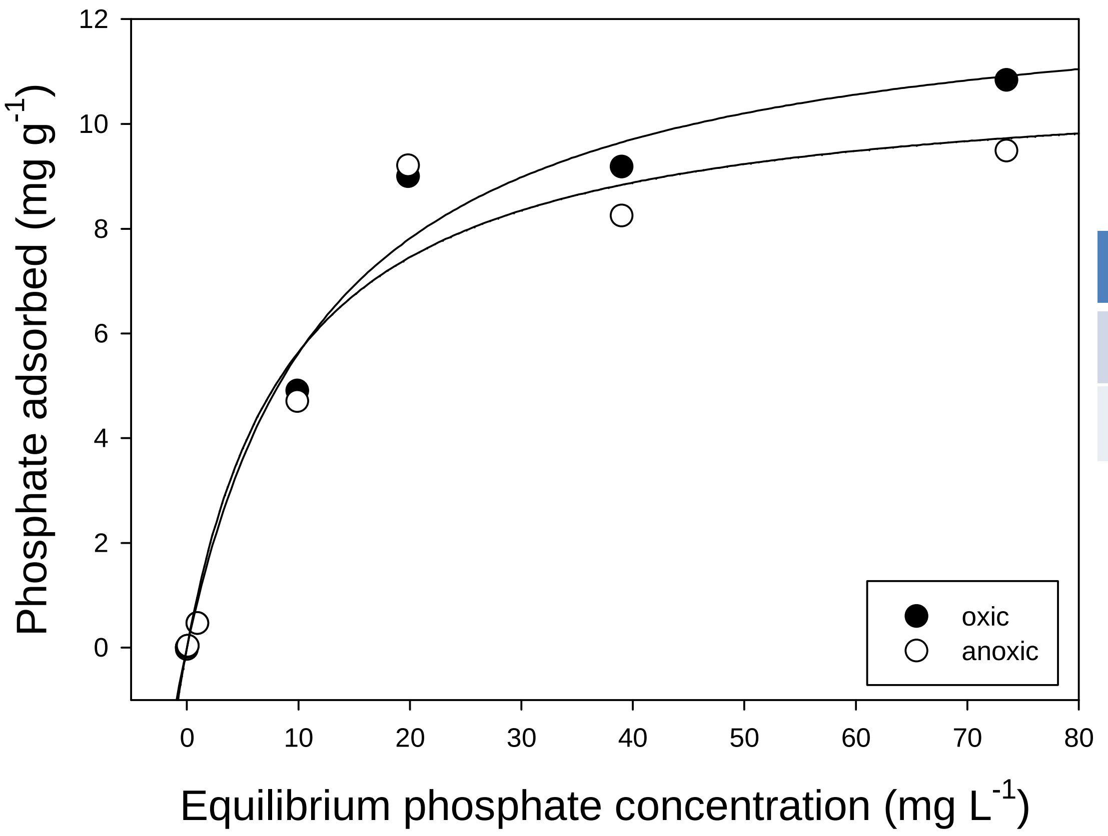


Test of phosphate precipitation adsorption

Determination of P adsorption capacity – Langmuir equation

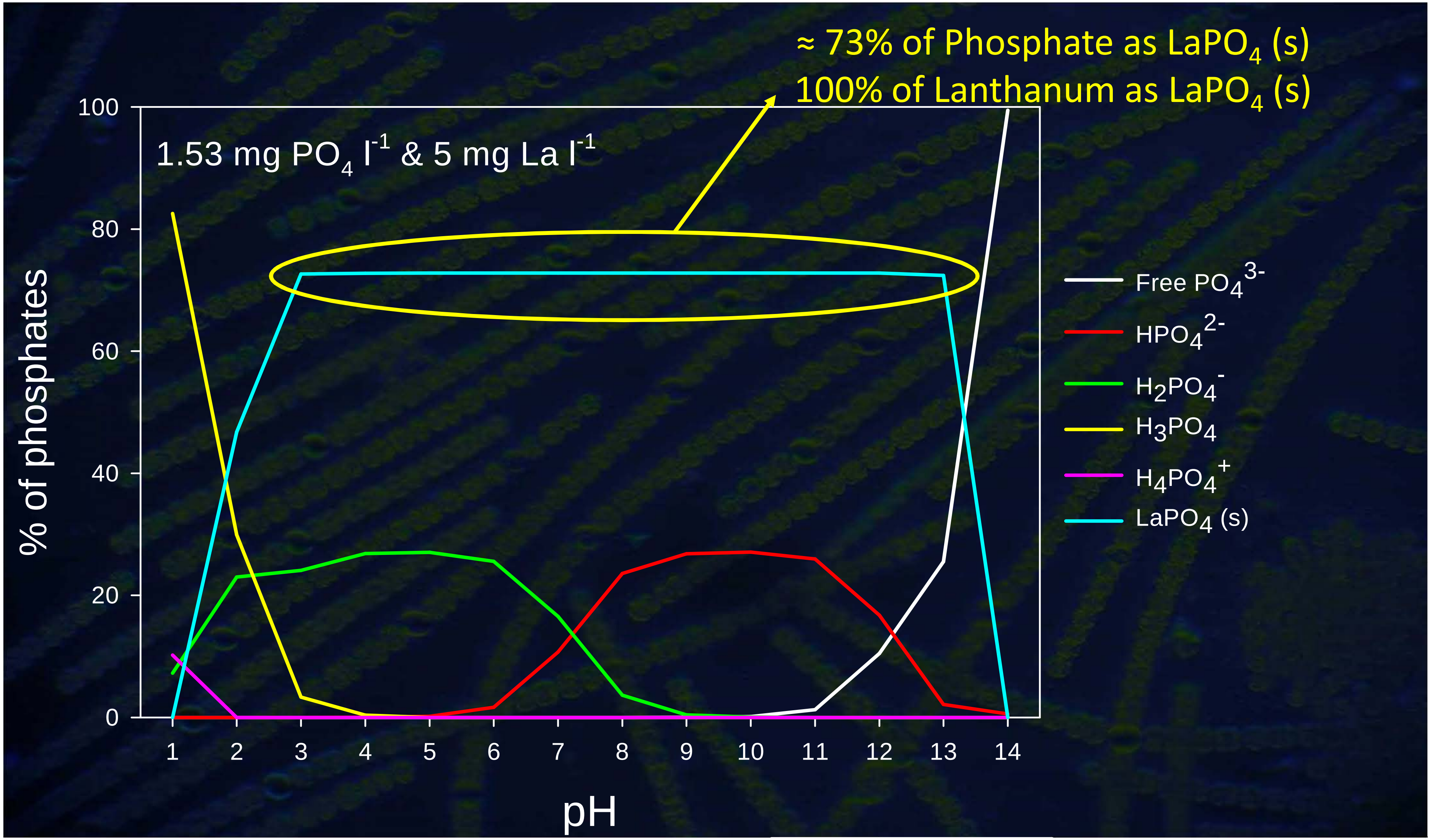
$$\frac{C_e}{q_e} = \frac{C_e}{Q} + \frac{1}{QK}$$

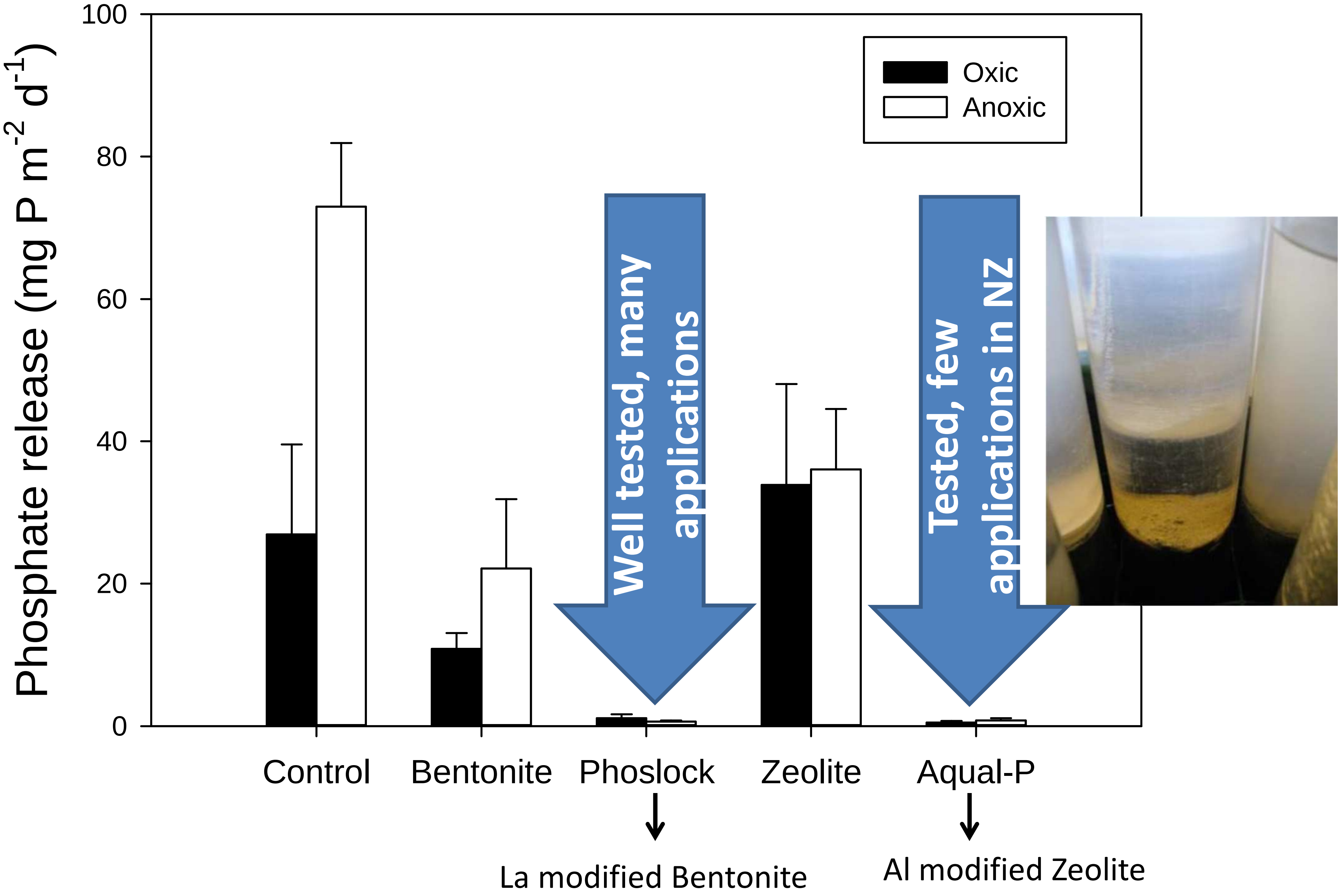
q_e = amount adsorbed at equilibrium (mg g^{-1})
C_e = equilibrium solution concentration (mg L^{-1})
Q = maximum adsorption capacity (mg g^{-1})
K = Langmuir constant (L mg^{-1})



	Q (mg g^{-1})	K (L mg^{-1})	r^2_{adj}
Oxic	12.8	0.078	0.983
Anoxic	10.9	0.106	0.960

Chemical Equilibrium Modelling





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AQWA Aquatische ecologie Waterkwaliteitsbeheer

Elsevier Editorial System(tm) for Water Research
Manuscript Draft

Manuscript Number:

Title: Responses in sediment phosphorus and lanthanum concentrations and composition across 10 lakes following applications of lanthanum modified bentonite

Article Type: SI:Geo-engineering in lakes

Keywords: Lake restoration, dissolved organic carbon (DOC), 31P NMR, lanthanum, P sequestration, EXAFS, full scale, lanthanum modified bentonite

Corresponding Author: Mr. Kasper Reitzel, PhD

Corresponding Author's Institution: University of Southern Denmark

First Author: Line Dithmer

Order of Authors: Line Dithmer; Ulla G Nielsen; Miquel Lürling; Bryan M Spears; Said Yasseri; Daniel Lundberg; Alanna Moore; Nicholai D Jensen; Kasper Reitzel

EXAFS, 31P NMR → La in sediment as $LaPO_4 \cdot nH_2O$ and as $LaPO_4$

Solid proof of mechanism

Lanthanum: A Safe Phosphate Binder

Veerle P. Persy, Geert J. Behets, An R. Bervoets, Marc E. De Broe, and Patrick C. D'Haese
University of Antwerp, Antwerp, Belgium

FOSRENOL® (lanthanum carbonate)

Accumulation of inorganic phosphate due to renal functional impairment contributes to the increased cardiovascular mortality observed in dialysis patients. Phosphate plays a causative role in the development of vascular calcification in renal failure; treatment with calcium-based phosphate binders and vita-

and its effects in bone, liver and brain are discussed. Although lanthanum is a metal cation its effects are not comparable to those of aluminum. Indeed, in clinical studies no toxic effects of lanthanum have been reported after up to four years of follow-up. The bioavailability of lanthanum is extremely low. The ...cts observed in bone are due to phosphate depletion, with ... signs of direct bone toxicity yet observed in rats or humans. ... liver is the main route of excretion for lanthanum carbon..., which can be localized in the lysosomes of hepatocytes. No ...thanum could be detected in brain tissue.

Address correspondence to: Veerle P. Persy, MD, PhD, University of Antwerp, Universiteitsplein 1, B-2610 Wilrijk, Antwerp, Belgium, or e-mail: veerle.persy@ua.ac.be.

Seminars in Dialysis—Vol 19, No 3 (May–June) 2006 pp. 195–199

Nephrol Dial Transplant (2006) 21: 2217–2224
doi:10.1093/ndt/gfl146
Advance Access publication 4 April 2006

NDT Nephrology Dialysis Transplantation

Original Article

Evolution of bone and plasma concentration of lanthanum in dialysis patients before, during 1 year of treatment with lanthanum carbonate and after 2 years of follow-up

Goce B. Spasovski[1], Aleksandar Sikole[1], Saso Gelev[1], Jelka Masin-Spasovska[1], Tony Freemont[2], Isabel Webster[3], Maggie Gill[3], Chris Jones[3], Marc E. De Broe[4] and Patrick C. D'Haese[4]

are the results from one centre that participated in a multicentre trial to assess the effect of treatment with LC and calcium carbonate (CC) on the evolution of renal osteodystrophy in dialysis patients. Bone biopsies were performed at baseline, after 1 year of treatment and after a further 2-year follow-up period to assess the lanthanum concentration in bone and plasma.

Methods. Twenty new dialysis patients were randomized to receive LC (median dose 1250 mg) for 1 year ($n = 10$), followed by 2 years of CC treatment or CC ($n = 10$) during the whole study period (3 years).

Results. After 36 weeks of treatment, steady state was reached with plasma lanthanum levels varying around 0.6 ng/ml. Six weeks after cessation of 1 year of treatment, the plasma lanthanum levels declined to a value of 0.17 ± 0.12 ng/ml ($P < 0.05$) and after 2 years to 0.09 ± 0.03 ng/ml. Plasma and bone lanthanum levels did not correlate with the average lanthanum dose at any time point. The mean bone concentration in patients receiving LC increased from 0.05 ± 0.03 to 2.3 ± 1.6 µg/g ($P < 0.05$) after 1 year and slightly decreased at the end of the study to 1.9 ± 1.6 µg/g ($P < 0.05$).

Conclusions. Bone deposition after 1 year of treatment with LC is low (highest concentration: 5.5 µg/g). There is a slow release of lanthanum from its bone deposits 2 years after the discontinuation of the treatment

Introduction

In patients with chronic renal failure (CRF), abnormalities in bone histology known as renal osteodystrophy (ROD) are already observed before dialysis treatment is started [1,2]. The decline in renal function in end-stage renal disease (ESRD), leads to high serum phosphorus levels, which stimulate parathyroid hormone (PTH) secretion [3]. Additionally, insufficient calcitriol production in patients with ESRD and/or insufficient calcium intake [4] may increase PTH secretion and thus can contribute to the development of high-turnover ROD indirectly. Hence, to achieve an adequate control of hyperphosphataemia, patients are administered phosphate binders, of which aluminium hydroxide and calcium carbonate (CC) have historically been the most widely used. Although very effective, aluminium containing compounds accumulate in the body and can lead to the development of low-turnover bone diseases (osteomalacia or adynamic bone), encephalopathy and/or microcytic anaemia [5,6]. Calcium-based binders, particularly when used in combination with vitamin D analogues, may result in over-suppression of PTH and development of

Long-Term Efficacy and Tolerability of Lanthanum Carbonate: Results from a 3-Year Study

Nephron Clin Pract 2006;102:c61–c71

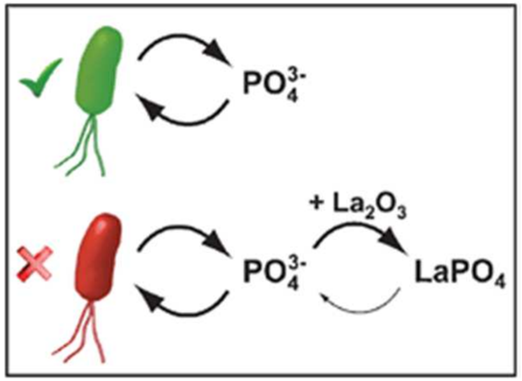
Alastair J. Hutchison[a] Bart Maes[b] Johan Vanwalleghem[c] Gernot Asmus[d] Elfatih Mohamed[a] Roland Schmieder[e] Wolfgang Backs[f] Rene Jamar[g] Andre Vosskühler[h]

lanthanum carbonate. It can be concluded that lanthanum is not genotoxic and that lanthanum carbonate is unlikely to present a latent hazard in therapeutic use.

Advance Access publication 6 December 2006

Lanthanum carbonate—new data on parathyroid hormone control without liver damage

Mario Cozzolino and Diego Brancaccio



Cite this: *Chem. Commun.*, 2012, **48**, 3869–3871
www.rsc.org/chemcomm

COMMUNICATION

Phosphate starvation as an antimicrobial strategy: the controllable toxicity of lanthanum oxide nanoparticles†

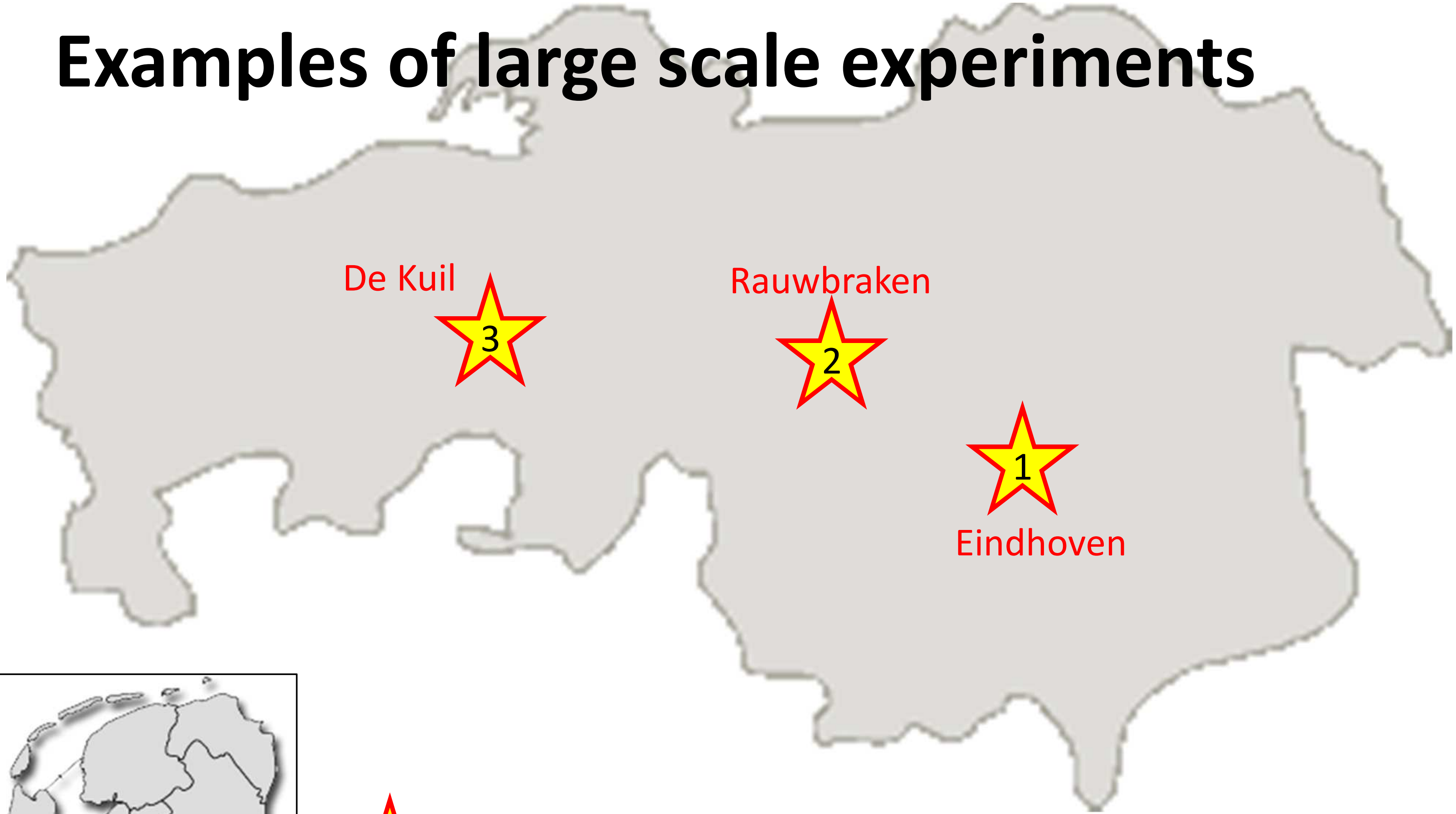
Lukas C. Gerber, Nadine Moser, Norman A. Luechinger, Wendelin J. Stark and Robert N. Grass*

Results of years lab/small scale testing

- Strong phosphate removal from water
- Strong phosphate removal under anoxia
- Strong reduction phosphate release sediment
- No effect on water quality variables pH, O_2, EC
- No toxicity

☞ **Upscaling to ecosystem level**

Examples of large scale experiments



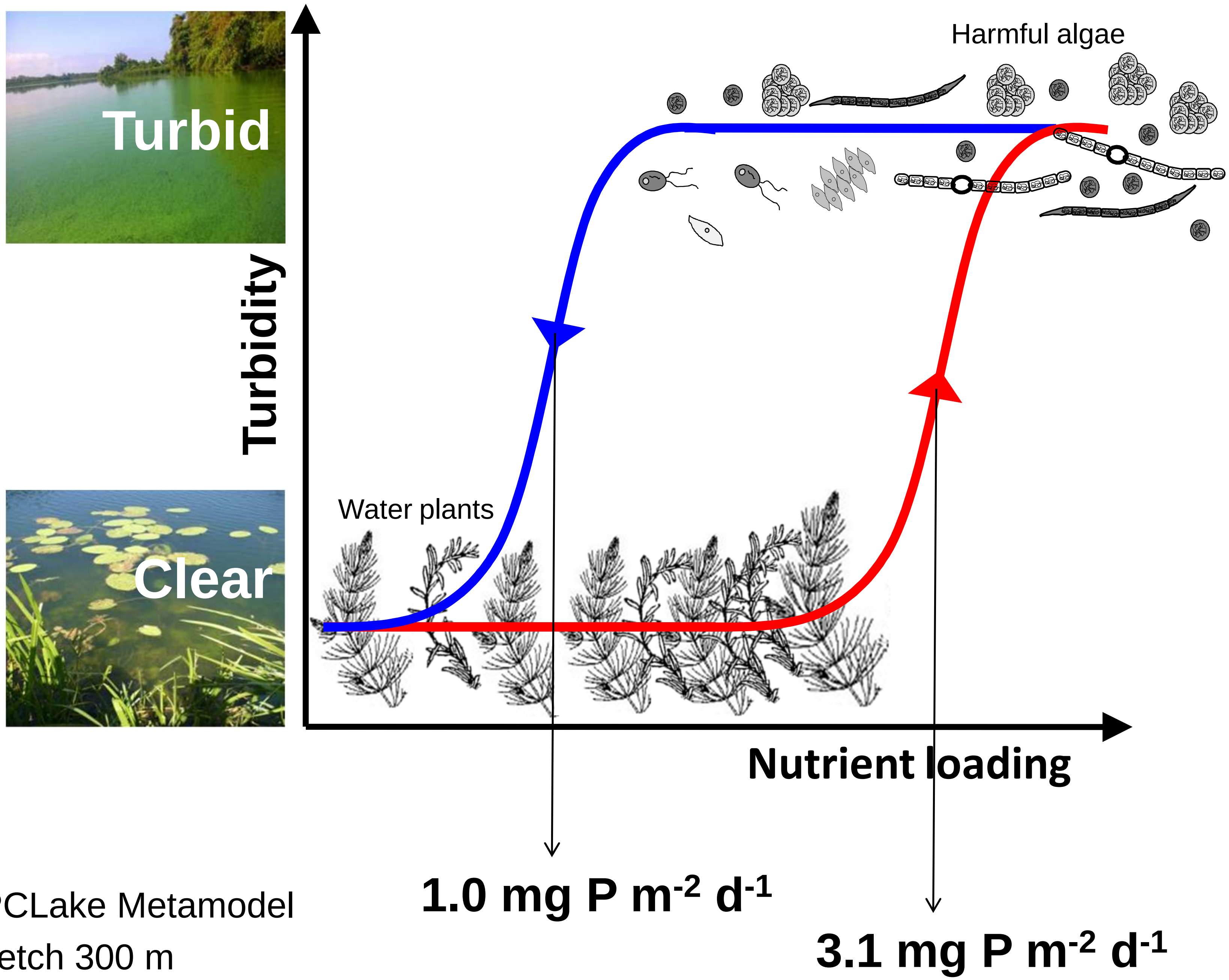
1 Urban pond Eindhoven: 6 compartments (20 x 20 m)

2 Lake Rauwbraken 2.6 ha (max 15 m): Flock & Lock

3 Lake De Kuil 6.7 ha (max 9 m): Flock & Lock

Pond 'Eindhoven'

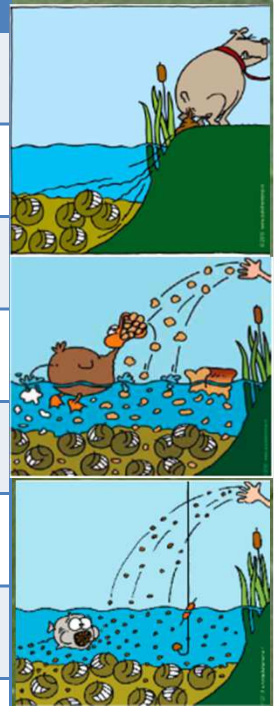
Pond Eindhoven



PCLake Metamodel
Fetch 300 m

External P – load

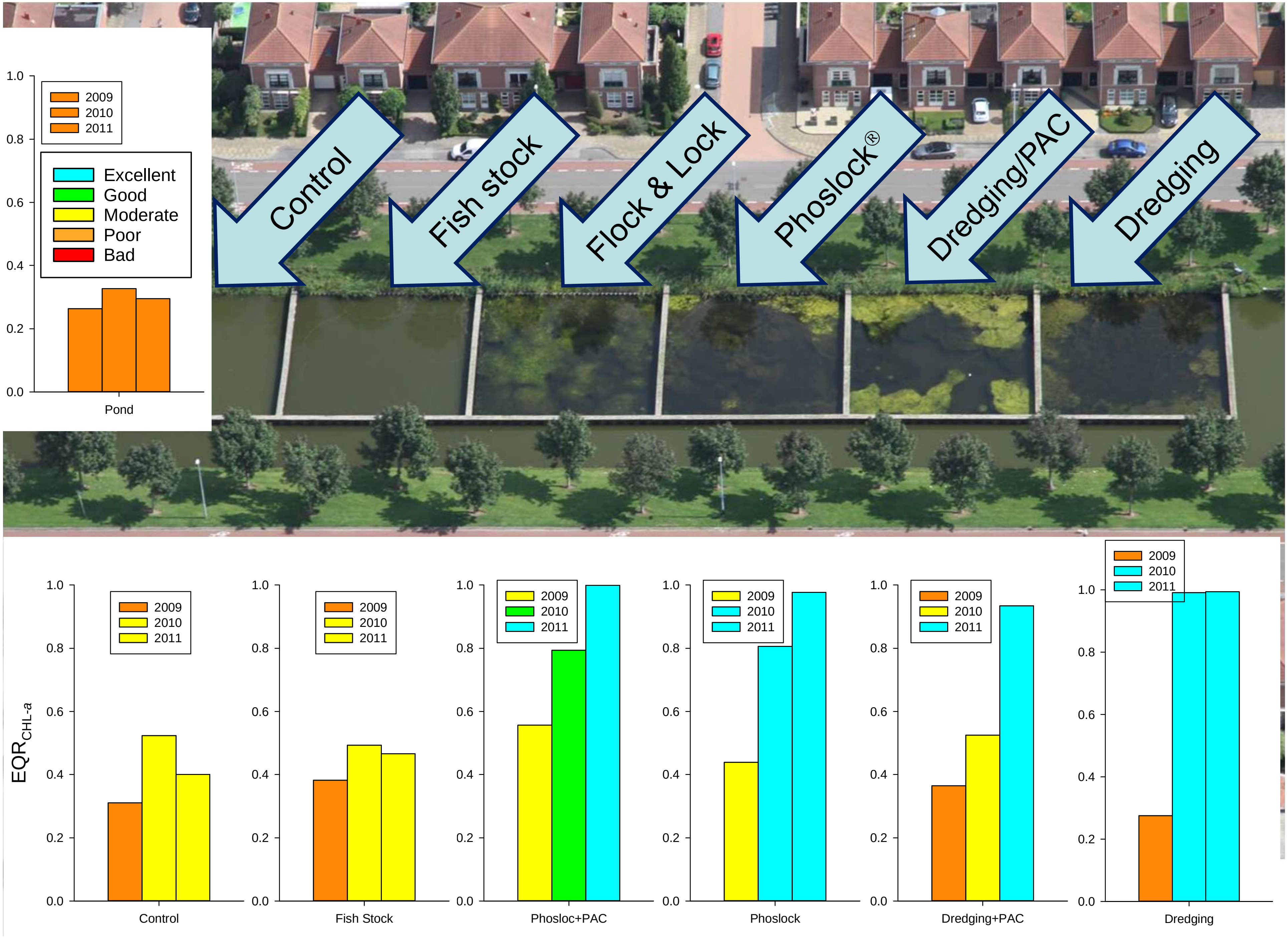
term	phosphorus load (mg P m^{-2} d^{-1})
runoff	4.69
groundwater	0.00
deposition on open water	0.11
‘Rainwater ‘ discharge	17.16
water birds	0.03
litter fall	0.00
angling (bait)	0.44
total	**22.43**



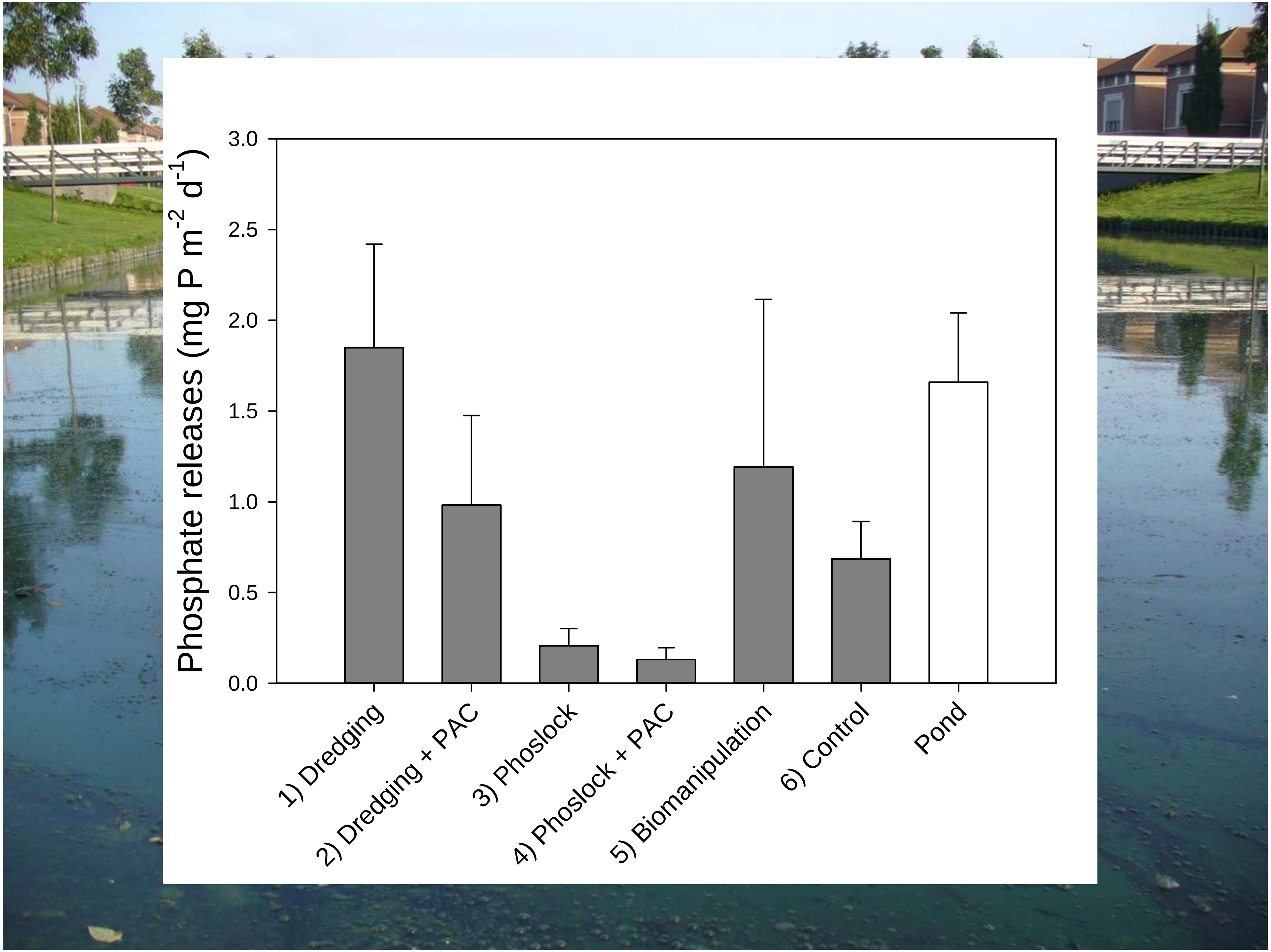
Internal P – load

1.66 ± 0.38 mg P m^{-2} d^{-1}

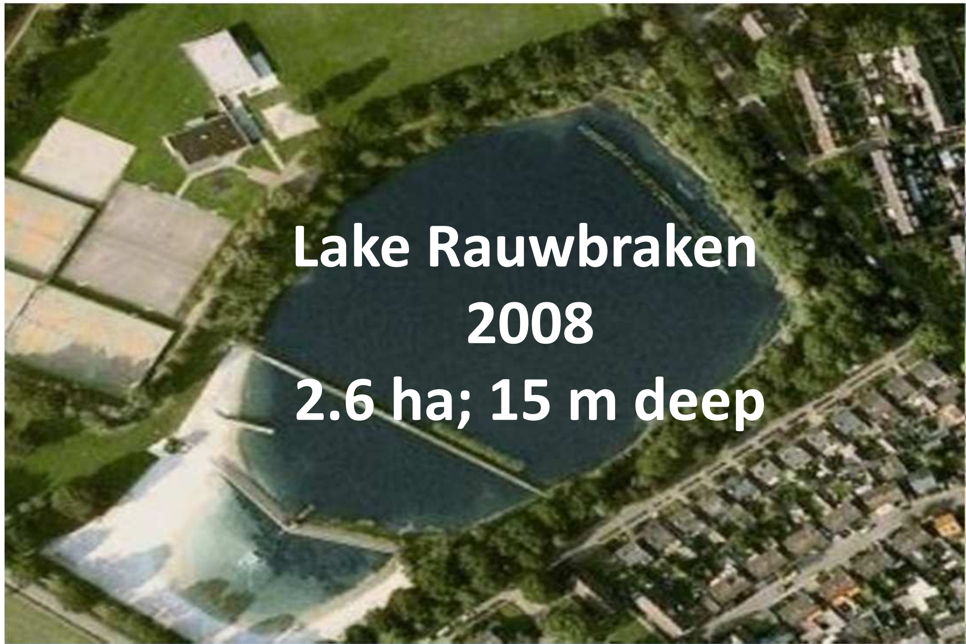
1250 kg ha^{-1}

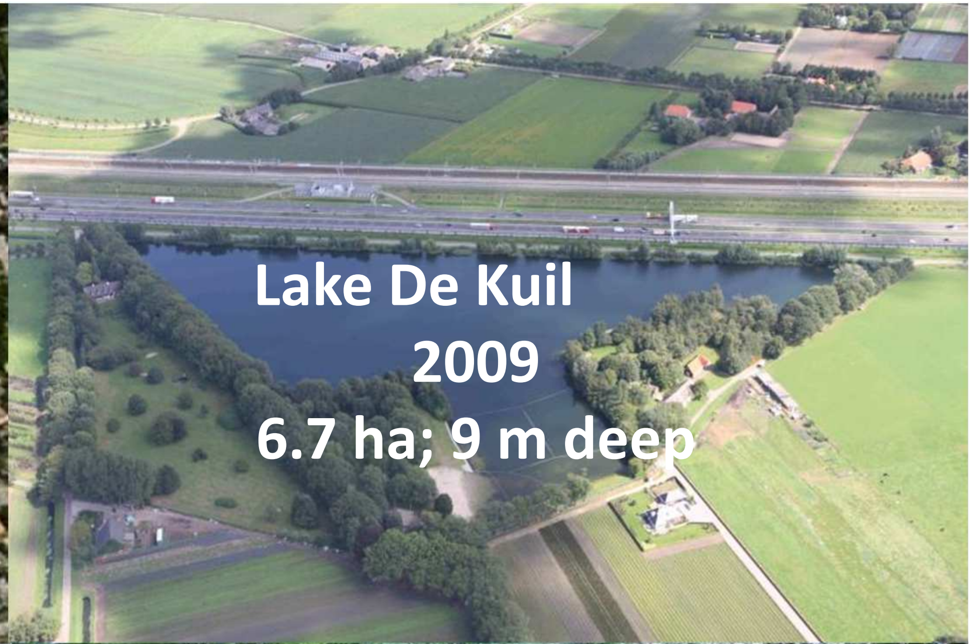


Control
Fish stock
Flock & Lock
Phoslock®
Dredging/PAC
Dredging
2009
2010
2011
Excellent
Good
Moderate
Poor
Bad
Pond
EQR_{CHL-a}
Control
Fish Stock
Phosloc+PAC
Phoslock
Dredging+PAC
Dredging


Phosphate releases (mg P m-2 d-1)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1) Dredging
2) Dredging + PAC
3) Phoslock
4) Phoslock + PAC
5) Biomanipulation
6) Control
Pond

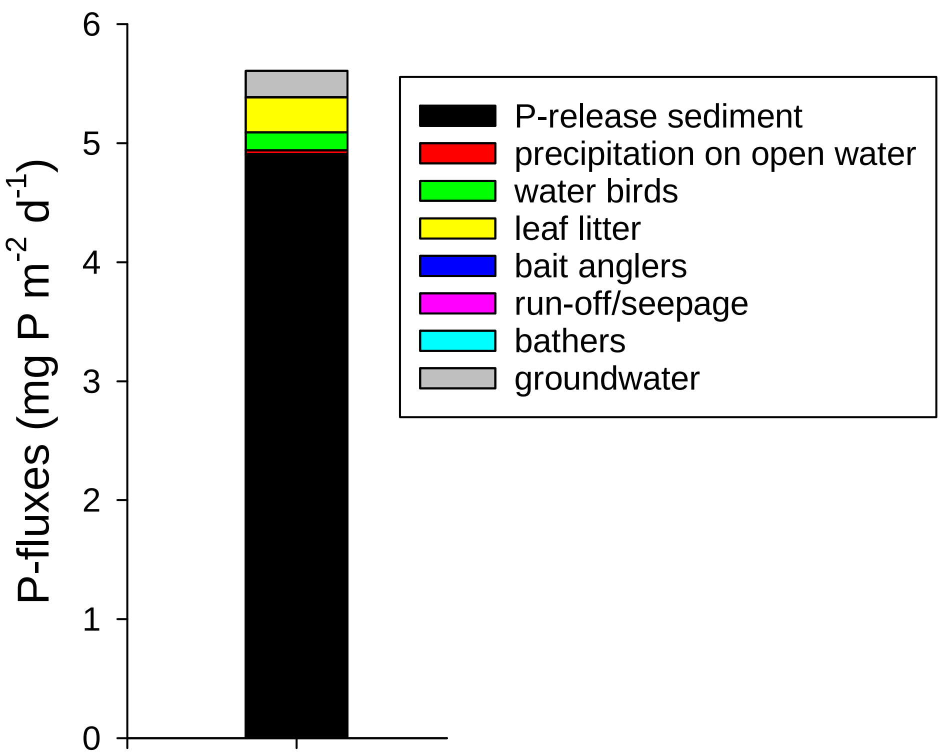
Flock & Lock whole lake experiments



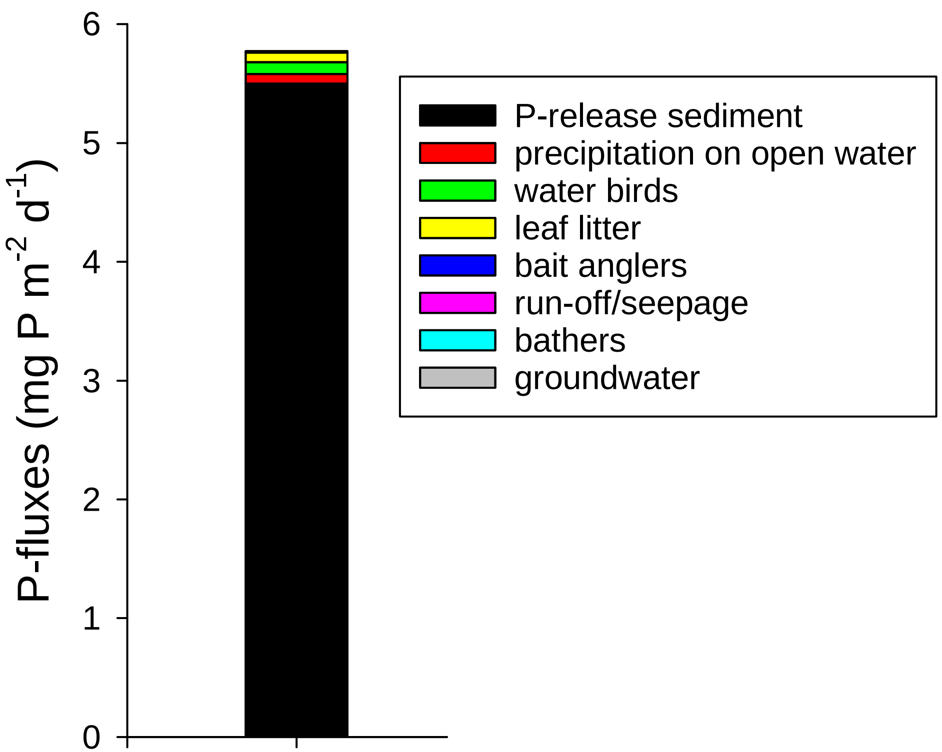


Both lakes rather isolated (no main water inflow); stratifying; official bathing sites

Lake De Rauwbraken



Lake De Kuil



Diagnosis: P – release from sediment is major source of in-lake P

Management: tackling P – release from sediment

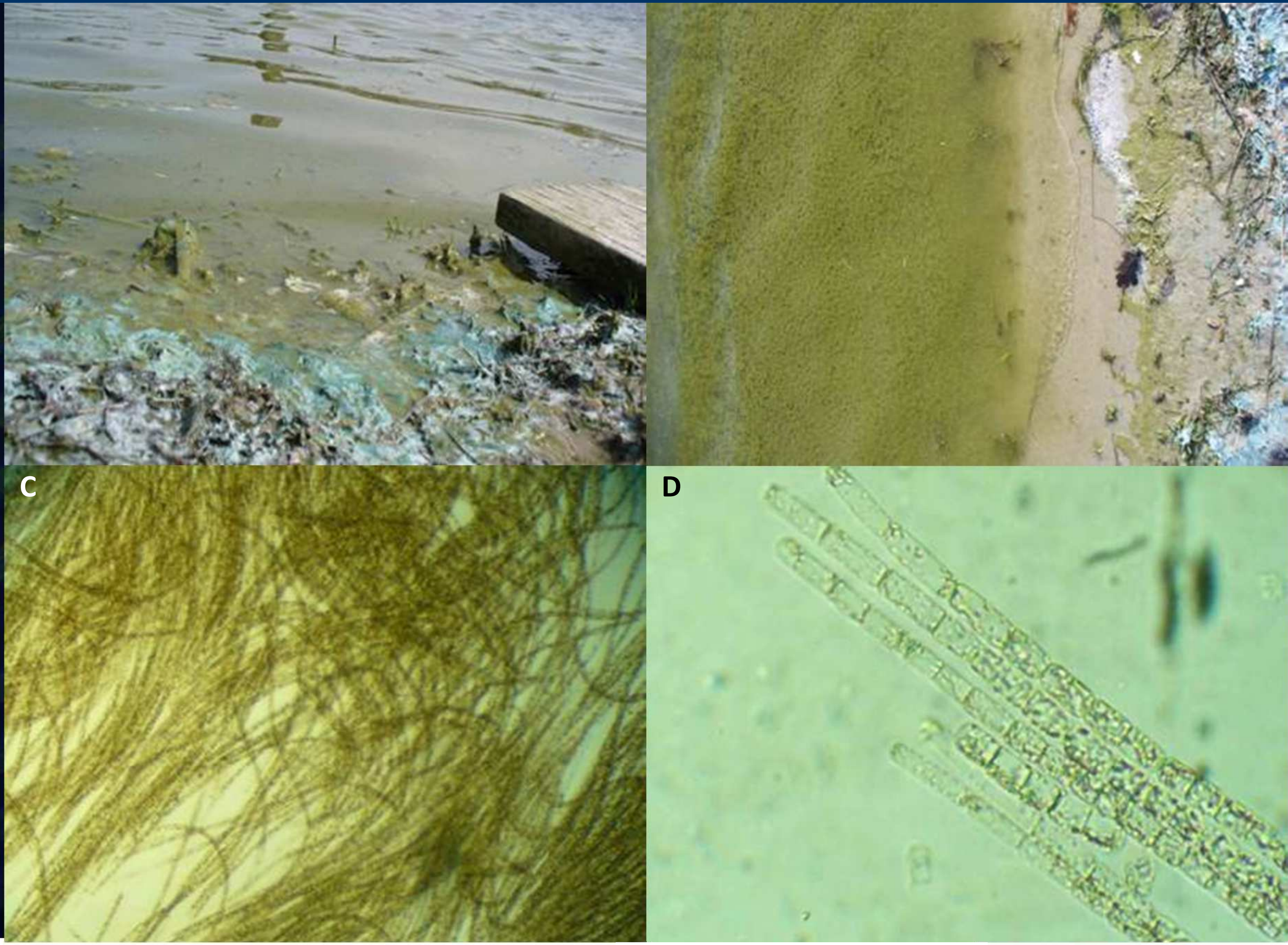
“Restoration Rauwbraken”

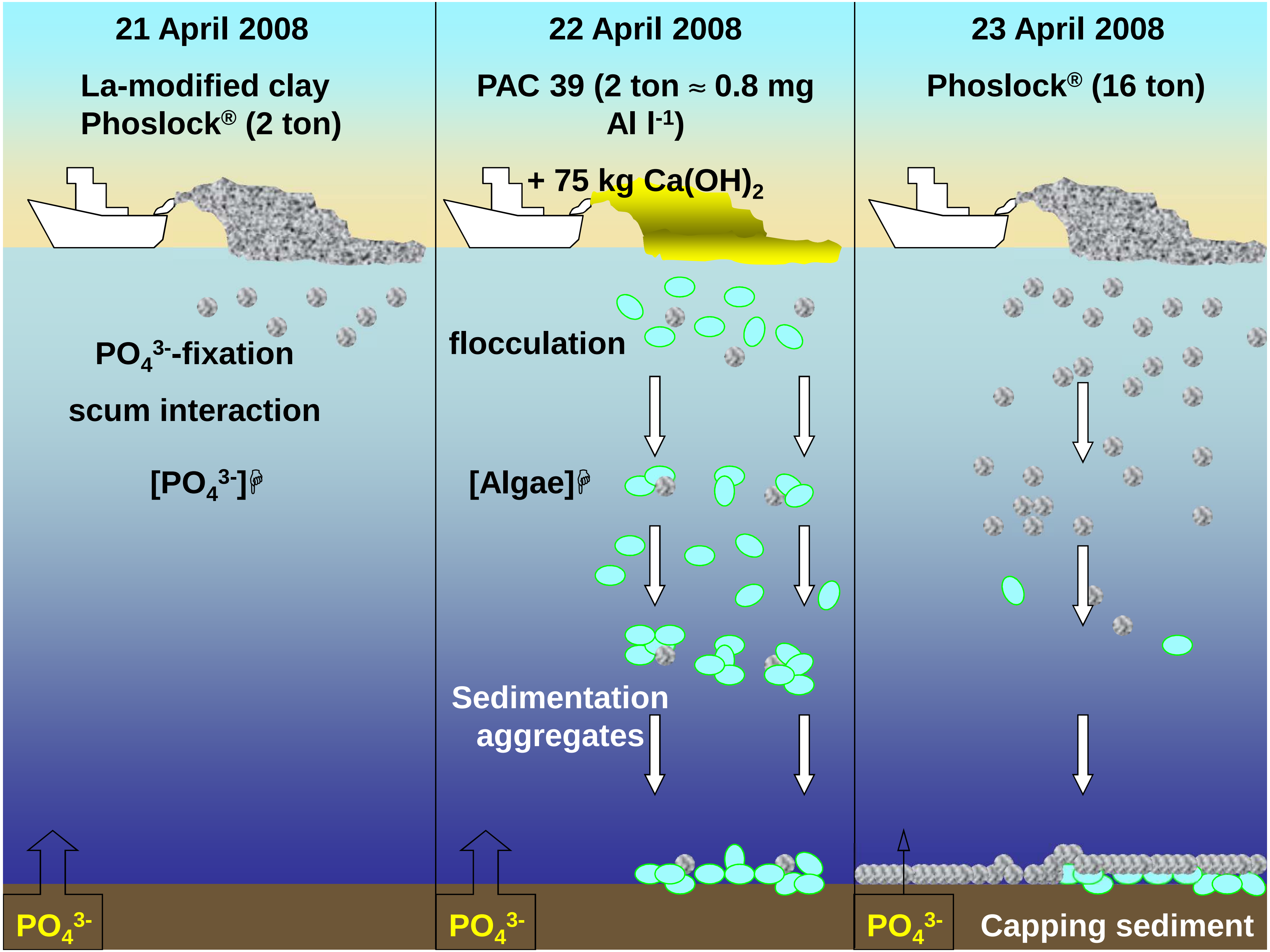
☞ **Bank restoration/vegetation**

☞ **Fish removal 2001 – 2003**

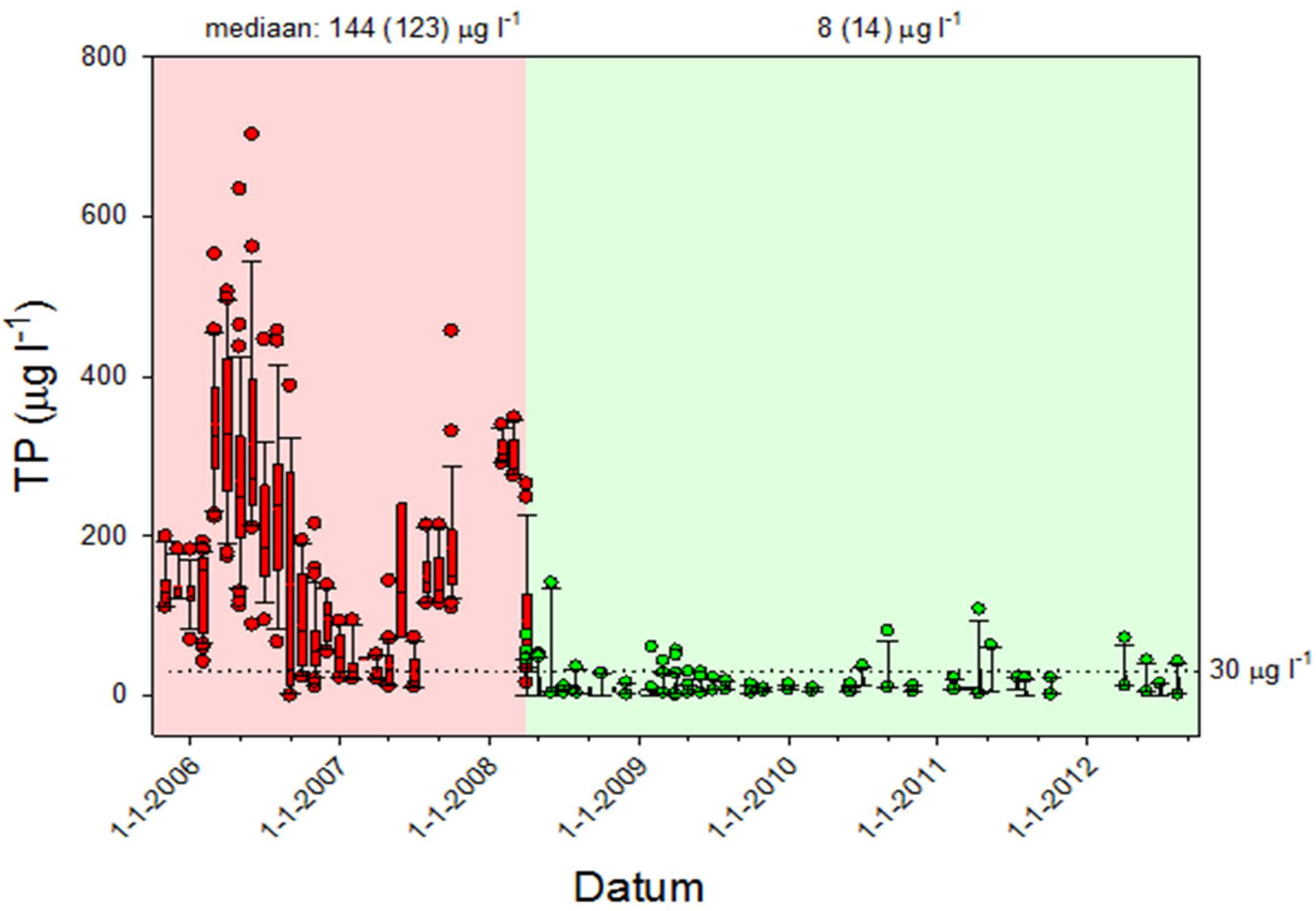
(Grass carps ≤ 92 cm) Rauwbraken stocked in 80-ies with 500 grass carps

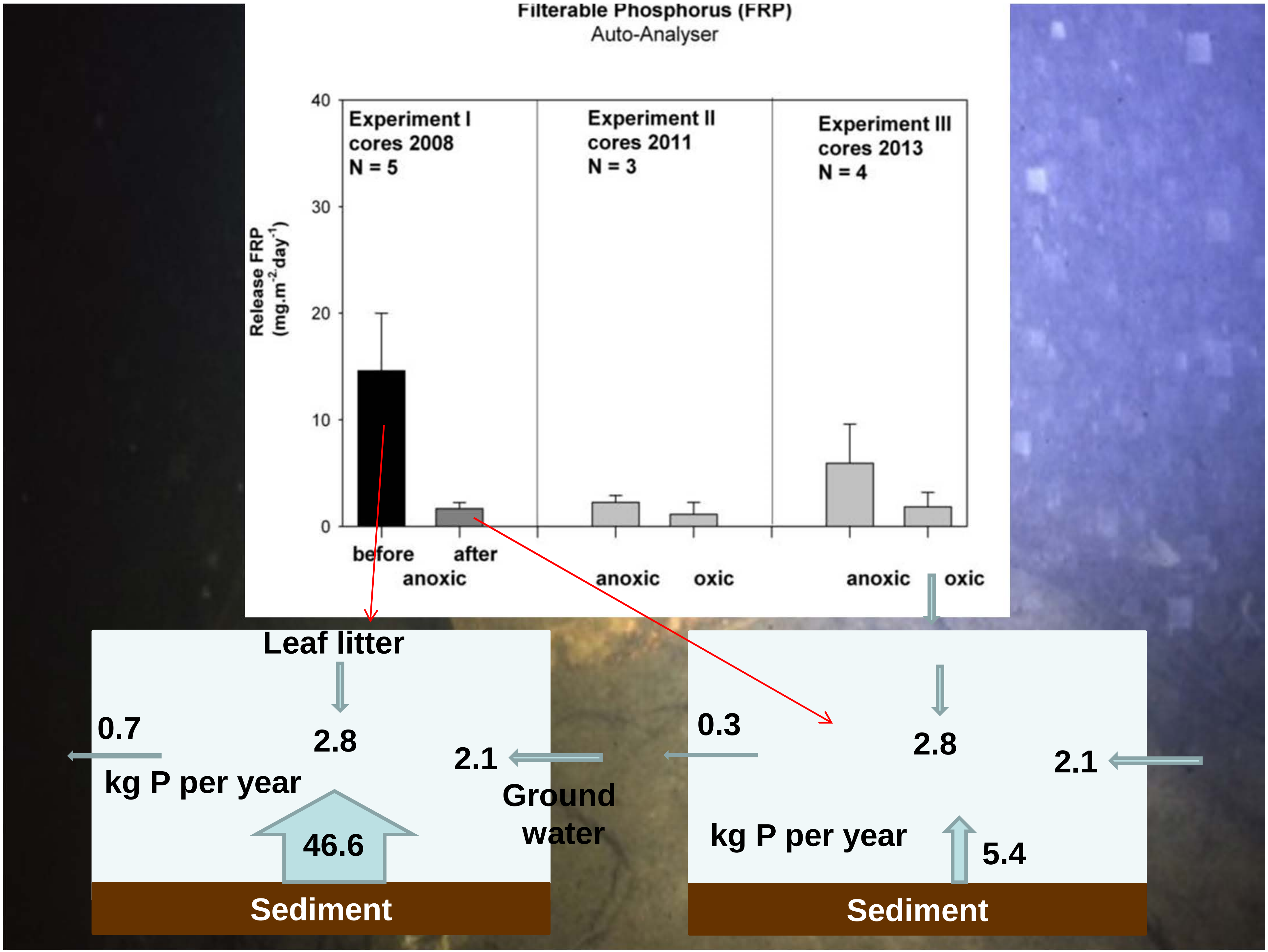
Lake Rauwbraken April 2008: Scum of *Aphanizomenon*



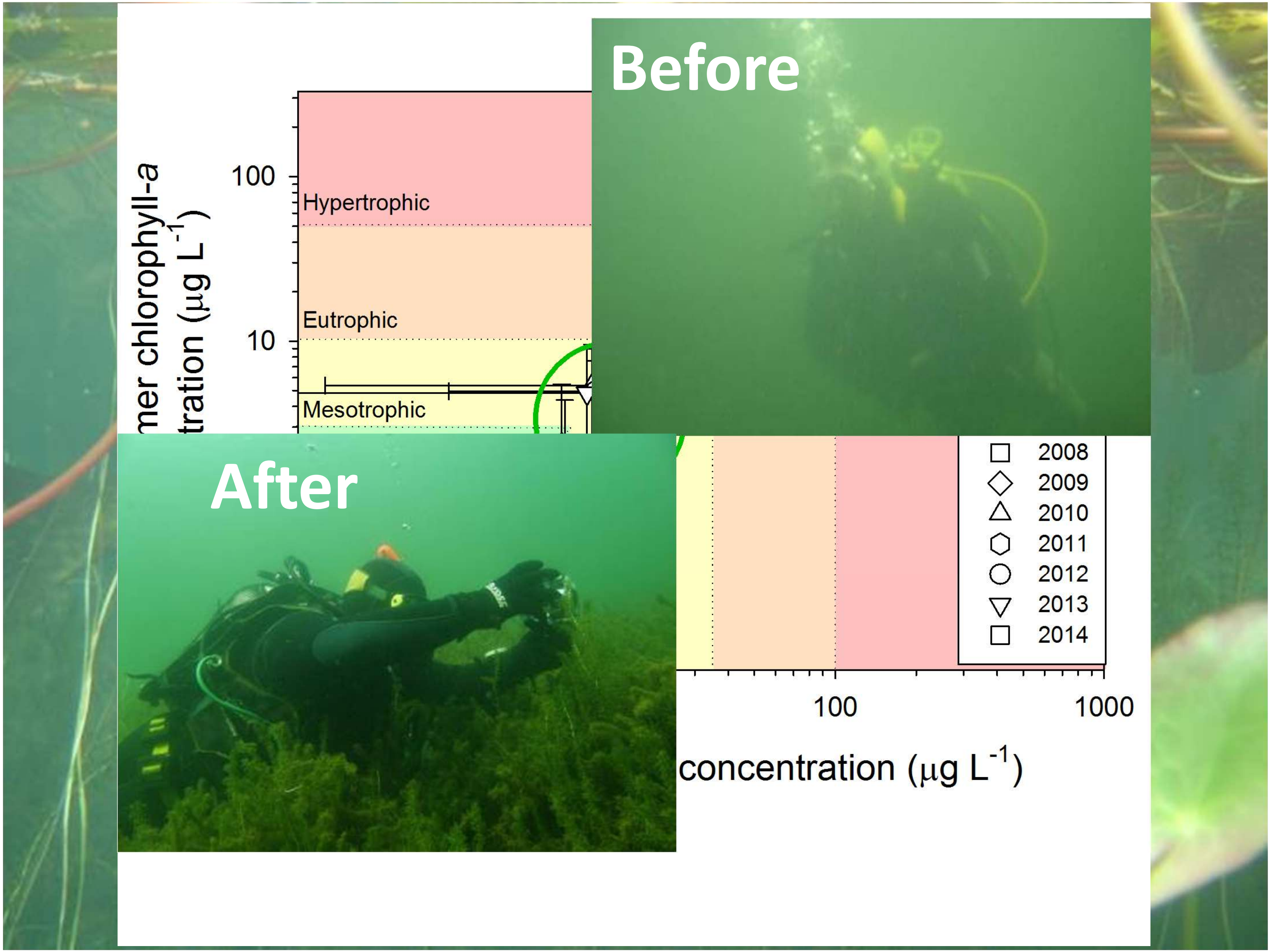


21 April 2008
La-modified clay
Phoslock® (2 ton)
PO$_4^{3-}$-fixation
scum interaction
[PO$_4^{3-}$]
PO$_4^{3-}$
22 April 2008
PAC 39 (2 ton ≈ 0.8 mg Al l^{-1})
+ 75 kg Ca(OH)$_2$
flocculation
[Algae]
Sedimentation aggregates
PO$_4^{3-}$
23 April 2008
Phoslock® (16 ton)
PO$_4^{3-}$
Capping sediment

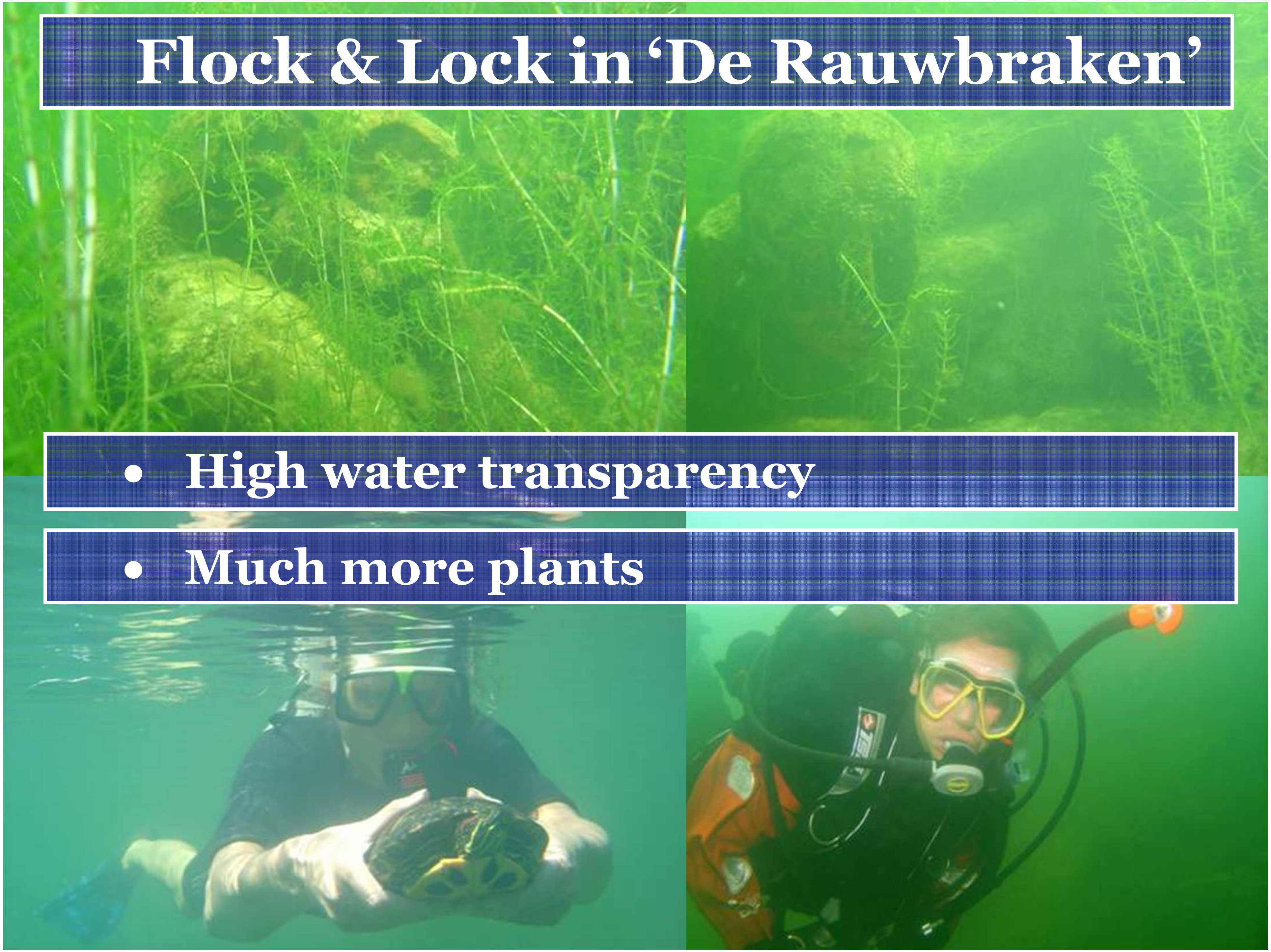

mediaan: 144 (123) µg l-1
8 (14) µg l-1
800
600
400
200
0
TP (µg l-1)
30 µg l-1
1-1-2006
1-1-2007
1-1-2008
1-1-2009
1-1-2010
1-1-2011
1-1-2012
Datum



Filterable Phosphorus (FRP)
Auto-Analyser
Release FRP (mg.m-2.day-1)
40
30
20
10
0
Experiment I
cores 2008
N = 5
Experiment II
cores 2011
N = 3
Experiment III
cores 2013
N = 4
before
after
anoxic
anoxic
oxic
anoxic
oxic
Leaf litter
0.7
2.8
2.1
kg P per year
46.6
Ground
water
Sediment
0.3
2.8
2.1
kg P per year
5.4
Sediment


Before
After
mer chlorophyll-a
tration (µg L-1)
100
10
Hypertrophic
Eutrophic
Mesotrophic
2008
2009
2010
2011
2012
2013
2014
100
1000
concentration (µg L-1)

Flock & Lock in 'De Rauwbraken'

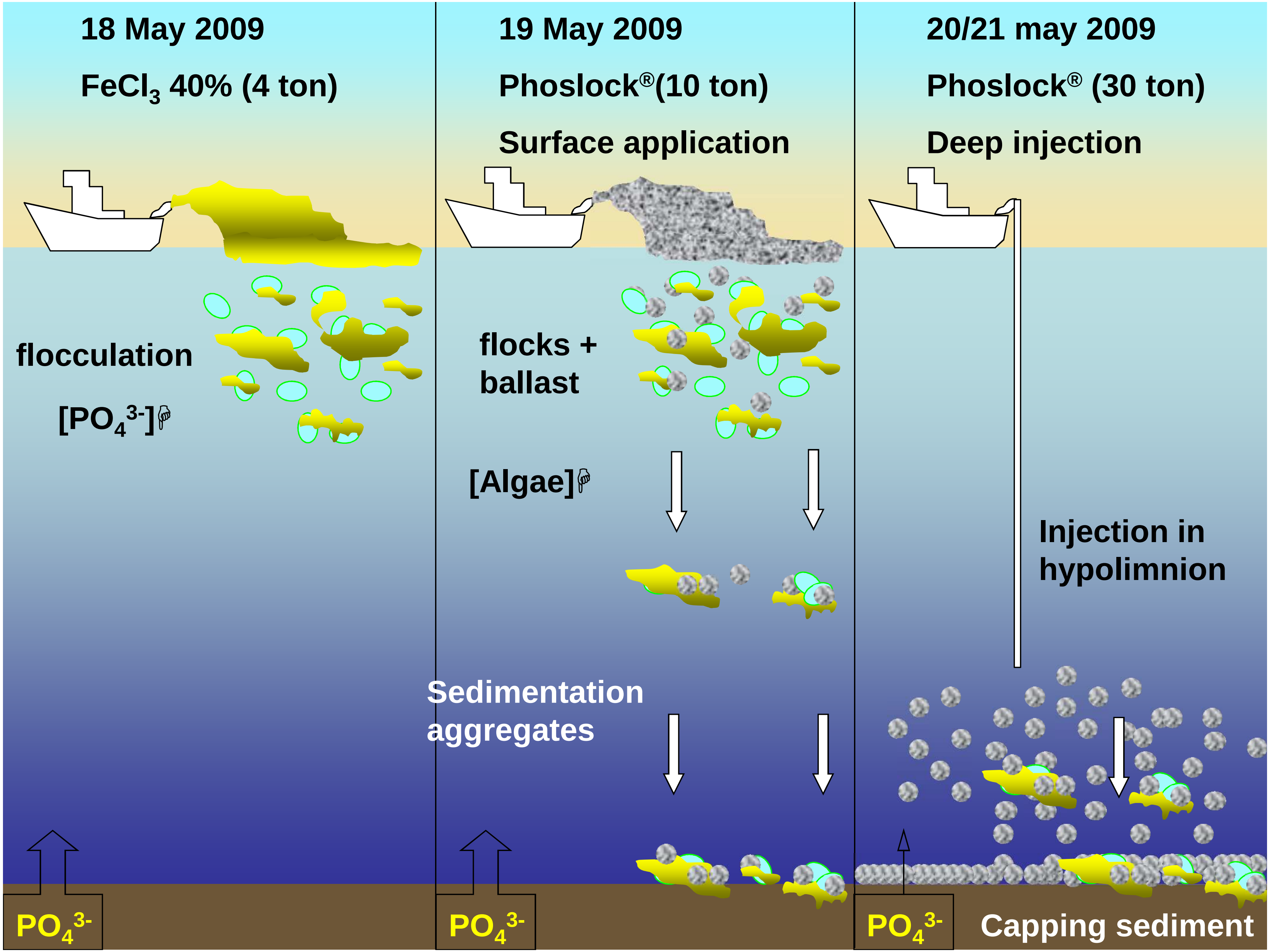


- High water transparency
- Much more plants

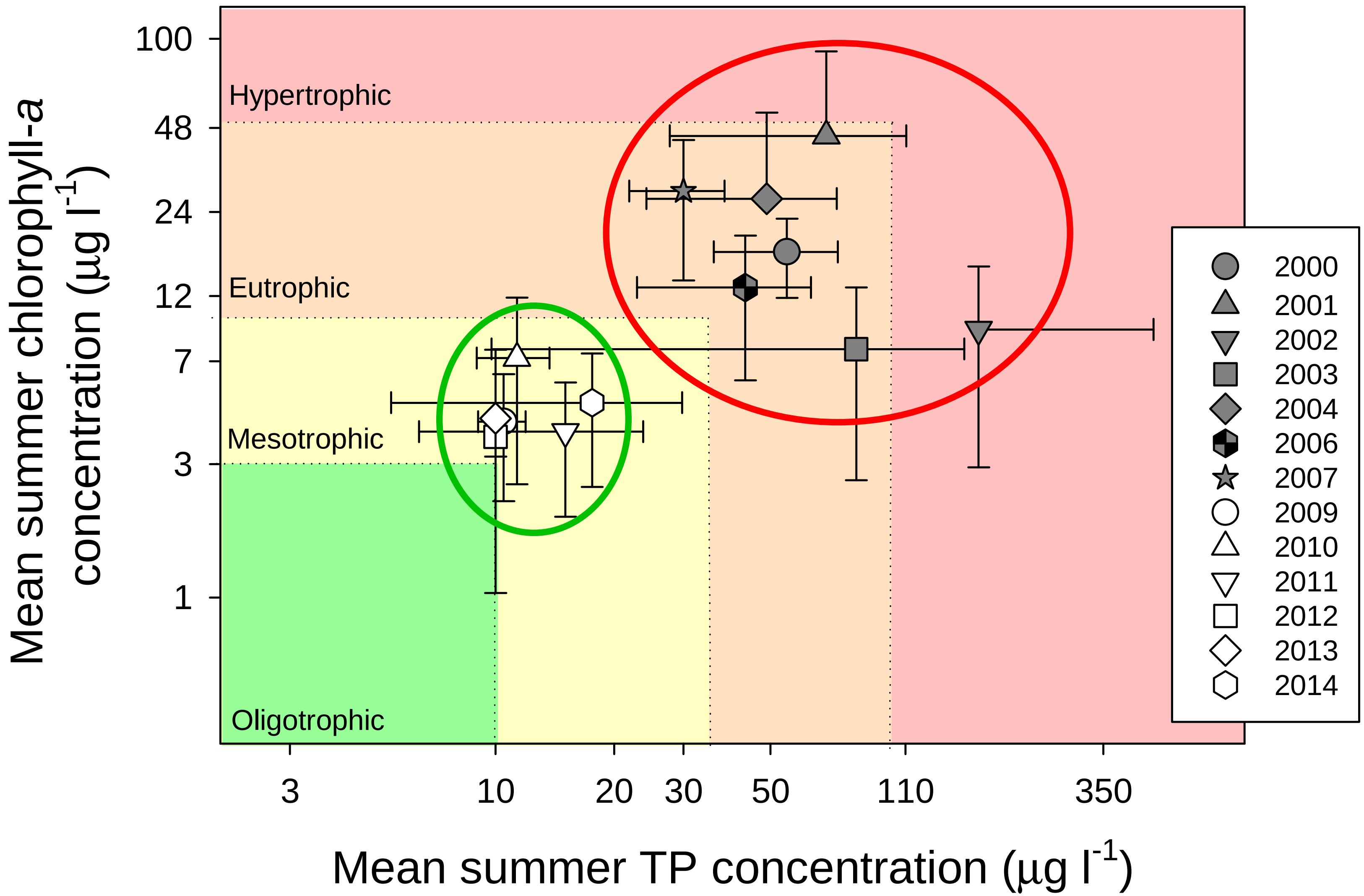
Lake De Kuil May 2009: developing *Aphanizomenon*

20.3 kg P in water

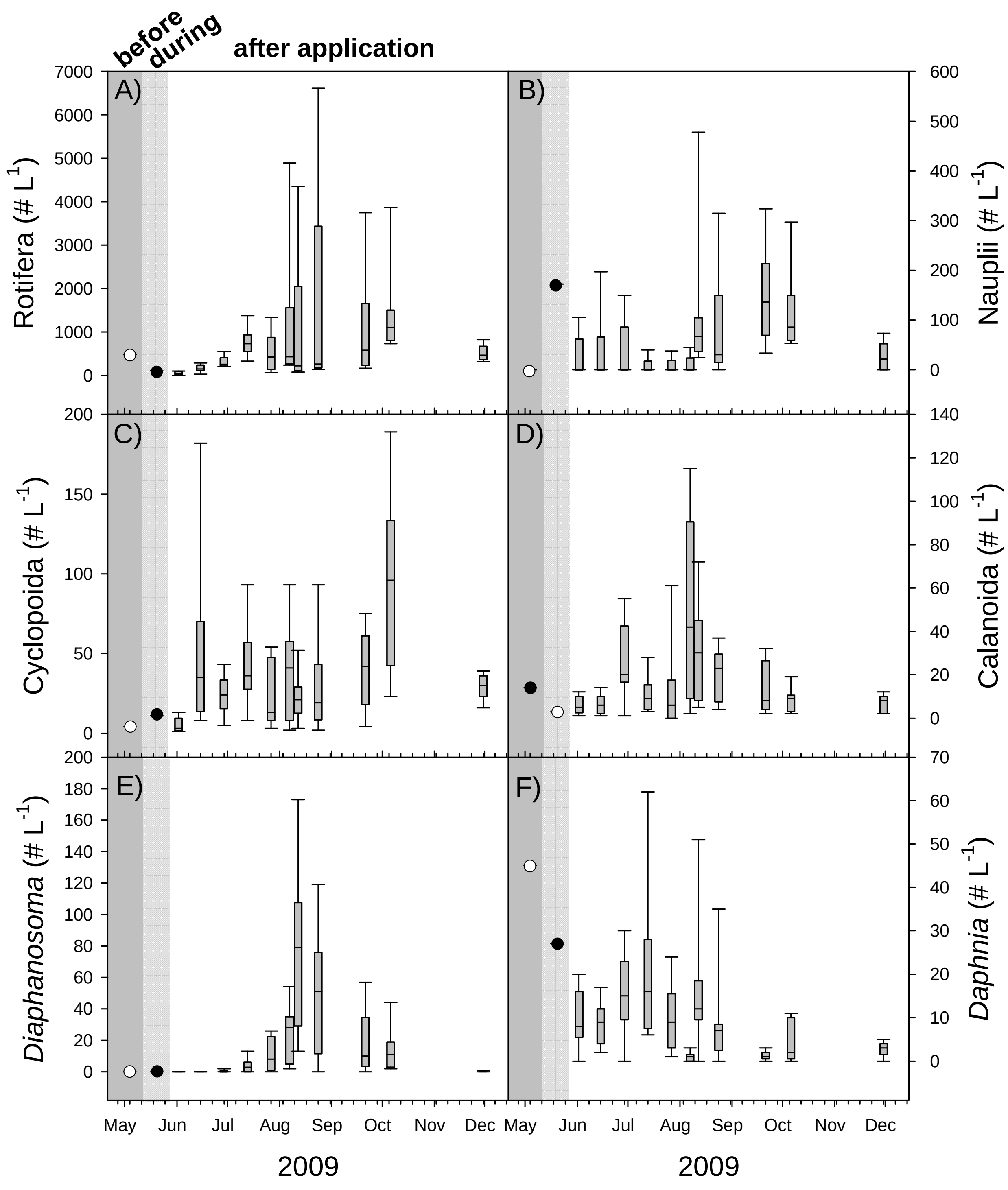
348 kg releasable P in sediment



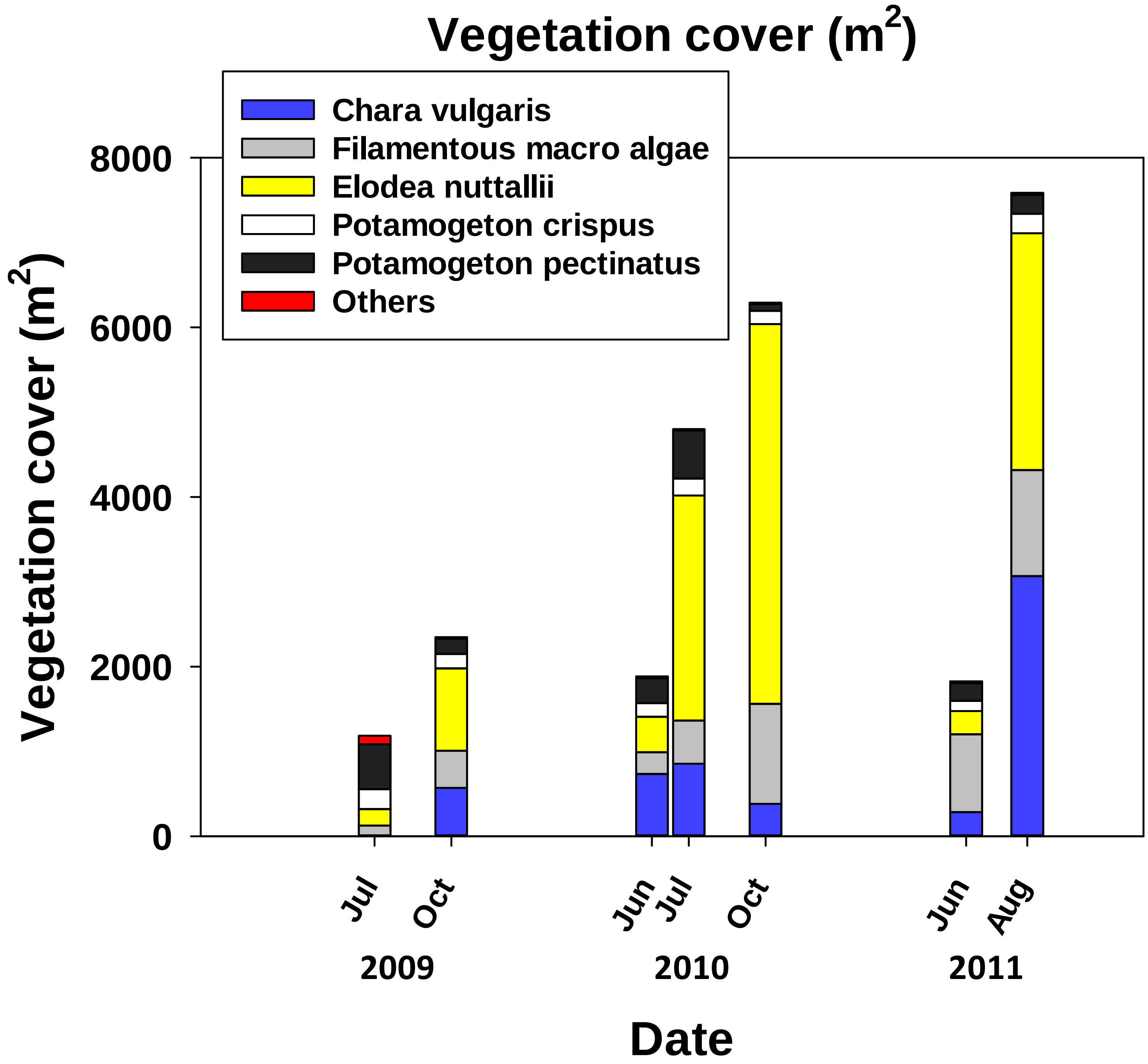
18 May 2009
FeCl3 40% (4 ton)
flocculation
[PO4 3-]
PO4 3-
19 May 2009
Phoslock®(10 ton)
Surface application
flocks +
ballast
[Algae]
Sedimentation
aggregates
PO4 3-
20/21 may 2009
Phoslock® (30 ton)
Deep injection
Injection in
hypolimnion
PO4 3-
Capping sediment

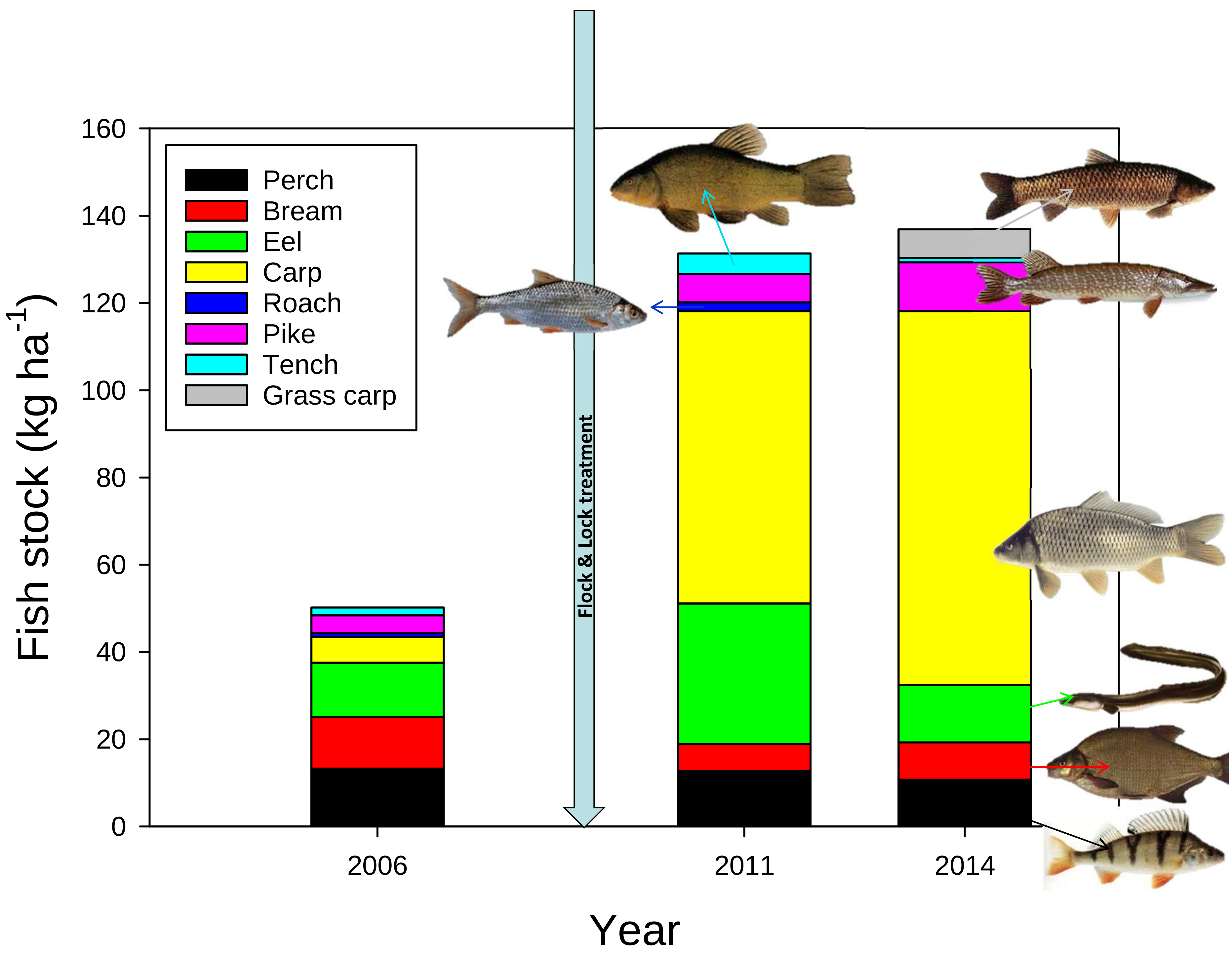


Hypertrophic
Eutrophic
Mesotrophic
Oligotrophic
100
48
24
12
7
3
1
3
10
20
30
50
110
350
Mean summer chlorophyll-a concentration (µg l-1)
Mean summer TP concentration (µg l-1)
2000
2001
2002
2003
2004
2006
2007
2009
2010
2011
2012
2013
2014



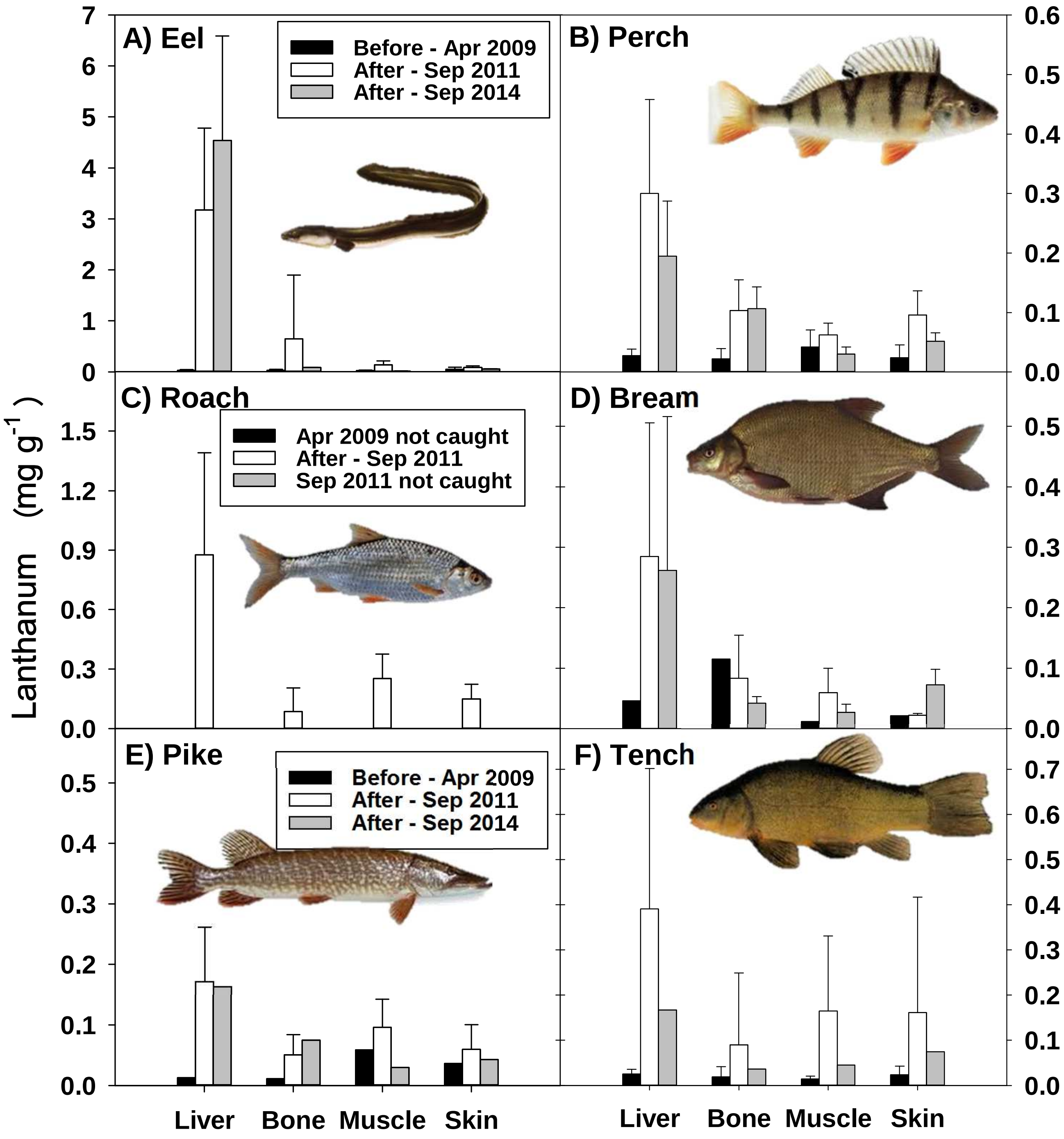
before
during
after application
A)
B)
C)
D)
E)
F)
Rotifera (# L-1)
Nauplii (# L-1)
Cyclopoida (# L-1)
Calanoida (# L-1)
Diaphanosoma (# L-1)
Daphnia (# L-1)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2009


Vegetation cover (m2)
Chara vulgaris
Filamentous macro algae
Elodea nuttallii
Potamogeton crispus
Potamogeton pectinatus
Others
Vegetation cover (m2)
8000
6000
4000
2000
0
Jul
Oct
Jun
Jul
Oct
Jun
Aug
2009
2010
2011
Date



Fish stock (kg ha⁻¹)
160
140
120
100
80
60
40
20
0
Perch
Bream
Eel
Carp
Roach
Pike
Tench
Grass carp
Flock & Lock treatment
2006
2011
2014
Year

Lanthanum from Phoslock is found in fish tissues



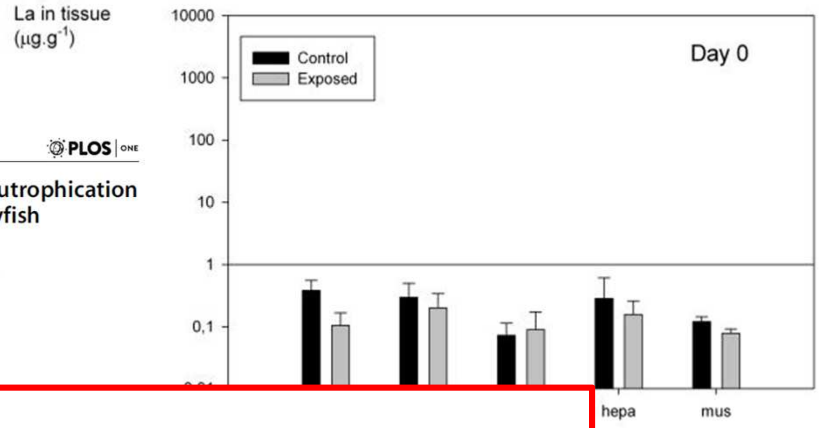
But NO signs of toxicity

Lanthanum from Phoslock is bioavailable to the Marbled crayfish (*Procambarus fallax*)

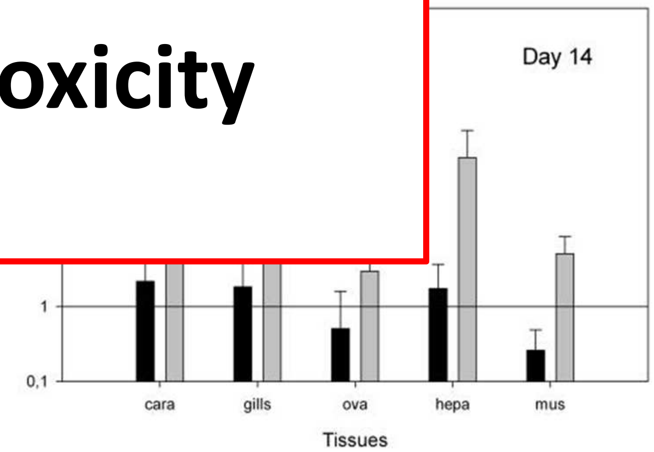

OPEN ACCESS Freely available online — PLOS ONE

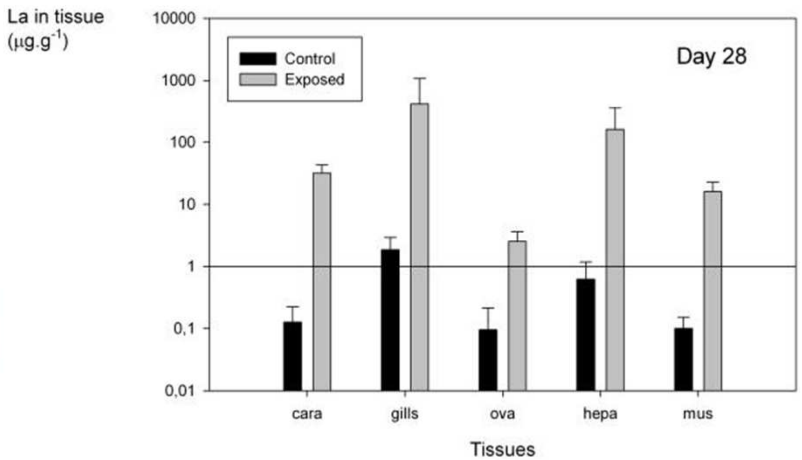
Lanthanum from a Modified Clay Used in Eutrophication Control Is Bioavailable to the Marbled Crayfish (*Procambarus fallax* f. *virginalis*)

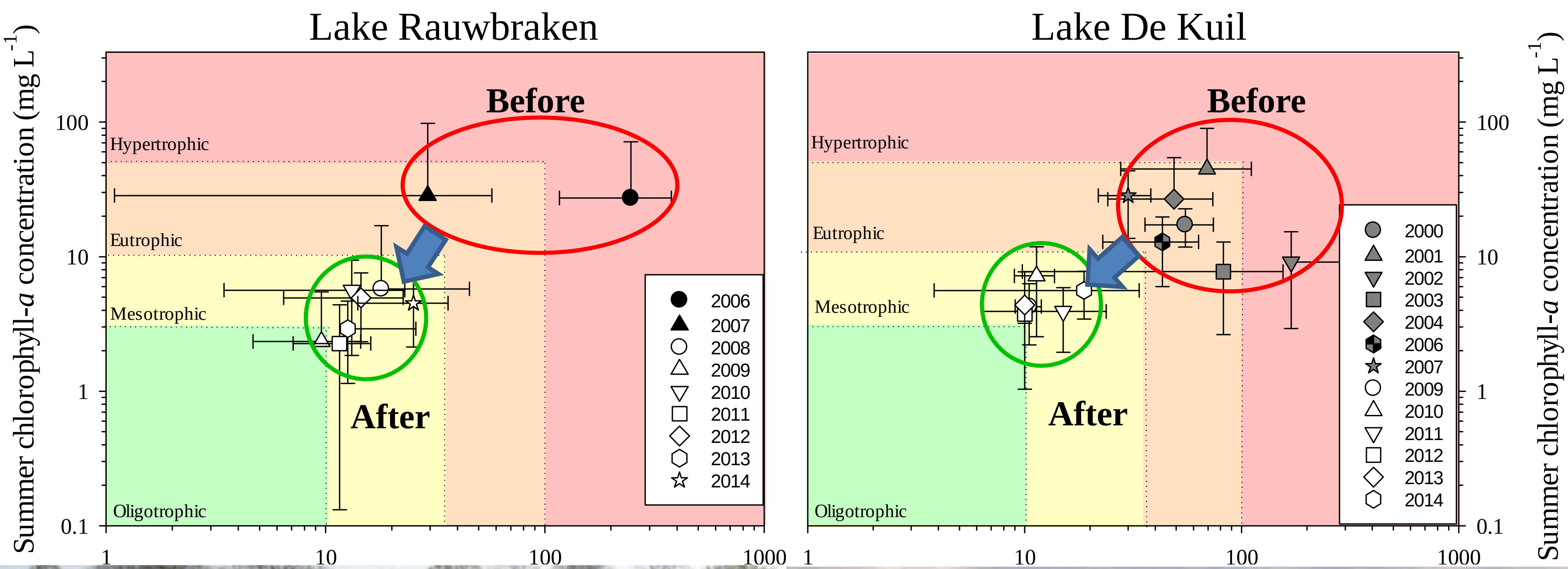
Frank van Oosterhout[1*], Eyerusalem Goitom[1], Ivo Roessink[2], Miquel Lürling[1,3]



But NO signs of toxicity







Geo-engineering can be powerful to evoke a 'regime-shift'

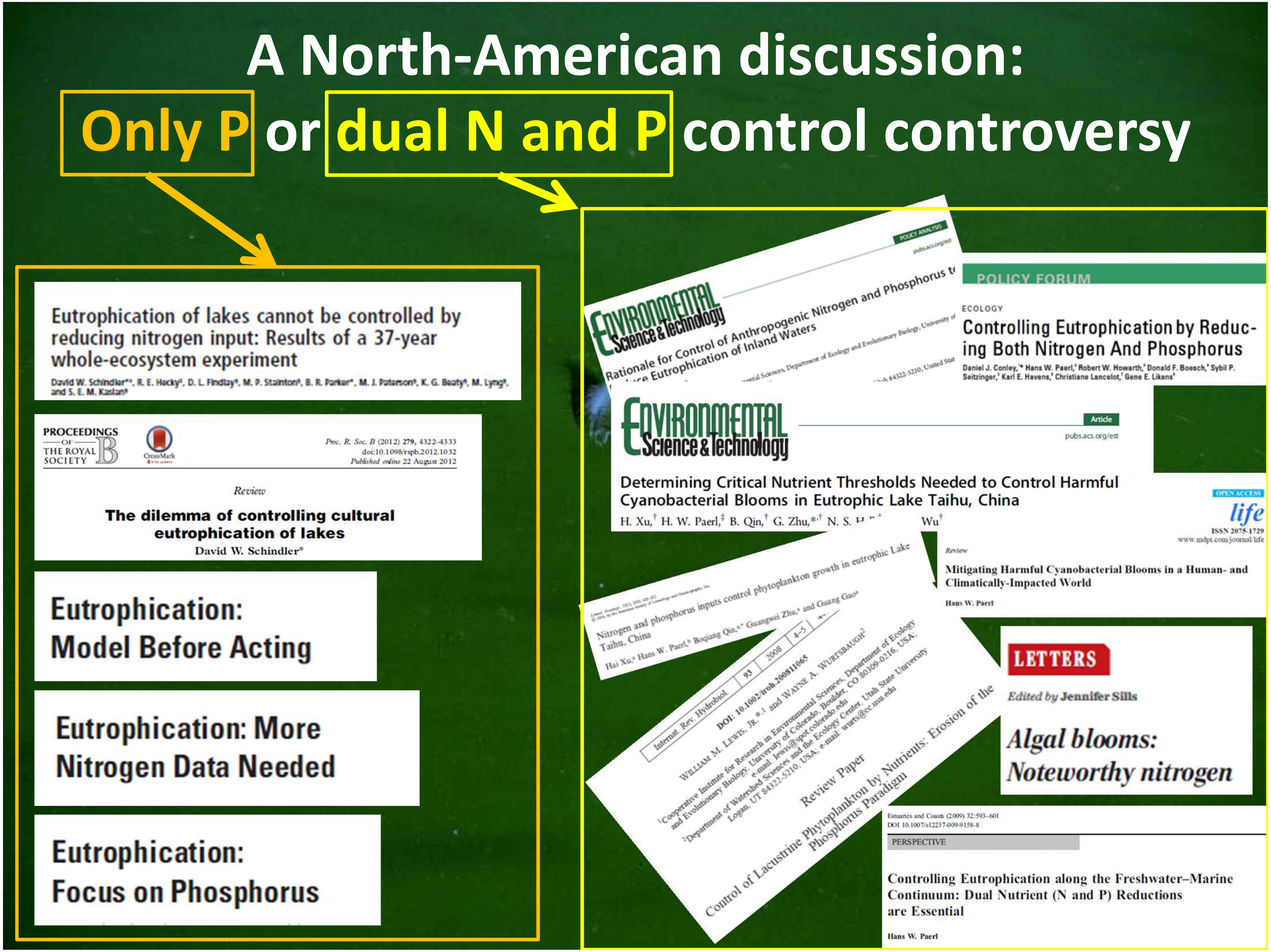
Both lakes are absolutely in better state than before

No toxicity observed

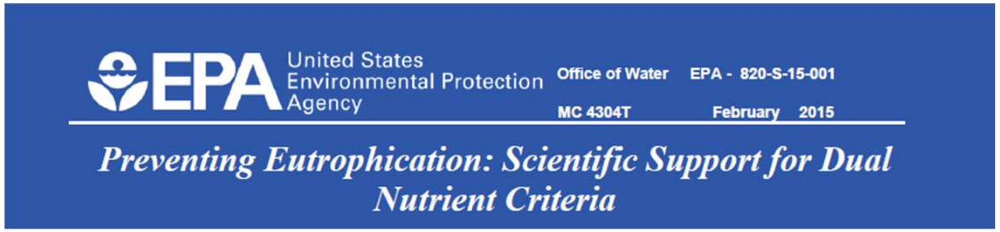
Lanthanum: A Safe Phosphate Binder

Veerle P. Persy, Geert J. Behets, An R. Bervoets, Marc E. De Broe, and Patrick C. D'Haese
University of Antwerp, Antwerp, Belgium

Seminars in Dialysis—Vol 19, No 3 (May–June) 2006 pp. 195–199



A North-American discussion:
Only P or dual N and P control controversy
Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment
David W. Schindler, R. E. Hecky, D. L. Findlay, M. P. Stainton, B. R. Parker, M. J. Paterson, K. G. Beaty, M. Lyng, and S. E. M. Kasian
PROCEEDINGS OF THE ROYAL SOCIETY B
Proc. R. Soc. B (2012) 279, 4322–4333
doi:10.1098/rspb.2012.1032
Published online 22 August 2012
Review
The dilemma of controlling cultural eutrophication of lakes
David W. Schindler*
Eutrophication: Model Before Acting
Eutrophication: More Nitrogen Data Needed
Eutrophication: Focus on Phosphorus
Environmental Science & Technology
POLICY ANALYSIS
pubs.acs.org/est
Rationale for Control of Anthropogenic Nitrogen and Phosphorus to Reduce Eutrophication of Inland Waters
POLICY FORUM
ECOLOGY
Controlling Eutrophication by Reducing Both Nitrogen And Phosphorus
Daniel J. Conley, Hans W. Paerl, Robert W. Howarth, Donald F. Boesch, Sybil P. Seitzinger, Karl E. Havens, Christiane Lancelot, Gene E. Likens
Environmental Science & Technology
Article
pubs.acs.org/est
Determining Critical Nutrient Thresholds Needed to Control Harmful Cyanobacterial Blooms in Eutrophic Lake Taihu, China
H. Xu, H. W. Paerl, B. Qin, G. Zhu, N. S.
OPEN ACCESS
life
ISSN 2075-1729
www.mdpi.com/journal/life
Review
Mitigating Harmful Cyanobacterial Blooms in a Human- and Climatically-Impacted World
Hans W. Paerl
Nitrogen and phosphorus inputs control phytoplankton growth in eutrophic Lake Taihu, China
Hai Xu, Hans W. Paerl, Boqiang Qin, Guangwei Zhu, and Guang Gao
Internat. Rev. Hydrobiol. 93 2008 4–5
DOI: 10.1002/iroh.200811065
WILLIAM M. LEWIS, JR. and WAYNE A. WURTSBAUGH
Review Paper
Control of Lacustrine Phytoplankton by Nutrients: Erosion of the Phosphorus Paradigm
LETTERS
Edited by Jennifer Sills
Algal blooms: Noteworthy nitrogen
Estuaries and Coasts (2009) 32:593–601
DOI 10.1007/s12237-009-9158-8
PERSPECTIVE
Controlling Eutrophication along the Freshwater–Marine Continuum: Dual Nutrient (N and P) Reductions are Essential
Hans W. Paerl



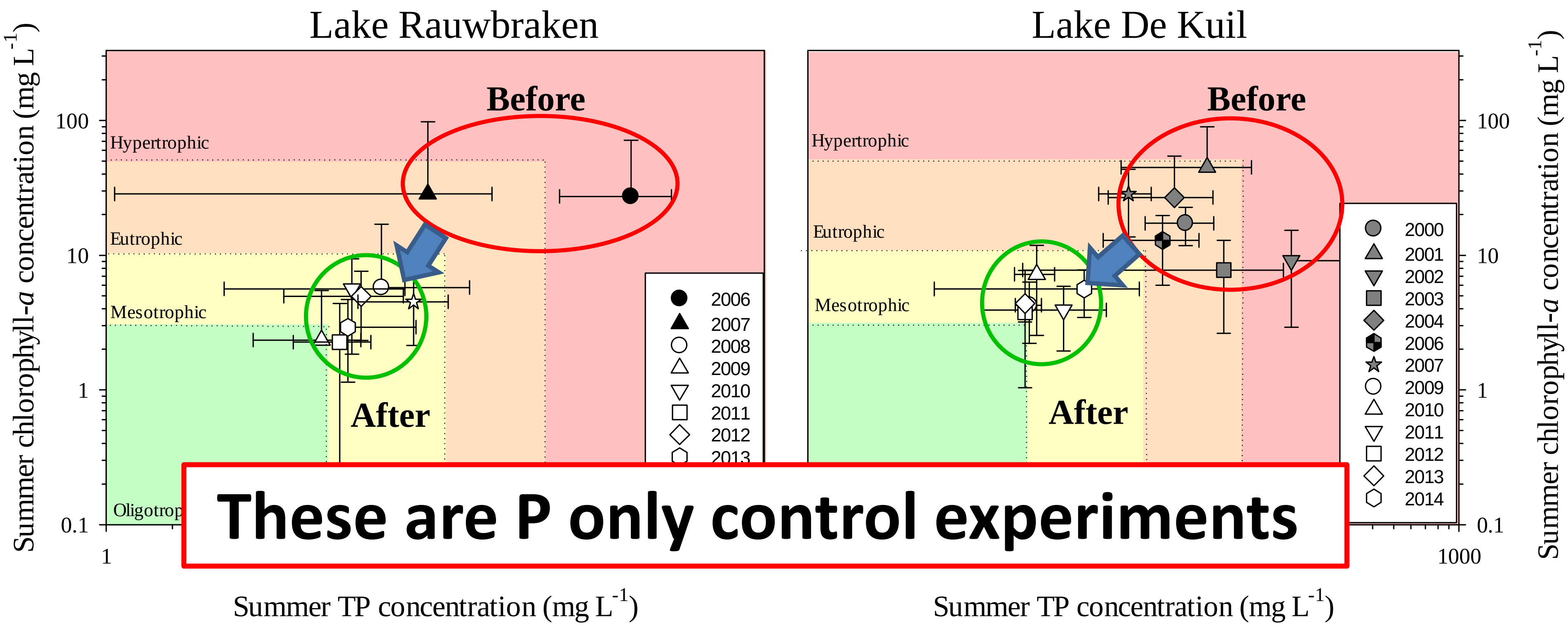
→ **Based on enrichment experiments**

Enrichment = eutrophication = external loading ≠ - mitigation (neglects inlake)

Controlling only P may ~~not~~ effectively prevent the occurrence of harmful algal blooms in freshwaters.

EPA, 2015

→ Controlling **only P** may effectively **prevent** the occurrence of **harmful algal blooms** In freshwaters.

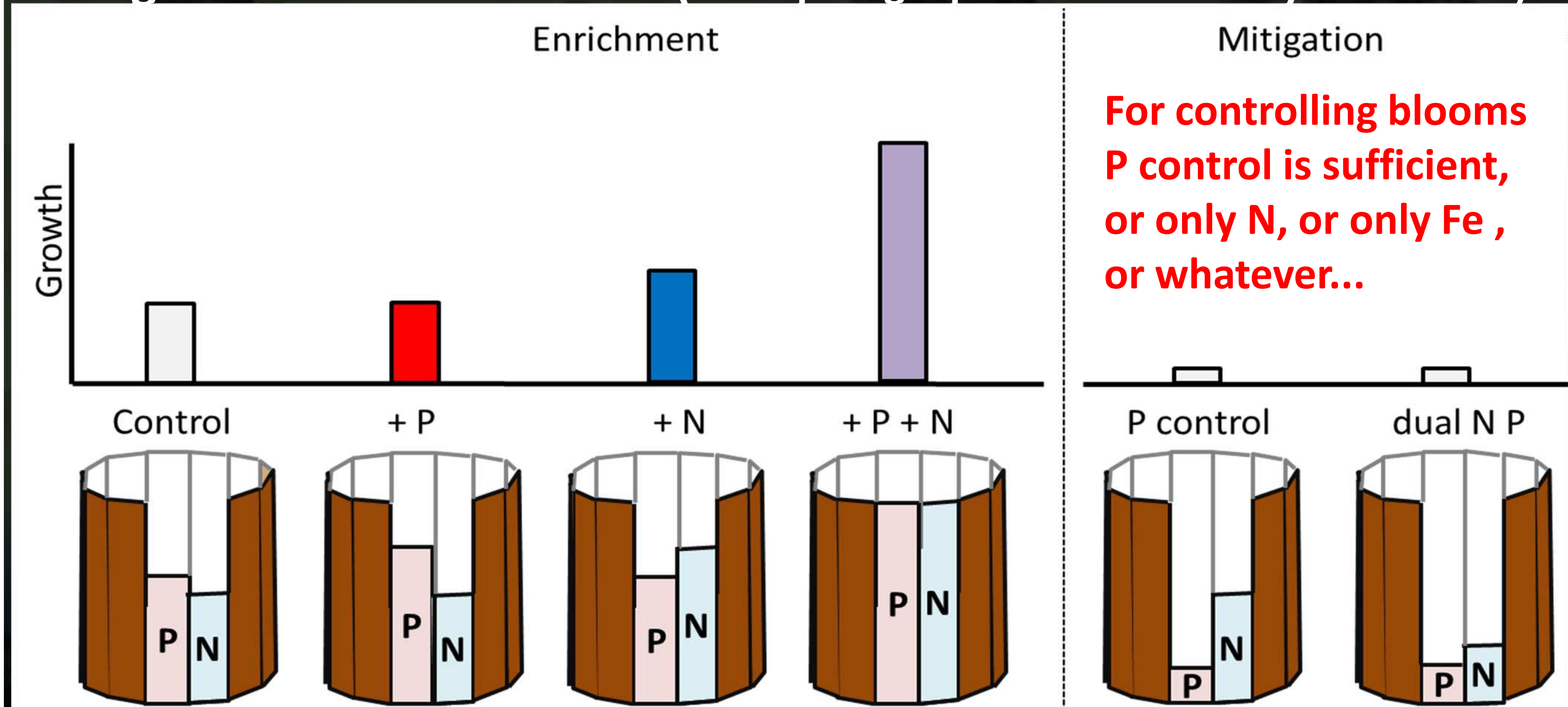


These are P only control experiments

“It is not important whether phosphate is currently the limiting factor or not, or even that it has ever been so; it is the only essential element that can be easily be made to limit algal growth”(Golterman, 1975).

Redfield ratio (P:N:C is 1:16: 106) means that P limitation is the most efficient stoichiometrically

Liebig’s law of the minimum (Carl Sprengel published this 27 years earlier)



cf. Hans Arnold von Dobeneck, 1903

There are many other reasons to control N, also in-lake

- Toxicity issues
- Effects on zooplankton
- Effects on plants
- …

Available online at www.sciencedirect.com
SCIENCE DIRECT
Environment International 32 (2006) 831–849
ENVIRONMENT INTERNATIONAL
www.elsevier.com/locate/envint

Review article

Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment

Julio A. Camargo [a,*], Álvaro Alonso [b]

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[b] *Laboratorio de Ecotoxicología, Departamento de Medio Ambiente, INIA, 28040 Madrid, Spain*

Received 20 September 2005; accepted 1 May 2006
Available online 16 June 2006

ELSEVIER
Chemosphere 58 (2005) 1255–1267
CHEMOSPHERE
www.elsevier.com/locate/chemosphere

Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates

Julio A. Camargo *, Alvaro Alonso, Annabella Salamanca

Departamento Interuniversitario de Ecología, Edificio de Ciencias, Universidad de Alcalá, E-28871 Alcalá de Henares, Madrid, Spain

Received 9 December 2003; received in revised form 19 October 2004; accepted 25 October 2004

Ecology and Evolution
Open Access

Nitrate enrichment alters a *Daphnia*–microparasite interaction through multiple pathways

Tad Dallas & John M. Drake

Odum School of Ecology, University of Georgia, Athens, Georgia 30606 – 4280

Freshwater Biology
Freshwater Biology (2015) **60**, 1525–1536 doi:10.1111/fwb.12585

Strong impact of nitrogen loading on submerged macrophytes and algae: a long-term mesocosm experiment in a shallow Chinese lake

SAARA OLSEN*,†, FENGYI CHAN‡, WEI LI†,‡, SUTING ZHAO‡, MARTIN SØNDERGAARD* AND ERIK JEPPESEN*,†
*Department of Bioscience, Aarhus University, Silkeborg, Denmark
†Sino-Danish Centre for Education and Research (SDC), University of Chinese Academy of Sciences (UCAS), Beijing, China
‡Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan, China

☞ Modified zeolites (aluminosilicate "molecular sieves")

Chemical Engineering Journal 271 (2015) 204–213

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Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Simultaneous phosphate and ammonium removal from aqueous solution by a hydrated aluminum oxide modified natural zeolite

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Journal of Hazardous Materials

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Comparative sorption kinetic studies of ammonium onto zeolite

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Removal of low concentration nutrients in hydroponic wetlands integrated with zeolite and calcium silicate hydrate functional substrates

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Ammonium removal from water by natural and modified zeolite: kinetic, equilibrium, and thermodynamic studies

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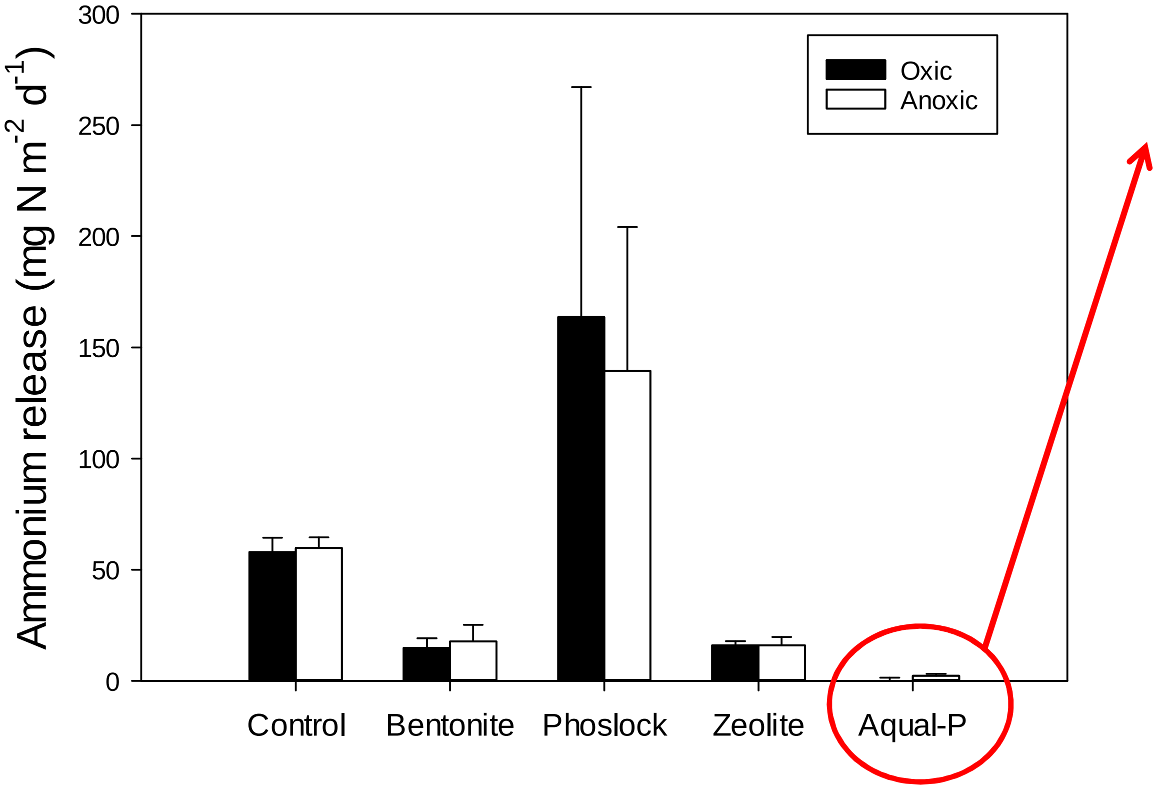
LAKE RESTORATION

Effects of a modified zeolite on P and N processes and fluxes across the lake sediment–water interface using core incubations

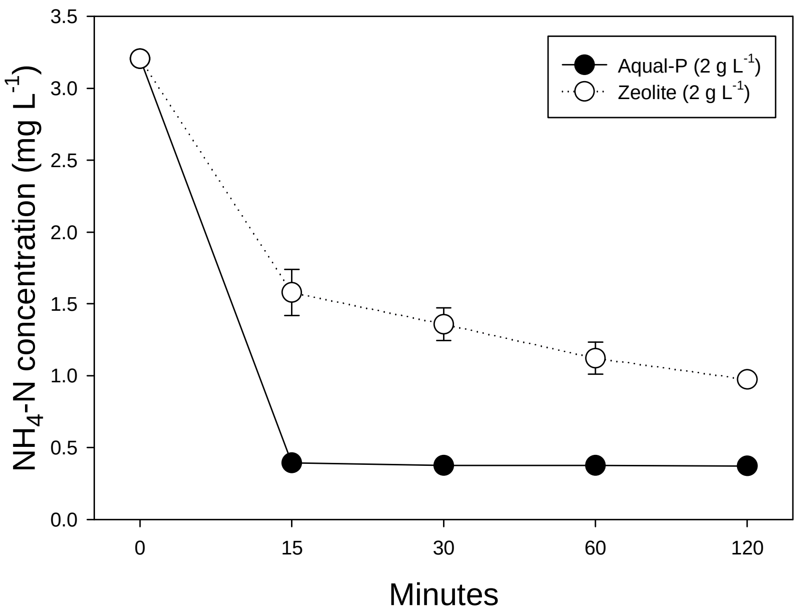
Max Gibbs · Deniz Özkundakci



NH_4-N release from sediment can be blocked

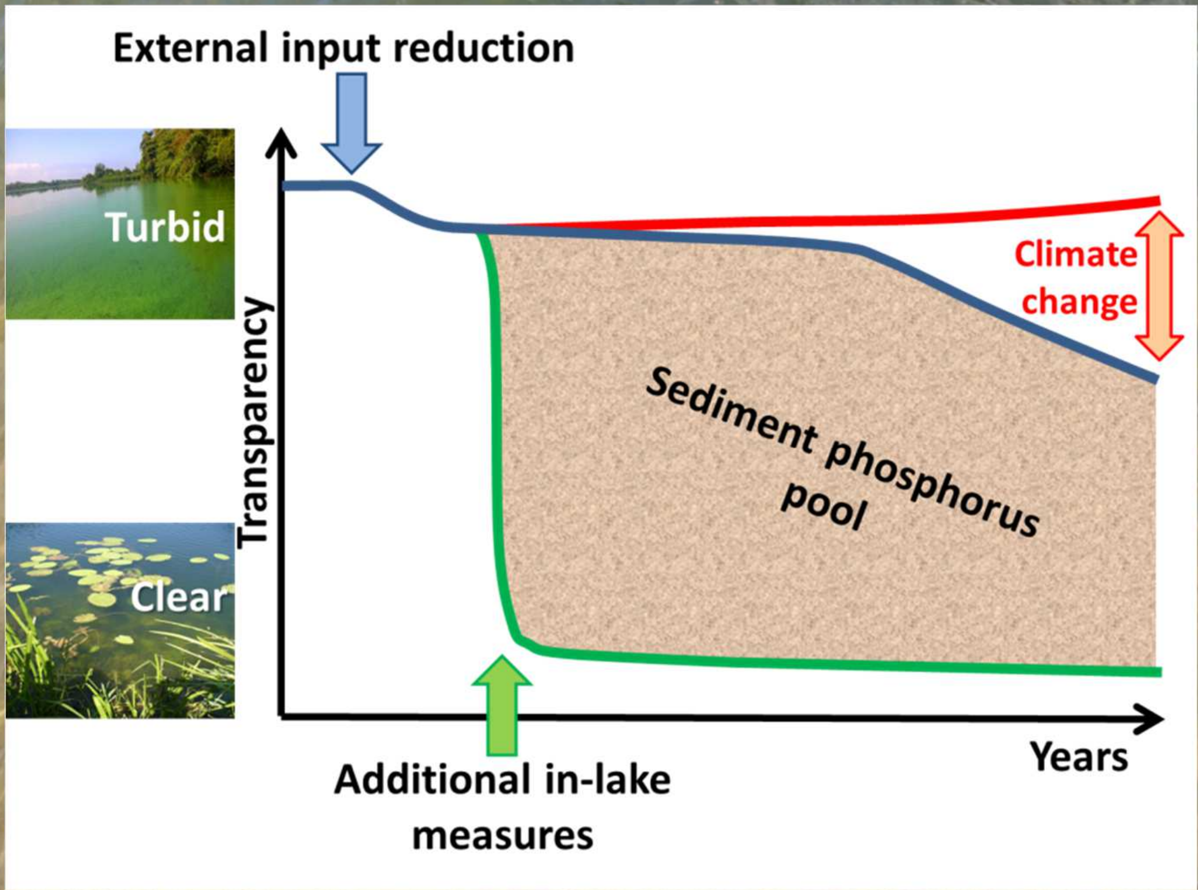
Aqual-P adsorbs up to 300 mg NH_4-N m^{-2} d^{-1}

Gibbs & Ozkundakci 2011
Hydrobiologia 661:21–35



Dual control of NH_4 and PO_4 in water and release from sediment seems possible → More research

Mitigation should always start with a system analysis



Scenarios:

☹ Doing nothing

😐 Curative measures
= fighting the symptoms
→ Flock & Sink 👍
→ Algaecides 👎

☺ Preventive measures
= tackling nutrient fluxes
→ External/internal

☺ Combined measures
= speeding up recovery

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Upcoming Special Issue in Water Research on Geo-engineering for the control of eutrophication in lakes

Eds. M. Lurling, E. Mackay, K. Reitzel, B.M. Spears

Management of eutrophication in Lake De Kuil (The Netherlands) using combined flocculant – Lanthanum modified bentonite treatment

Water Research xxx (2015) 1–11

Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

Influence of dissolved organic carbon on the efficiency of P sequestration by a lanthanum modified clay

Line Dithmer [a,b], Ulla Gro Nielsen [a], Daniel Lundberg [c], Kasper Reitzel [b,*]

Water Research xxx (2015) 1–5

Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

A meta-analysis of water quality and aquatic macrophyte responses in 18 lakes treated with lanthanum modified bentonite (Phoslock®)

Bryan M. Spears [a,*], Eleanor B. Mackay [b], Said Yasseri [c], Iain D.M. Gunn [a], Kate E. Waters [a], Christopher Andrews [a], Stephanie Cole [d], Mitzi De Ville [b], Andrea Kelly [e], Sebastian Meis [a,f], Alanna L. Moore [a], Gertrud K. Nürnberg [g], Frank van Oosterhout [h], Jo-Anne Pitt [i], Genevieve Madgwick [j], Helen J. Woods [a], Miquel Lürling [h,k]

Water Research xxx (2015) 1–11

Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

Analysis of the La:P ratio in lake sediments – Vertical and spatial distribution assessed by a multiple-core survey

Said Yasseri*, Tim S. Epe

Water Research xxx (2015) 1–7

Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

Longevity and effectiveness of aluminum addition to reduce sediment phosphorus release and restore lake water quality

Brian J. Huser [a,*], Sara Egemose [b], Harvey Harper [c], Michael Hupfer [d], Henning Jensen [b], Keith M. Pilgrim [e], Kasper Reitzel [b], Emil Rydin [f], Martyn Futter [a]

Water Research xxx (2015) 1–9

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/watres

Removal of *Microcystis aeruginosa* using cationic starch modified soils

Wenqing Shi [a], Wanqiao Tan [a,b], Lijing Wang [a], Gang Pan [a,*]

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Water Research xxx (2015) 1–9

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/watres

In-lake measures for phosphorus control: The most feasible and cost-effective solution for long-term management of water quality in urban lakes

Brian J. Huser [a,*], Martyn Futter [a], Jeff T. Lee [b], Mike Perniel [c]

Water Research xxx (2015) 1–11

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/watres

Long-term efficiency of lake restoration by chemical phosphorus precipitation: Scenario analysis with a phosphorus balance model

Michael Hupfer [a,*], Kasper Reitzel [b], Andreas Kleeberg [a,1], Jörg Lewandowski [a]

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Ecotoxicological assessment of flocculant modified soil for lake restoration using an integrated biotic toxicity index

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Thank you !
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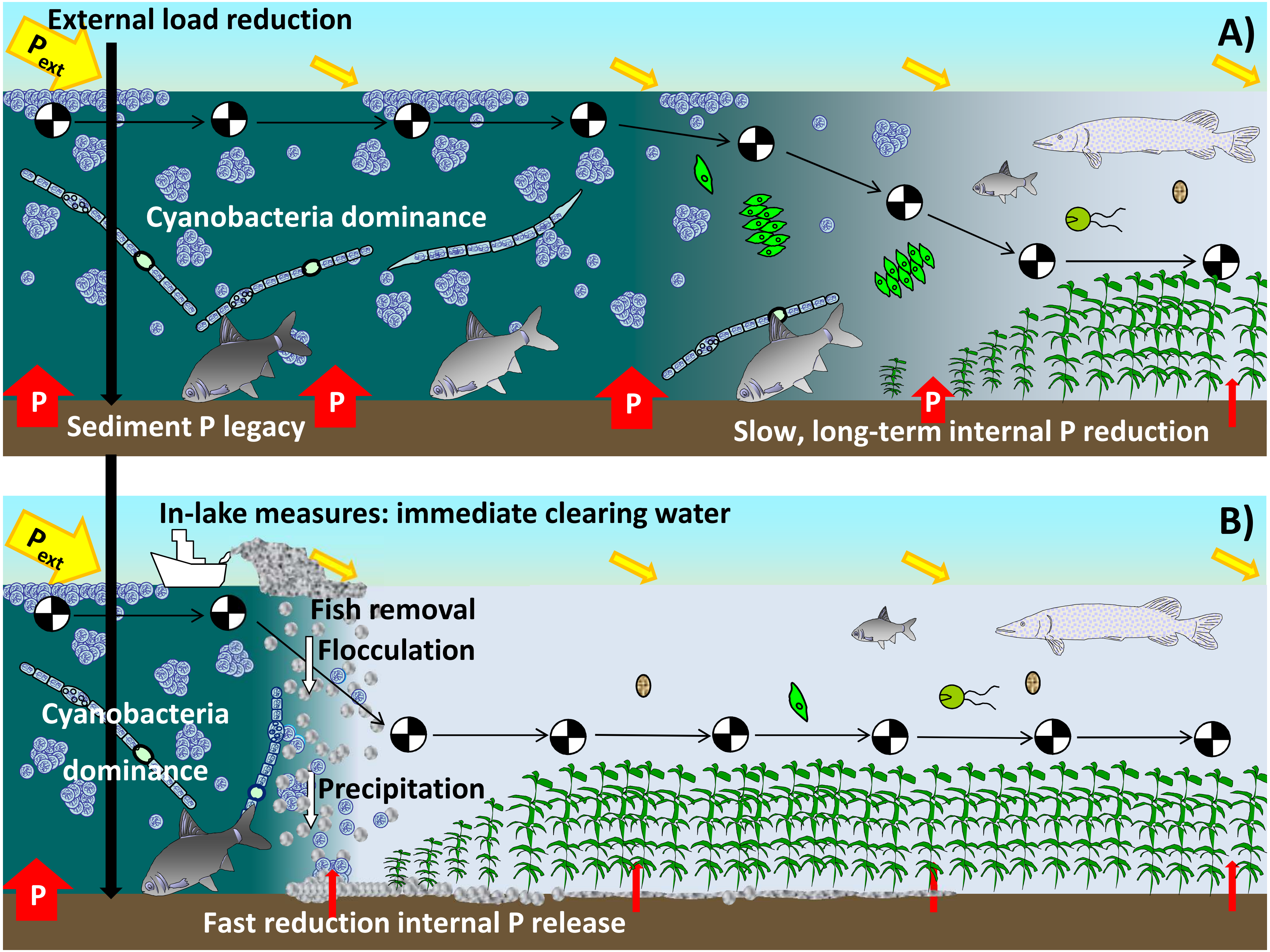
External load reduction
A)
P ext
Cyanobacteria dominance
Sediment P legacy
P
Slow, long-term internal P reduction
In-lake measures: immediate clearing water
B)
Fish removal
Flocculation
Cyanobacteria
dominance
Precipitation
Fast reduction internal P release

Diagnosis = System analysis: - water and nutrient balance
- actual/critical/expected loading
- biological make-up