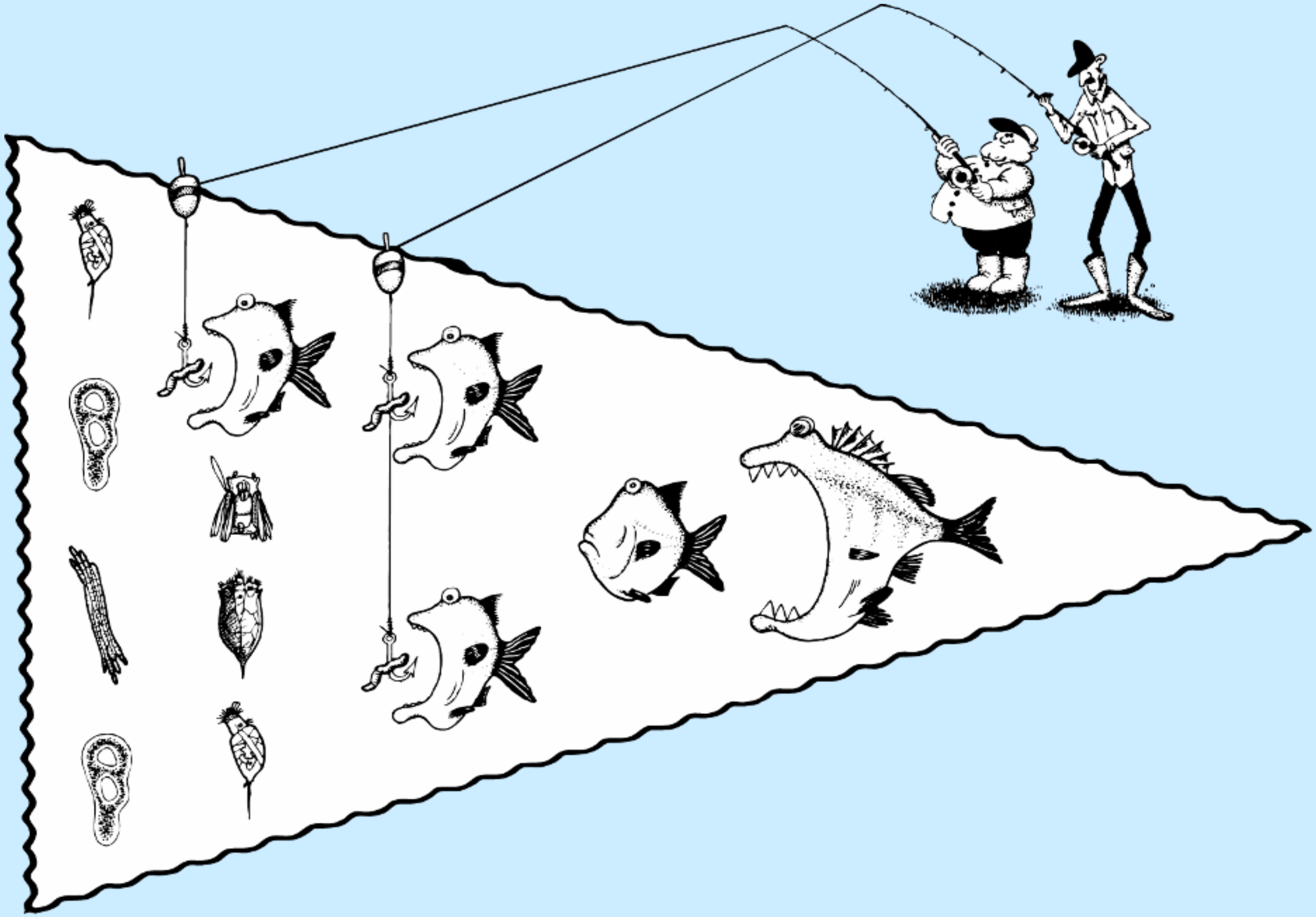
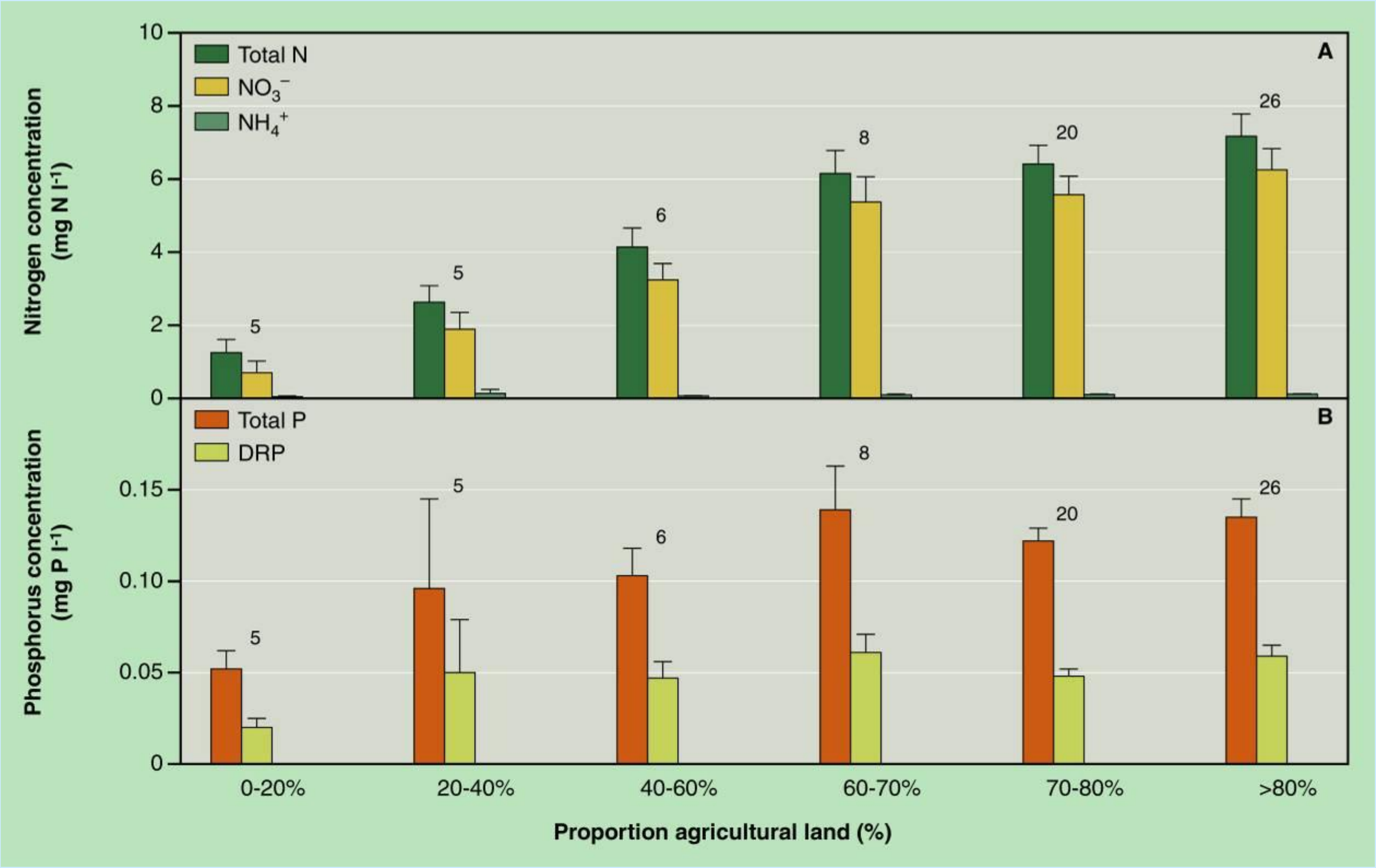
Lake restoration by biomanipulation



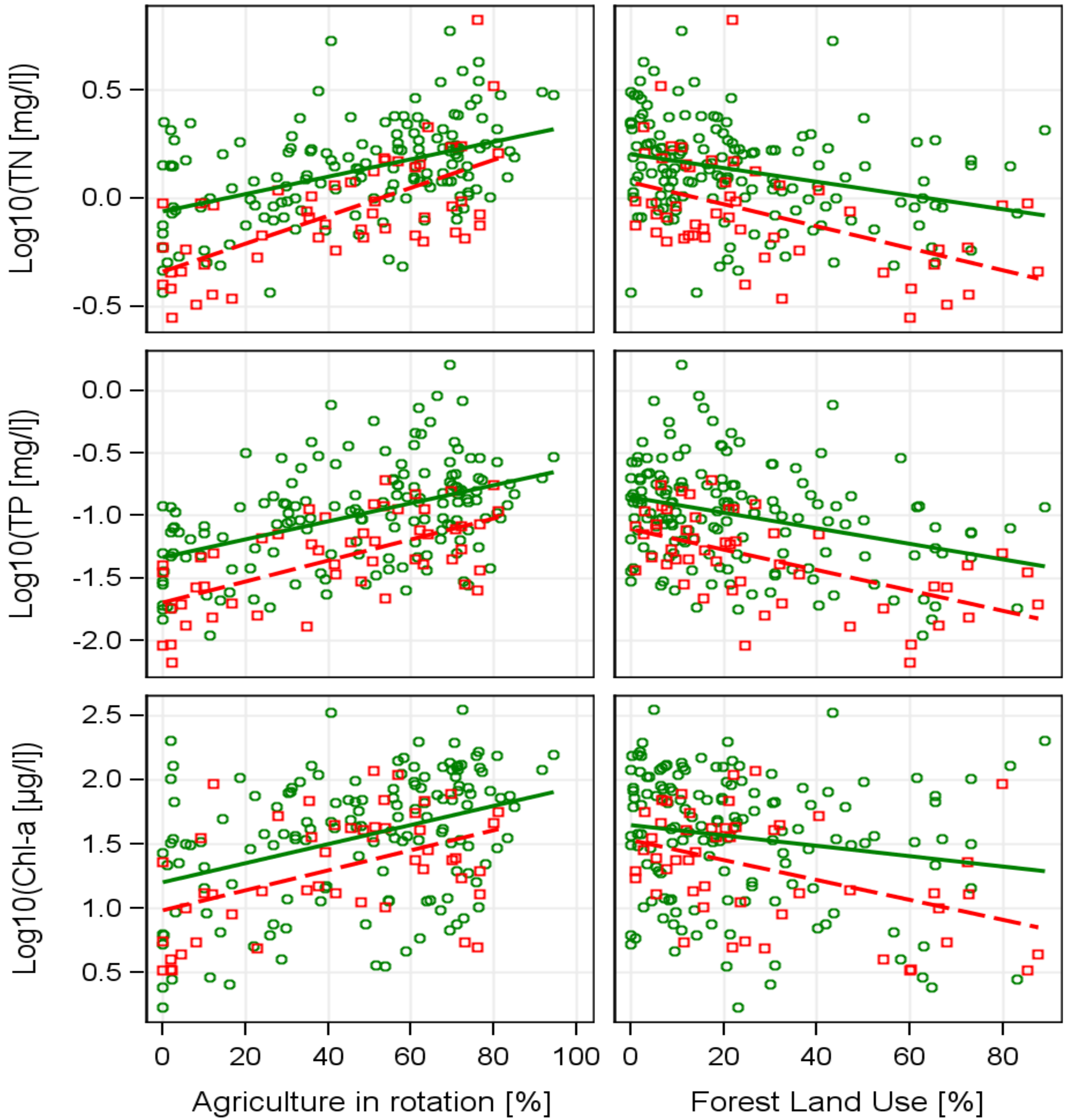
Diffuse pollution a hot topic in DK !

5 mill. people (great sewage treatment) and 20 mill. pigs and cattle, walking around even without any underpants!!!!!

Nitrogen and phosphorus loading depend on catchment type (Danish lakes)



Jeppesen et al, 1999



Shallow

Deep

Nielsen et al, 2011

Action folks!!!!

Reduce the external nutrient loading!

Cities or farmers
The bad guys??

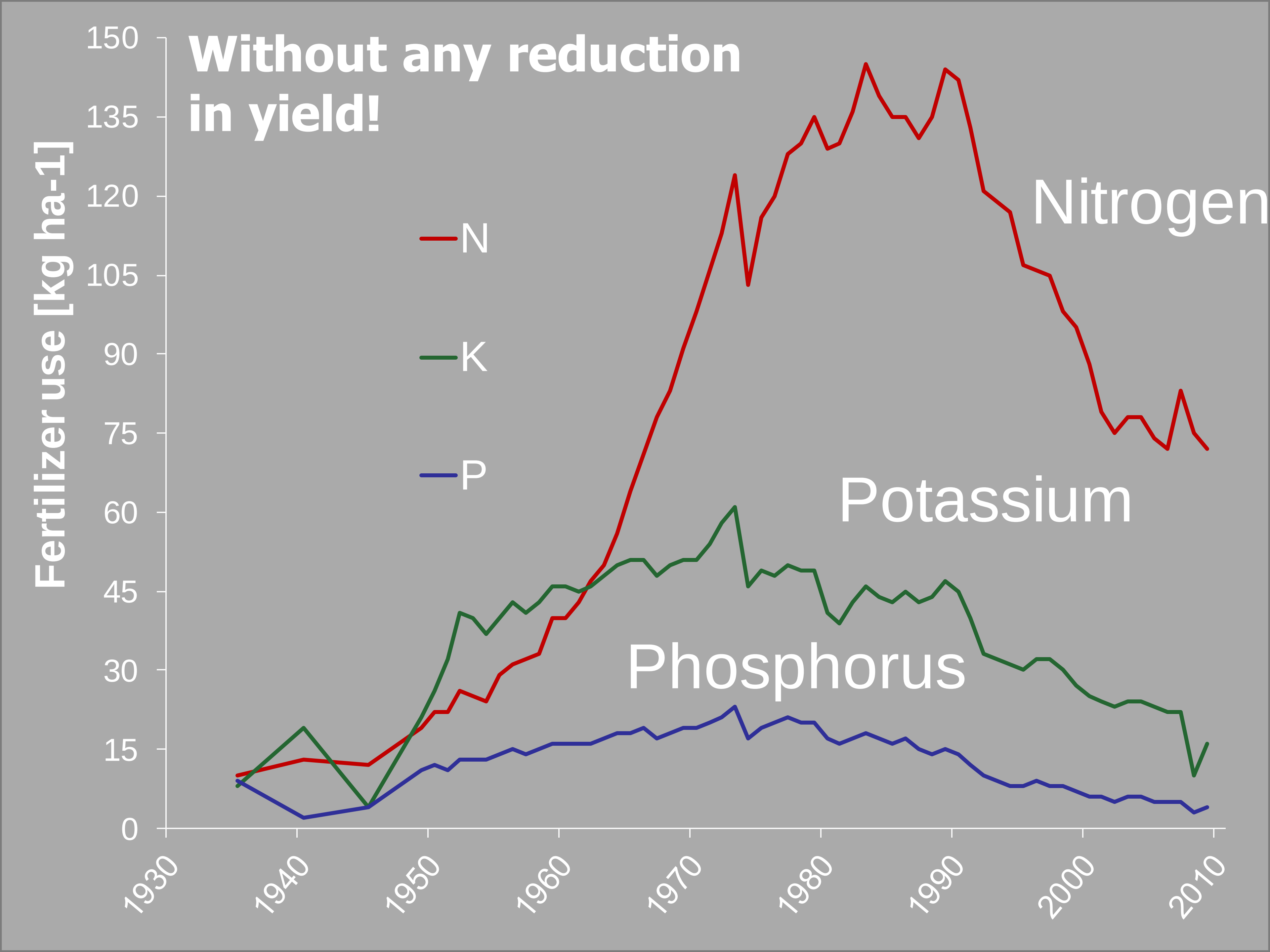
Danish Action Plans

Action Plan for Sustainable Agriculture, 1991 and 1996.

Action Plan for the Aquatic Environment II - 1998

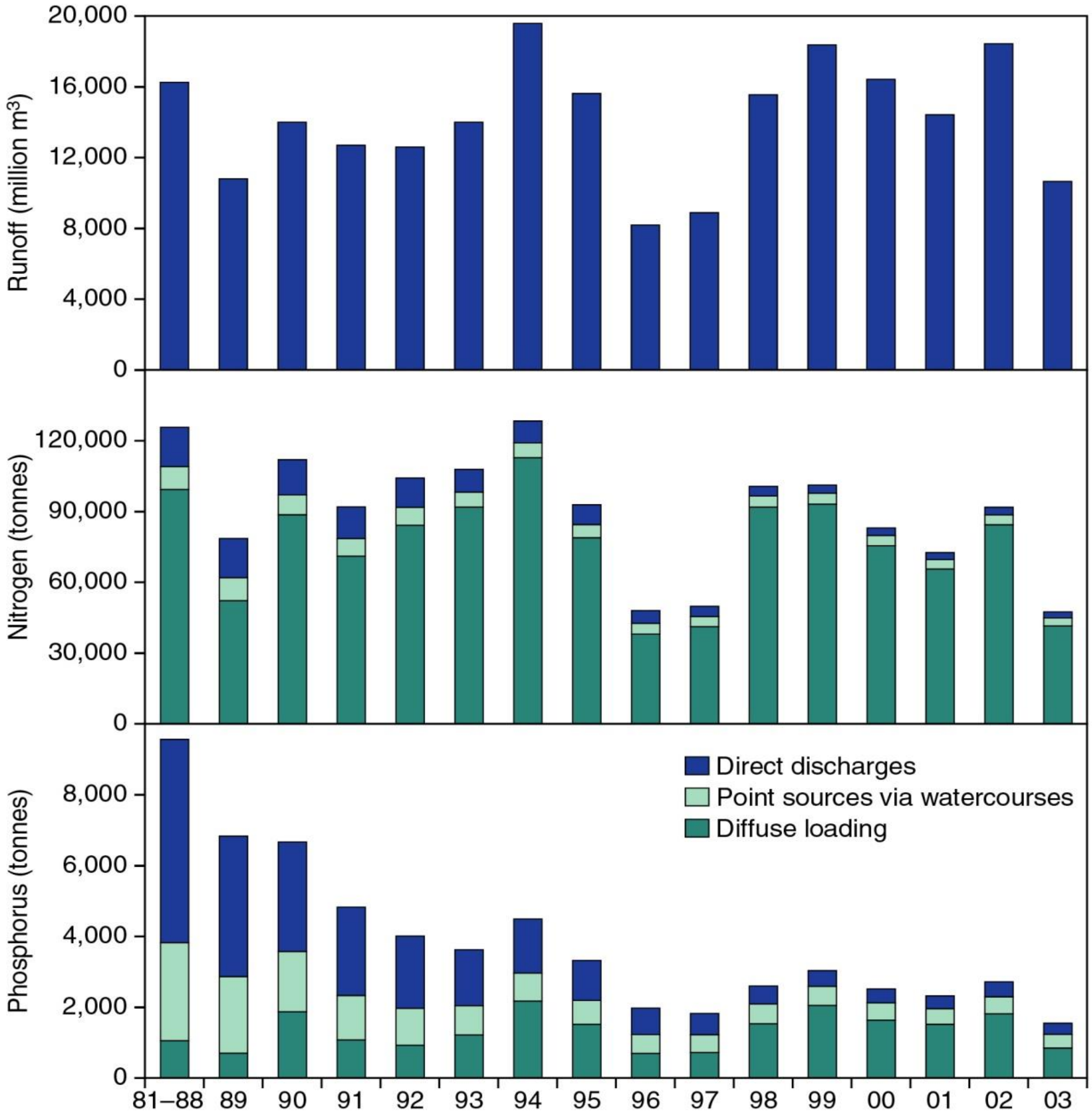
Action Plan for the Aquatic Environment III – 2004

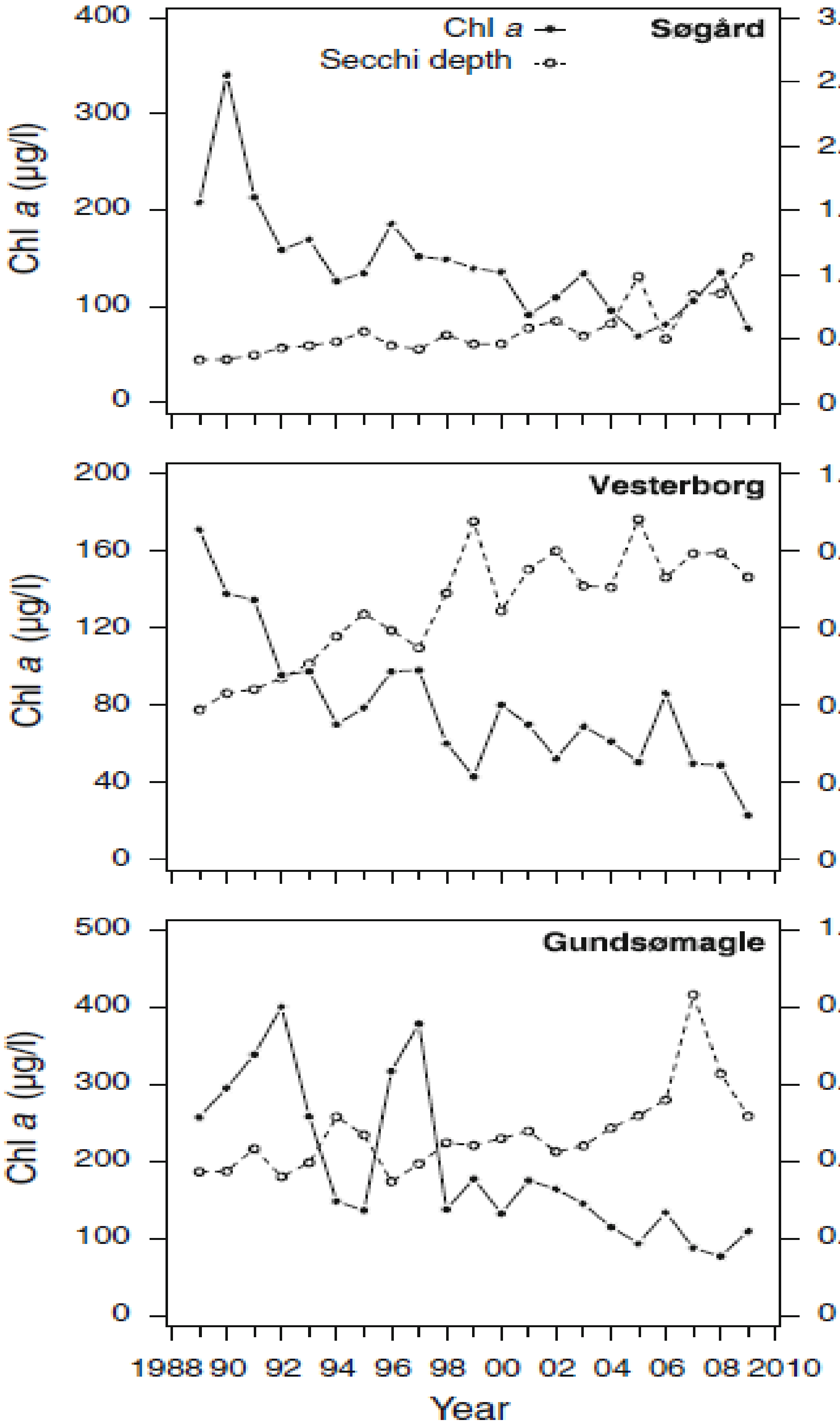
Water Framework Directive – 2009-2015



Without any reduction in yield!
Fertilizer use [kg ha-1]
150
135
120
105
90
75
60
45
30
15
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
N
K
P
Nitrogen
Potassium
Phosphorus

Sources of nitrogen and phosphorus in surface waters Mid 1980's to 2003



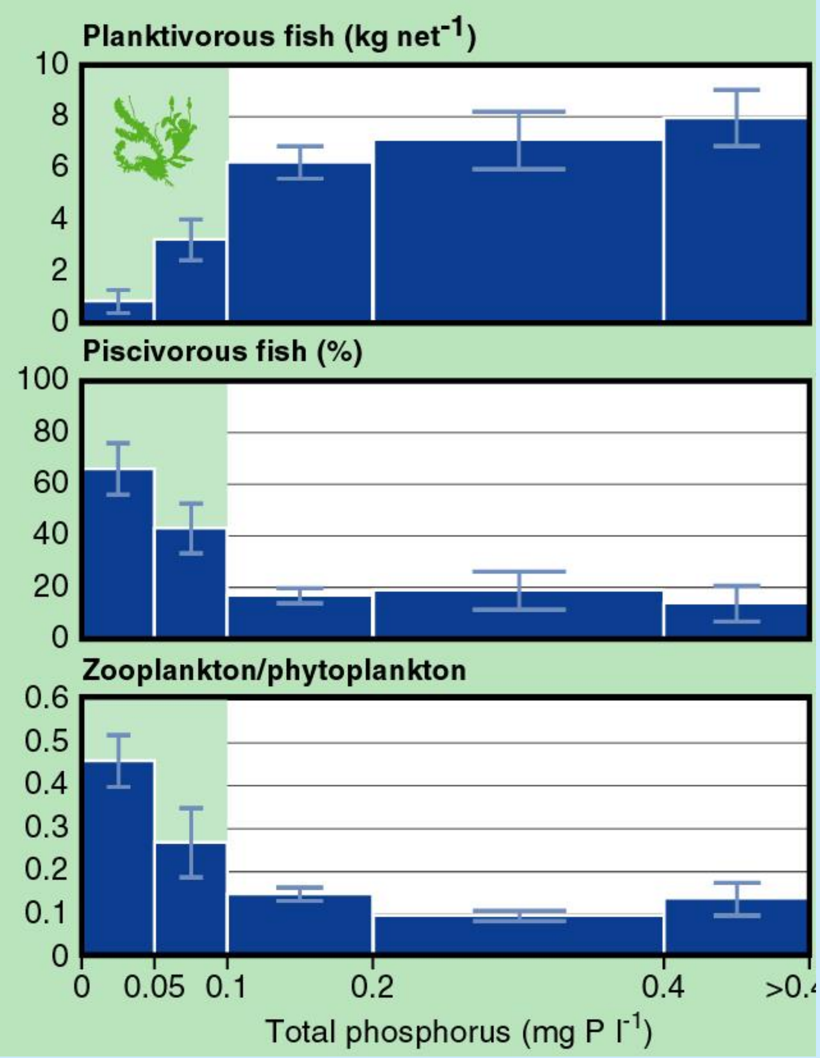


Algal biomass has declined and transparency increased markedly in most of the lakes

Enhanced bottom-up Control AND enhanced top-down control of phytoplankton

Søndergaard et al, 2013

Changes in fish community along a TP gradient

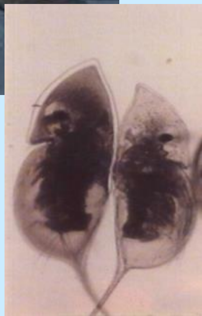


Jeppesen et al,2000

More bad guys when macrophyte disappear

"Good guys" (piscivores)

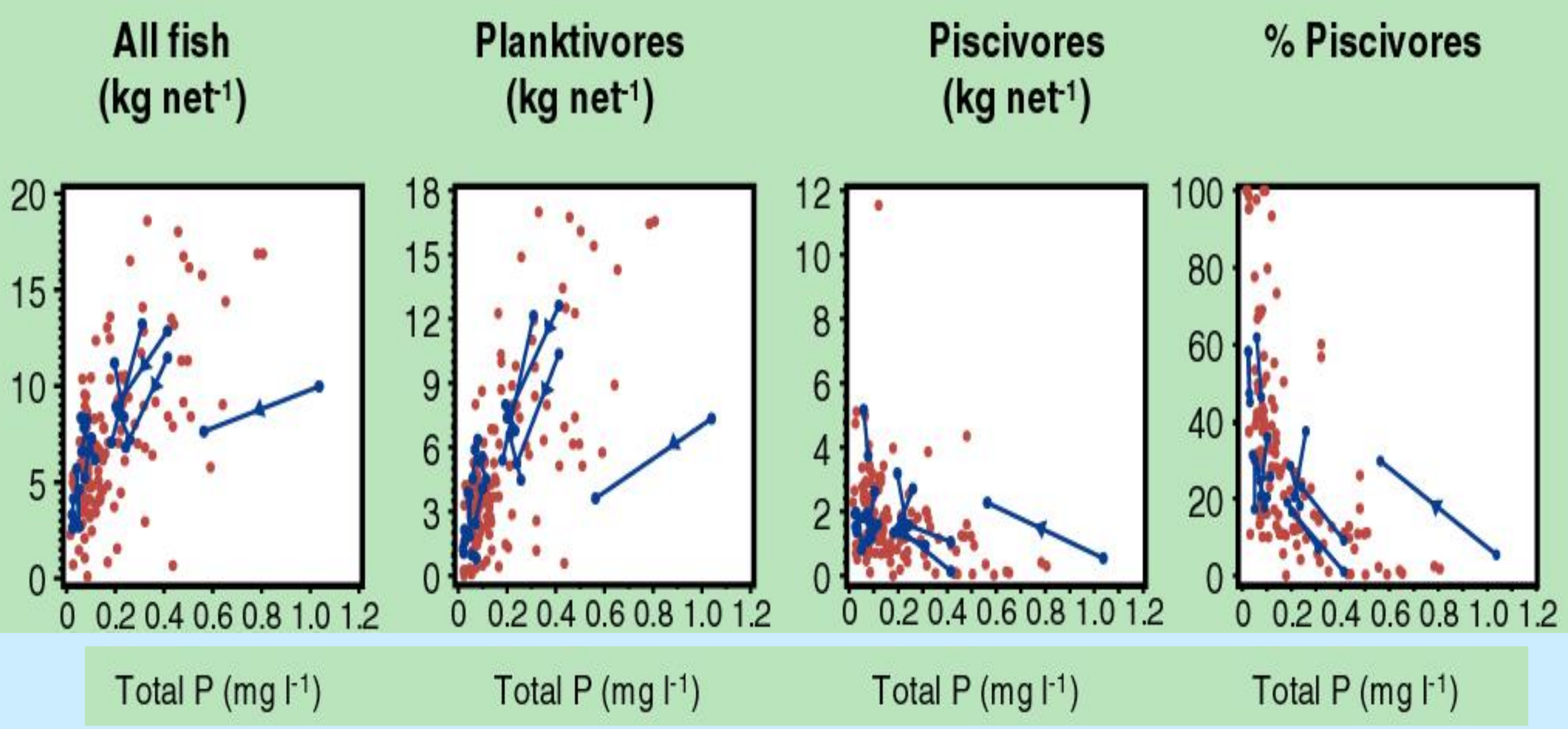
"Bad guys" (zooplanktivores)



carp-bad guy
good guy

Surveys of Danish lakes

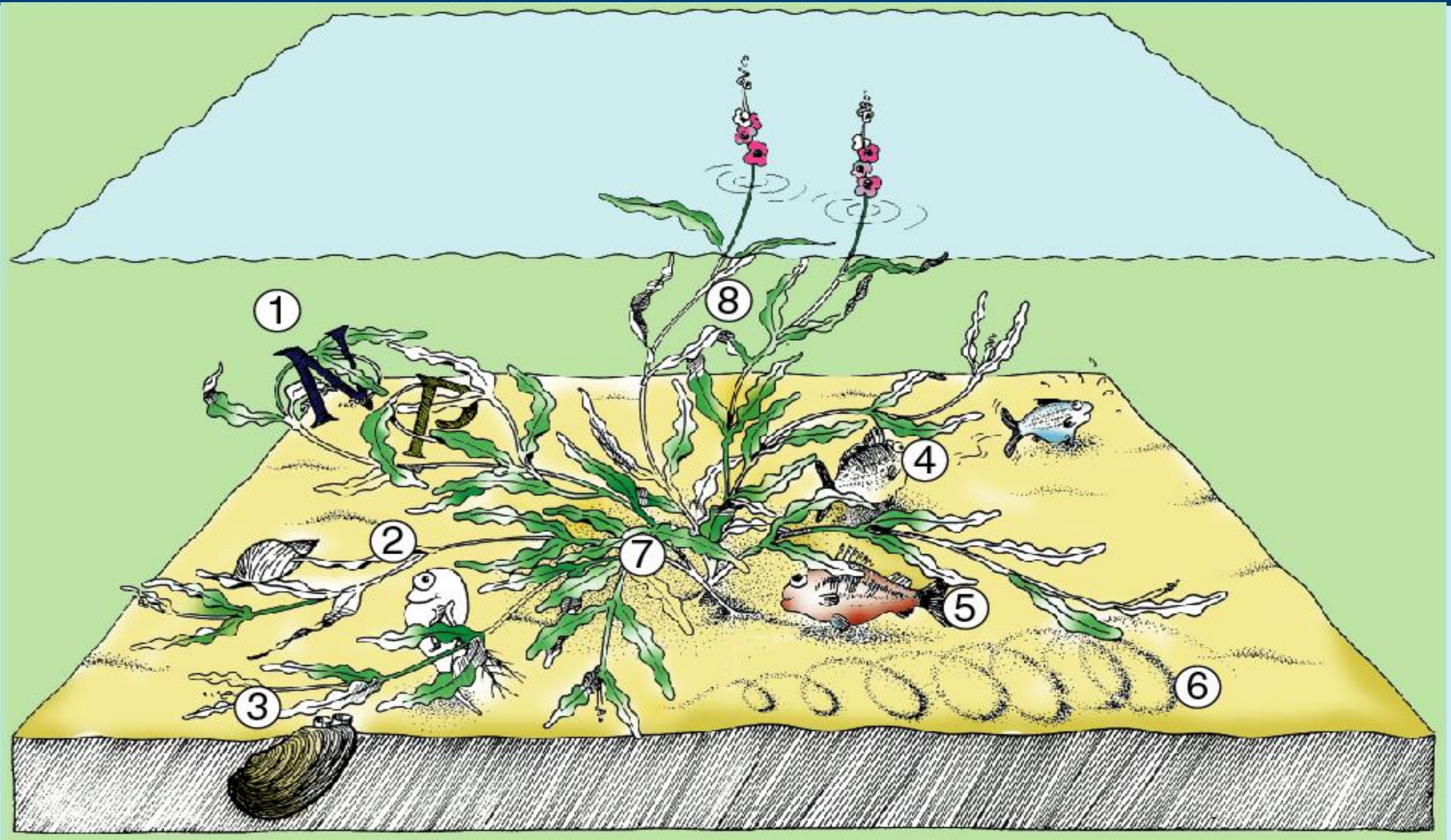
bad guys **good guys**



within 5 years!

Turbid

Submerged macrophytes and lake ecosystems

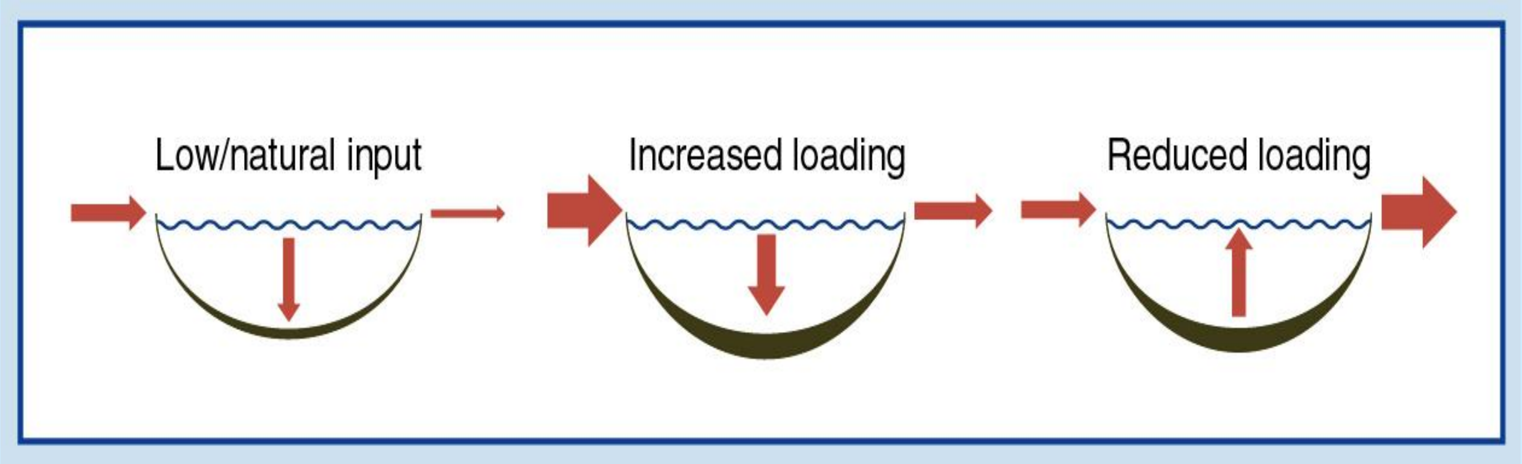


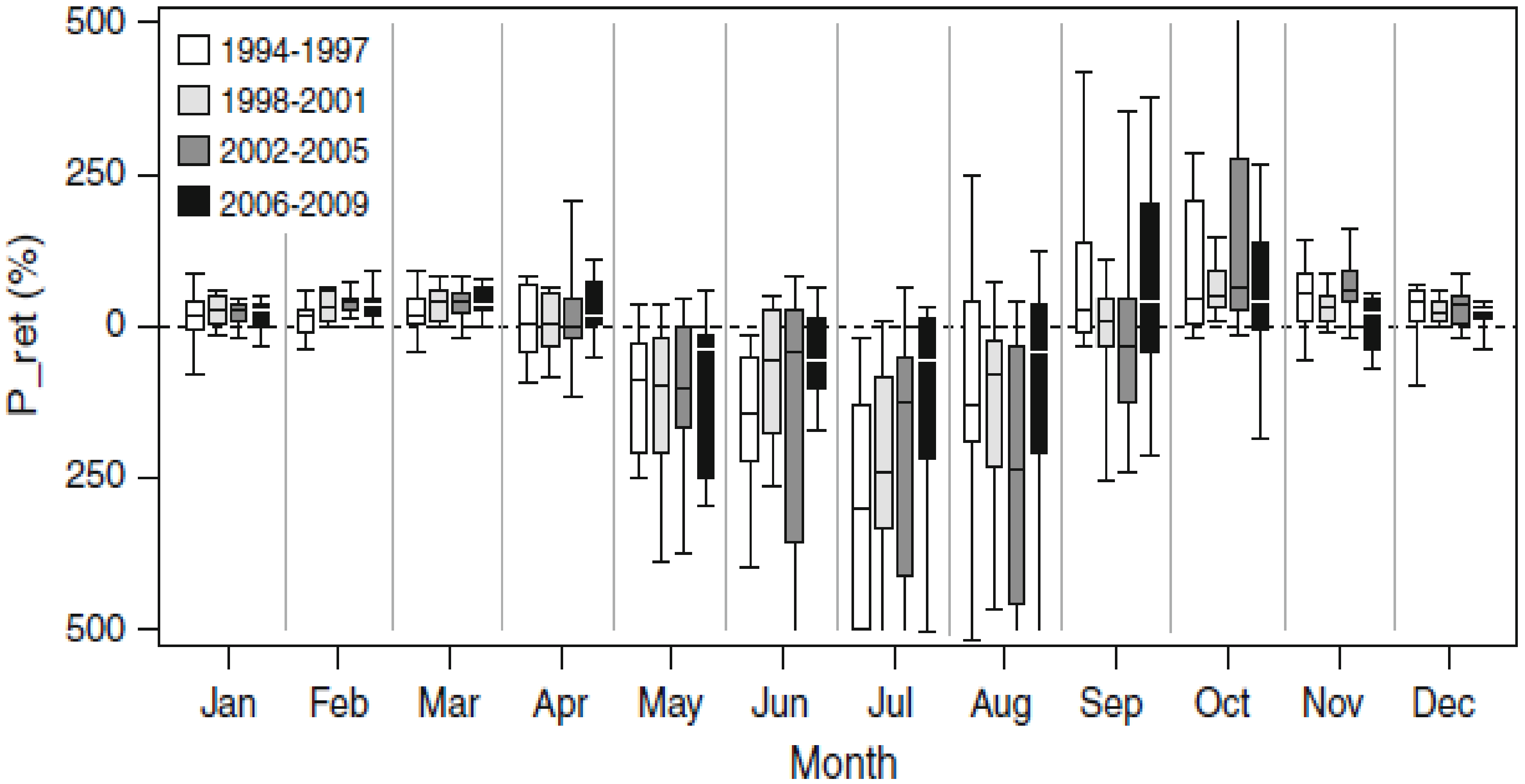
1. Remove nutrients for growth
2. Refuges for zooplankton
3. Improve conditions for macro filtrators
4. Favourize small perch over small roach
5. Refuges for small perch and small pikes
6. Stabilize sediment, reduce resuspension
7. Enchance denitrification
8. May have allelopathic effects

Why slow recovery of lakes

- Chemical based delay
  - Internal loading, accumulated phosphorus in the sediment

Chemical resistance may delay lake recovery





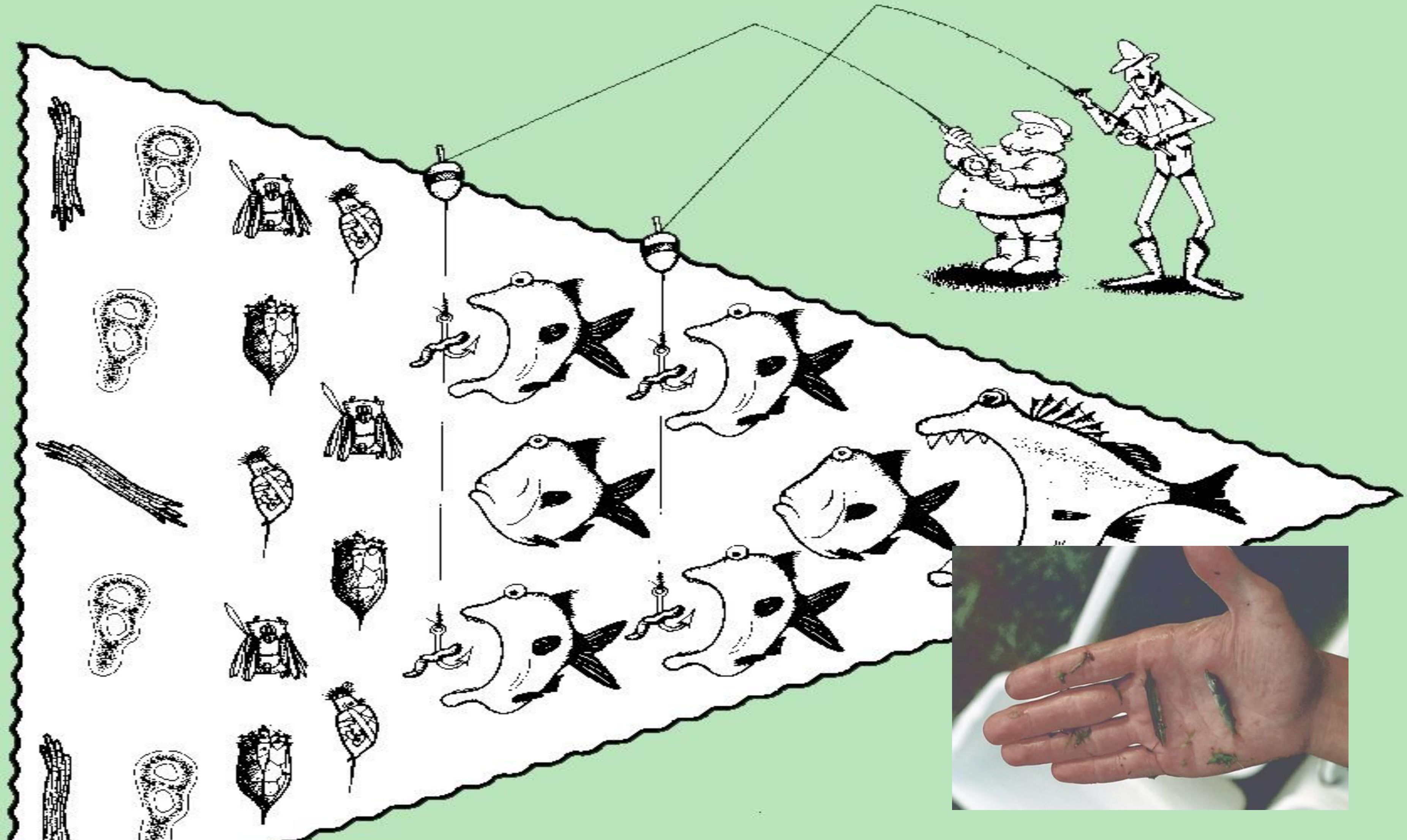
Mass balances show persistent high internal P loading in summer

Søndergaard et al, 2013

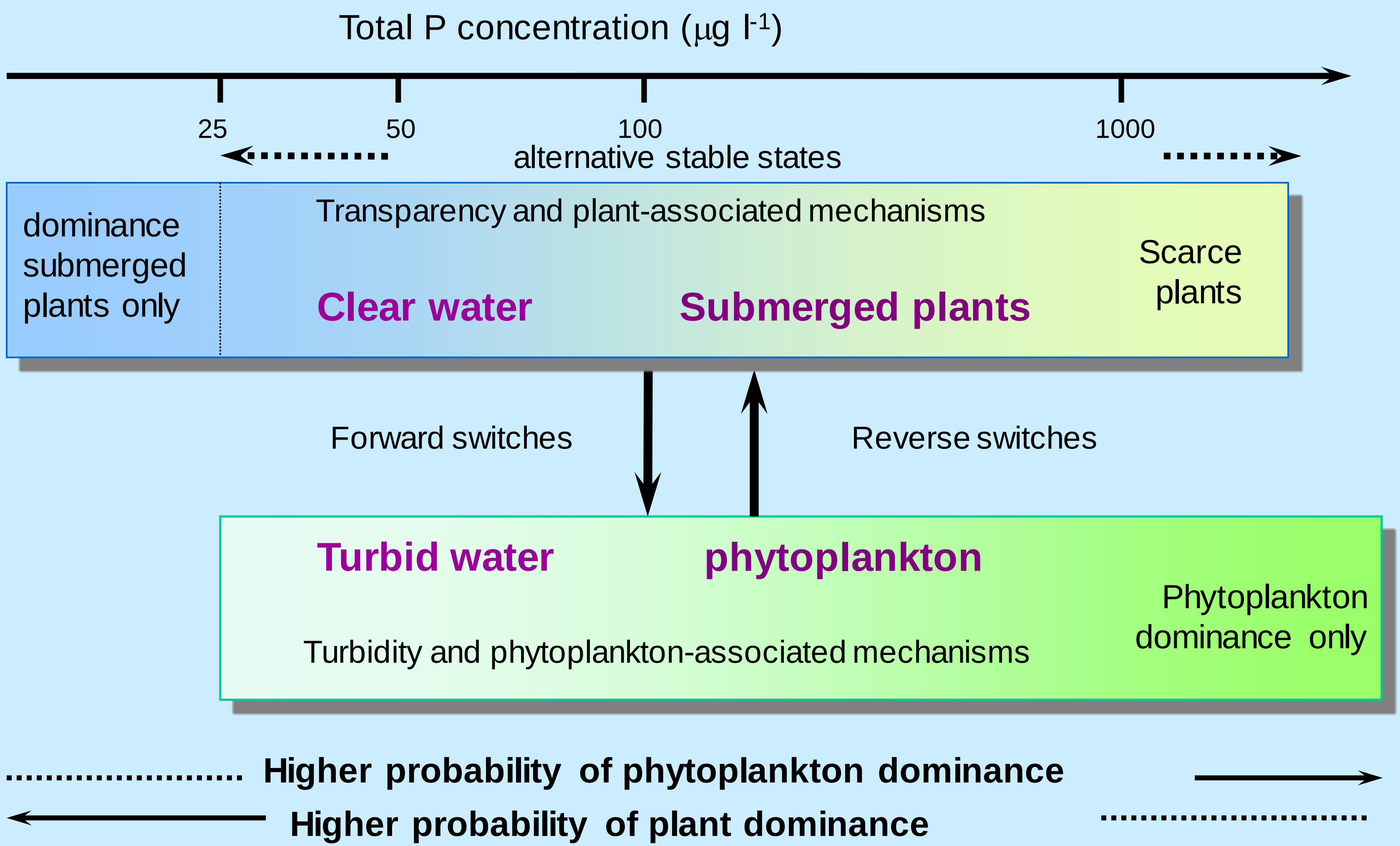
Why slow recovery of lakes

- Biological based delay
  - fish stock dominated by plankti-benthivorous species leading to low grazing control on phytoplankton and higher resuspension
  - submerged macrophytes delayed in recovery due to lack of seed bank, waterfowl grazing, etc.

Biomanipulation is for thick and thin



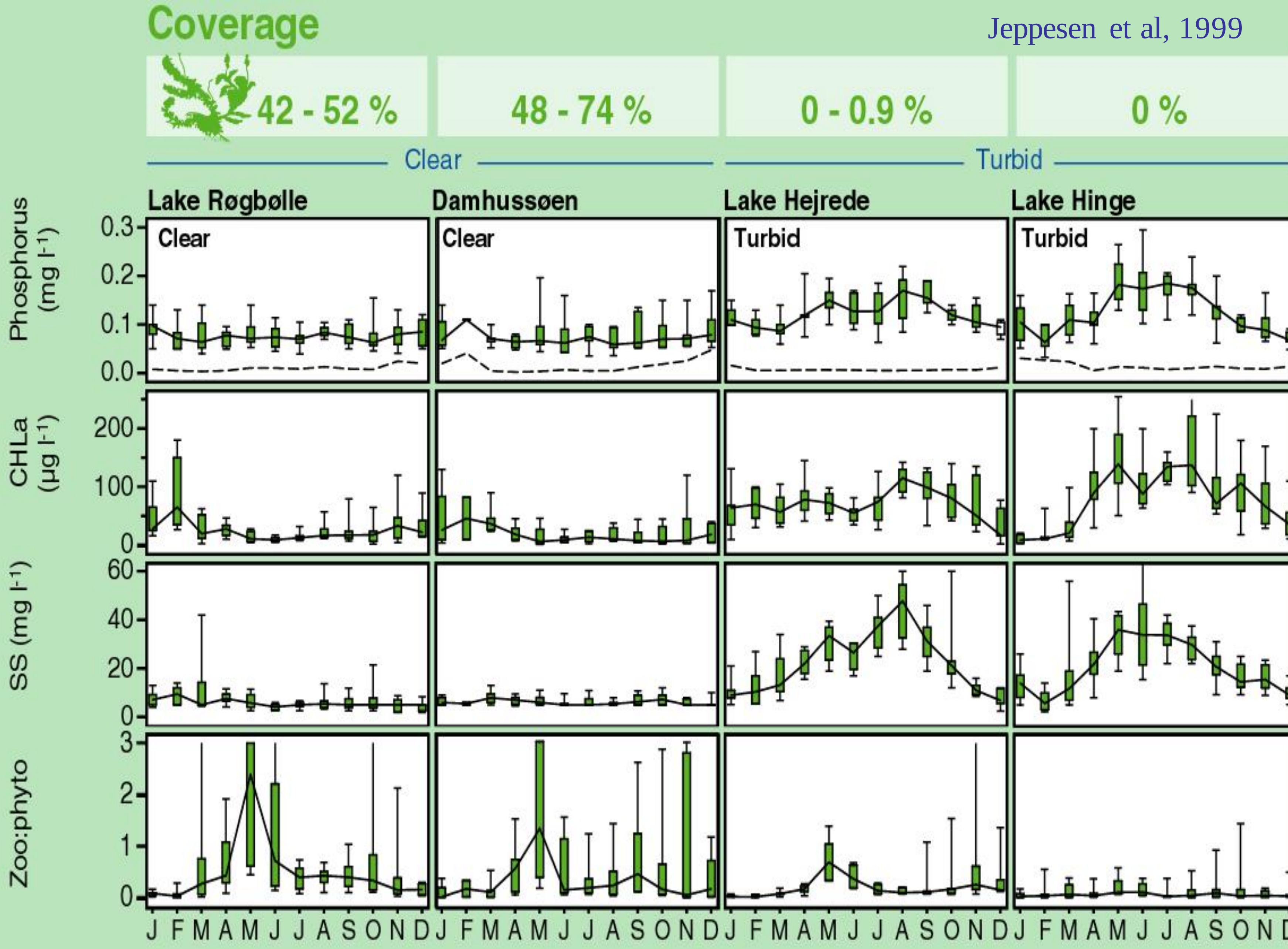
Alternative Stable States Hypothesis



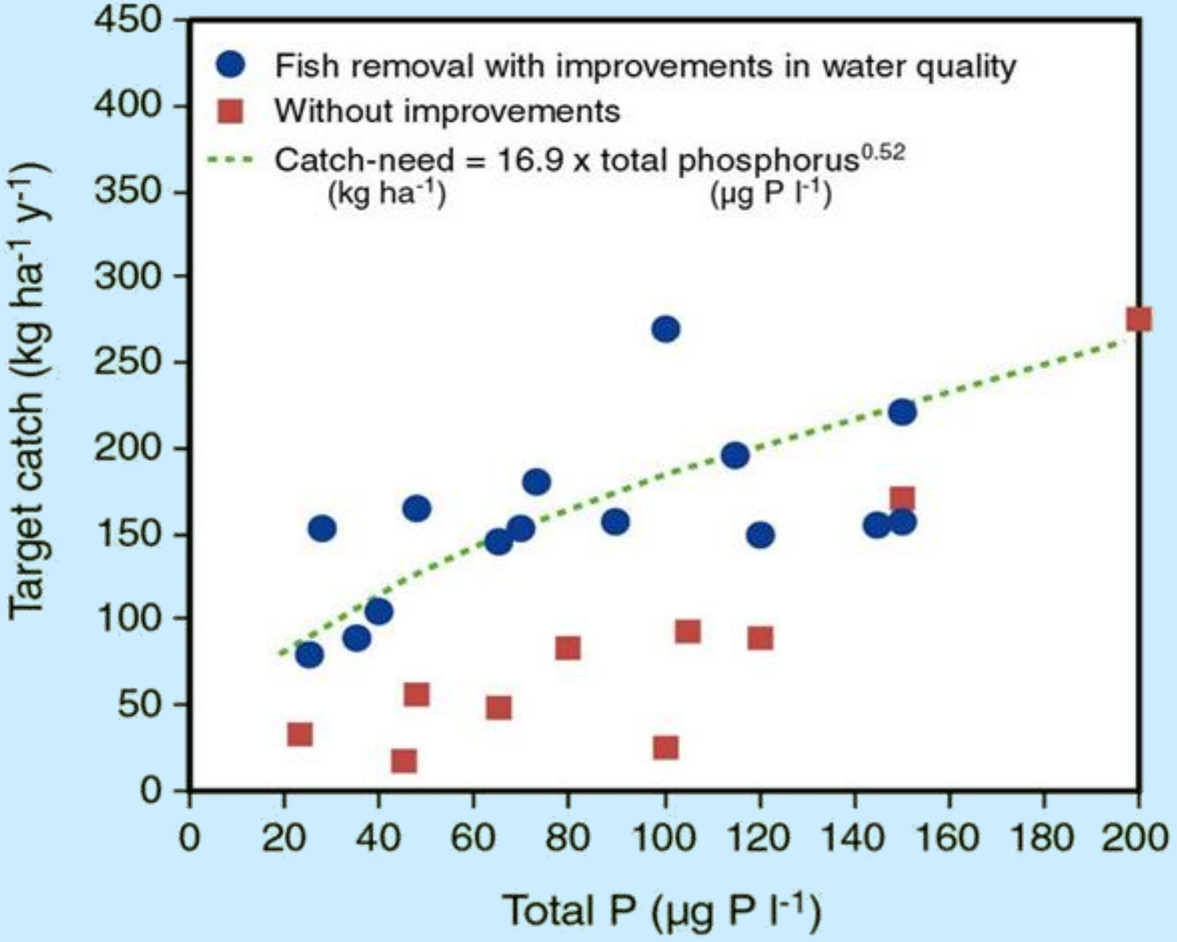
from Moss et al. (1996)

Example from Denmark

Jeppesen et al, 1999



How many fish should be removed relative to phosphorus ?



(Jeppesen & Sammalkorpi,

Trawling

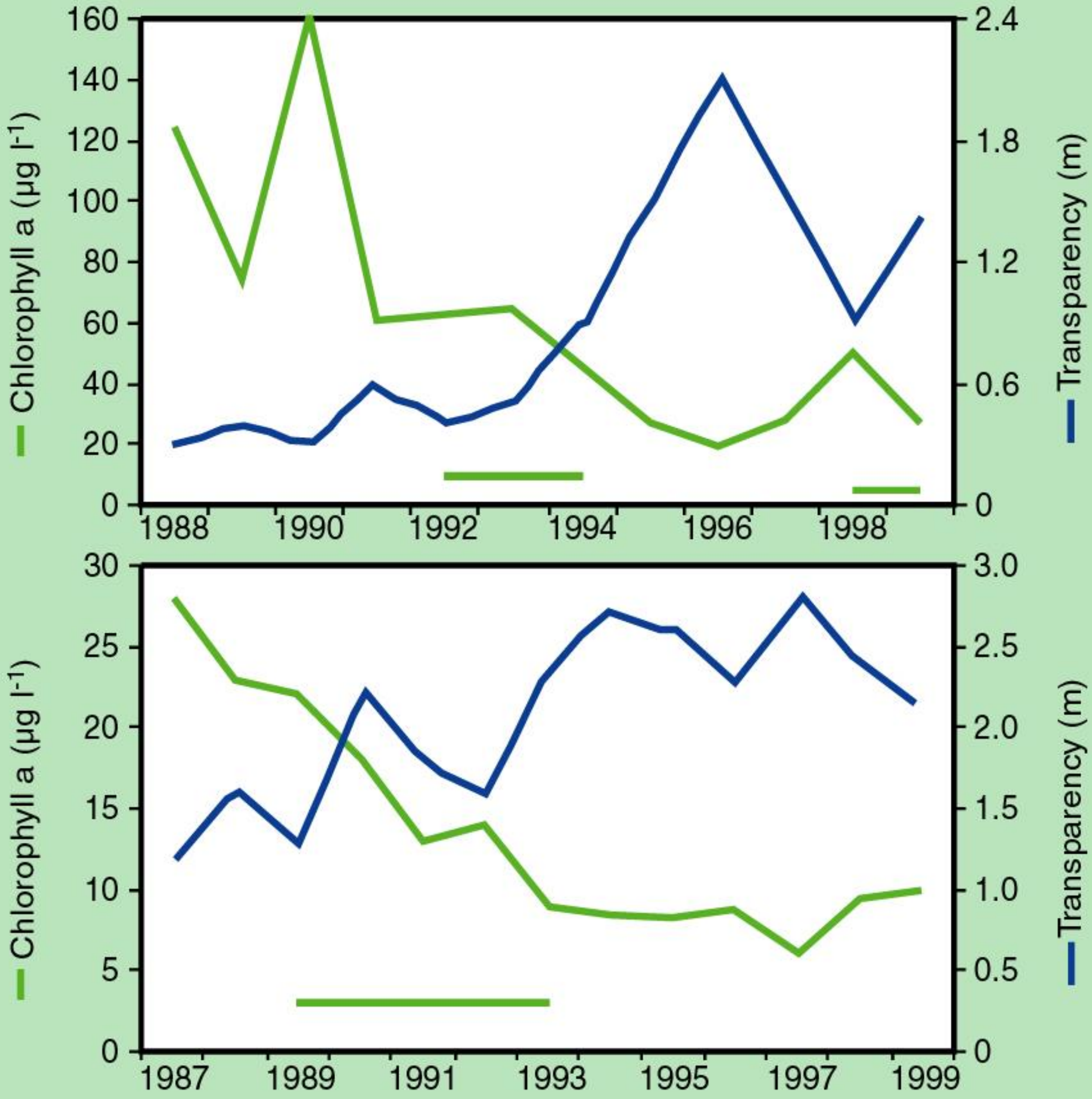

Fiskeøkologisk Laboratorium
Fiskeøkologisk Laboratorium

Biomanipulation: methods

What has been achieved ?

Lake restoration by removing fish

Examples of effects of fish removed



Lake Finjasjön, Sweden

Area	11 km^2
Max. depth	11 m
Mean depth	3 m
Retention time	0.25 years

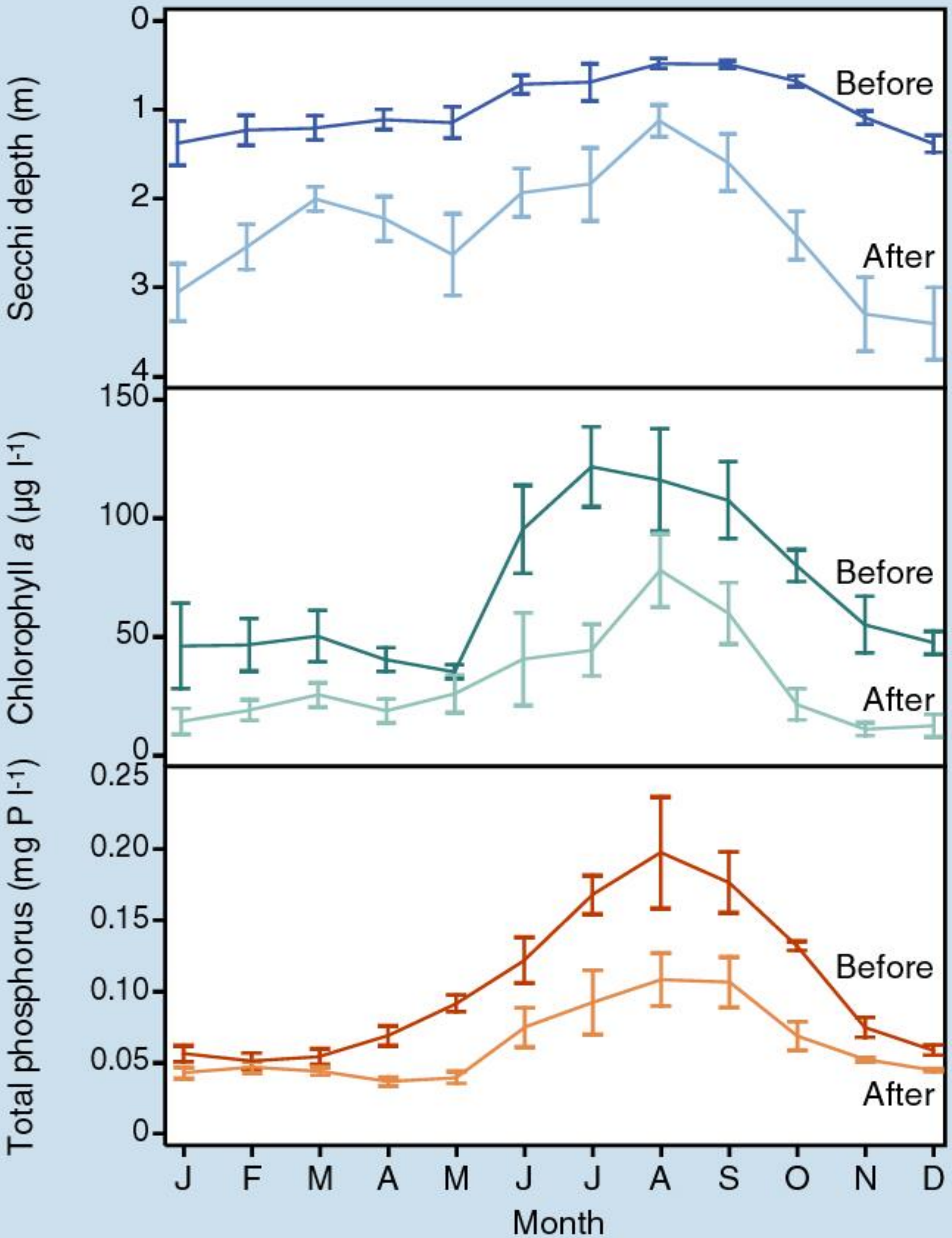
(Annadotter *et al.* 1999)
(Nilsson, 1999 and unpubl.)

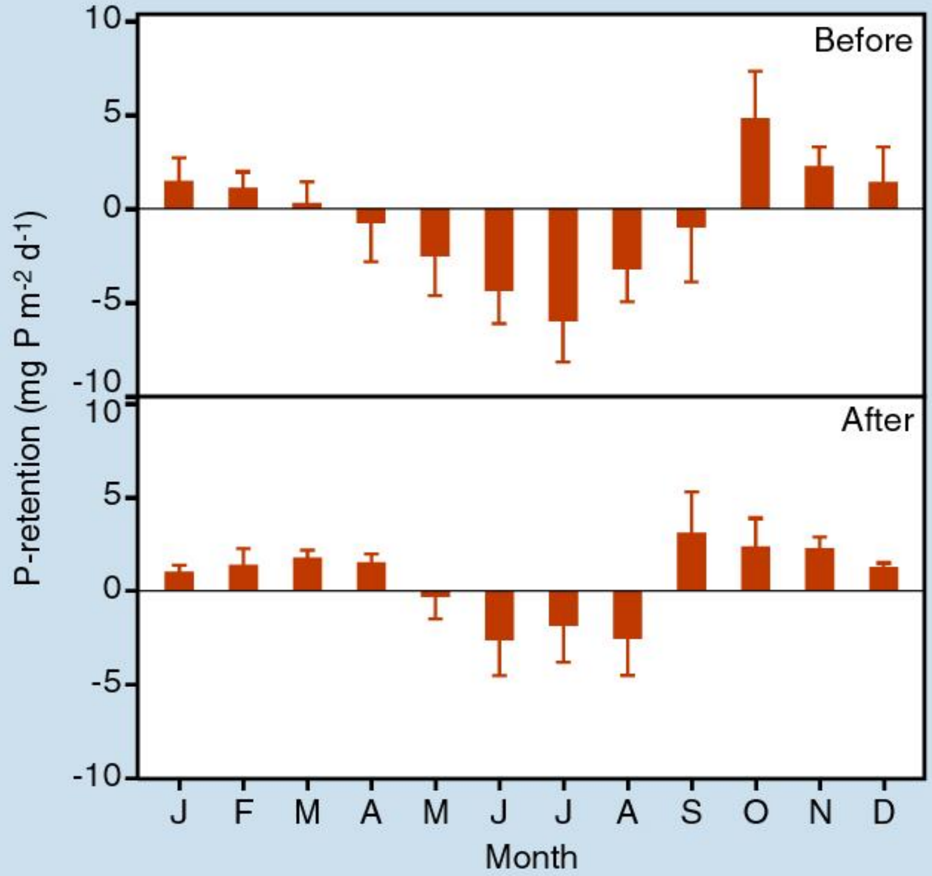
Lake Vesijärvi, Finland

Area	110 km^2
Max. depth	42 m
Mean depth	6 m
Retention time	5.4 years

(Keto & Sammalkorpi, 1998)
(Horppila *et al.* 1998, Peltonen *et al.* 1999)

Lake Engelsholm





Before: 1989-93

After: 1994-1999

Lake Engelsholm

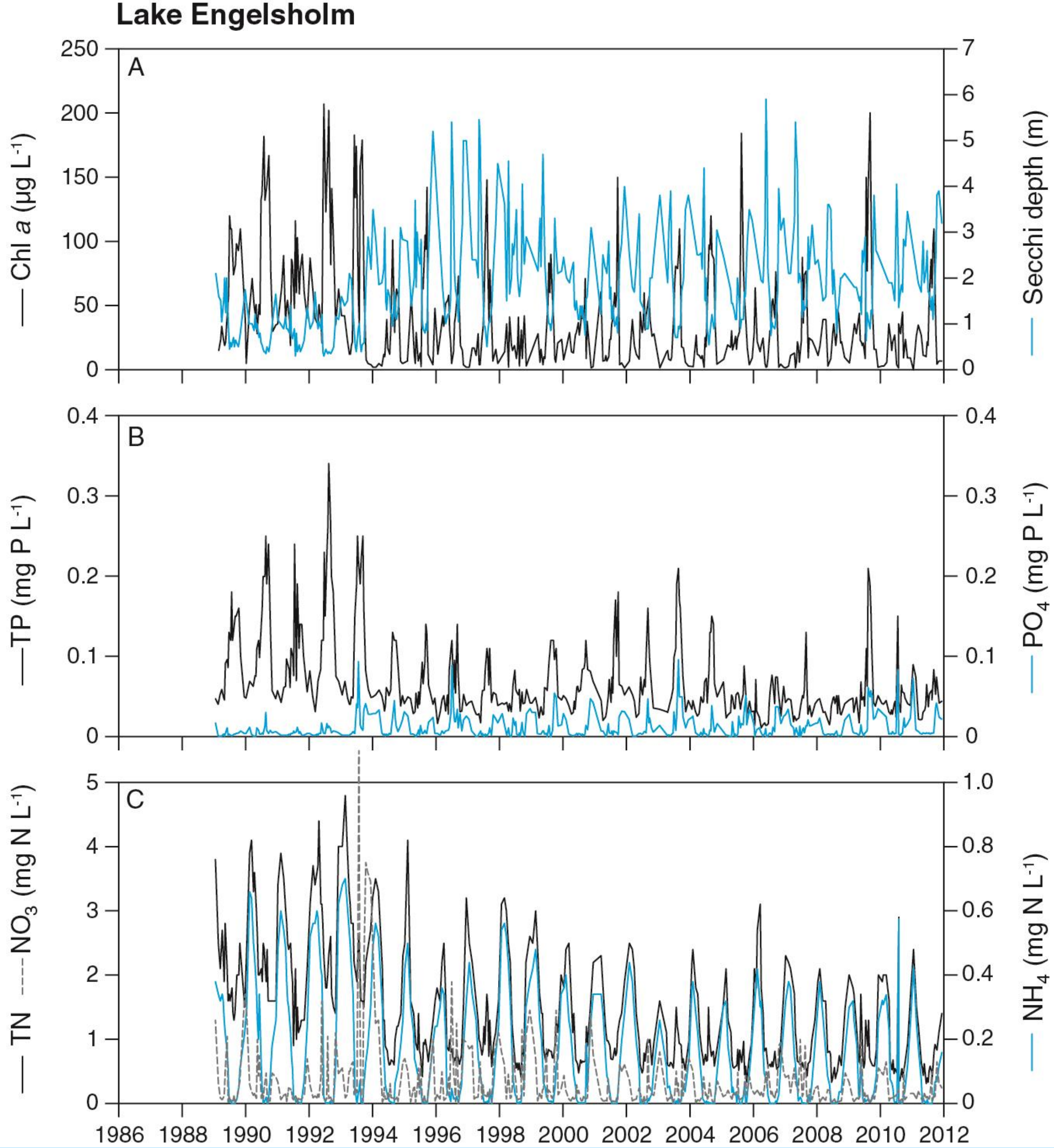


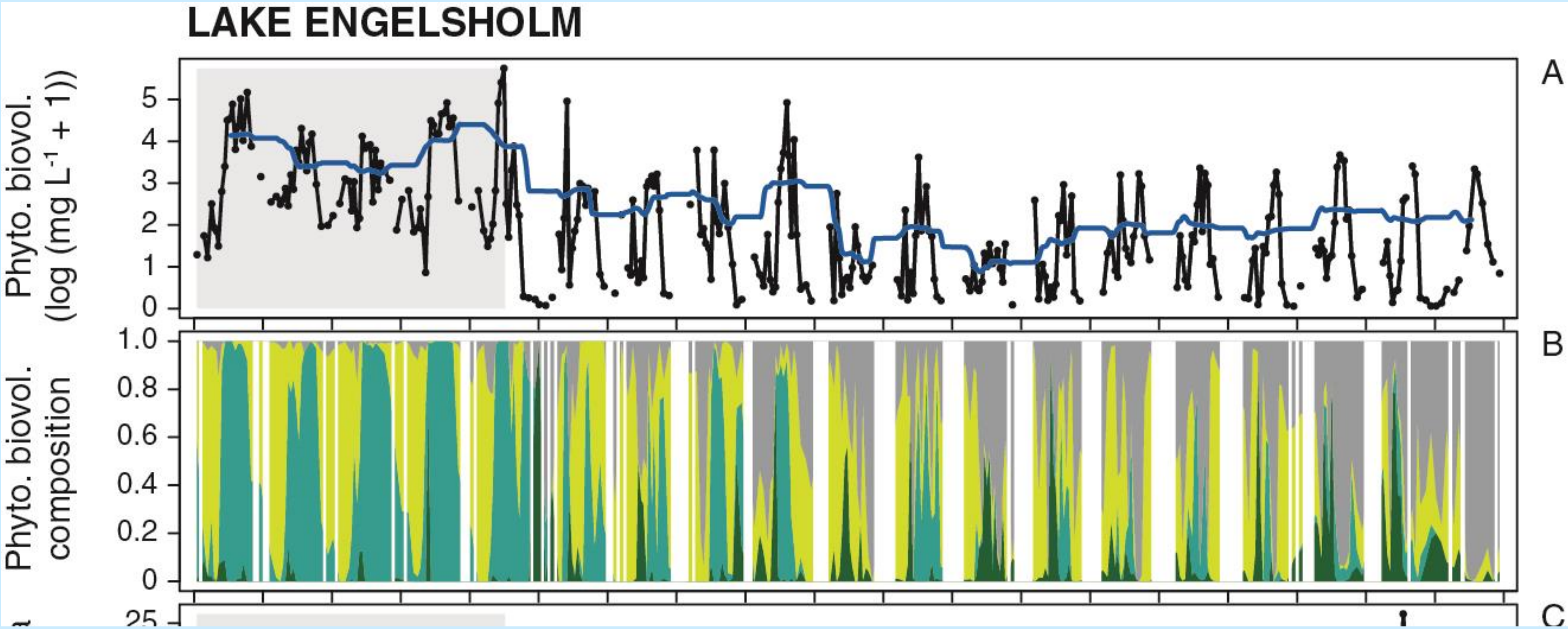
Fig. 11 Time series of chlorophyll *a* and Secchi depth (A), total phosphorus and orto-phosphate (B), total nitrogen, nitrate and ammonia (C) in Lake Engelsholm, Denmark, from 1989 to 2010. Fish removal was conducted in 1992-1993.

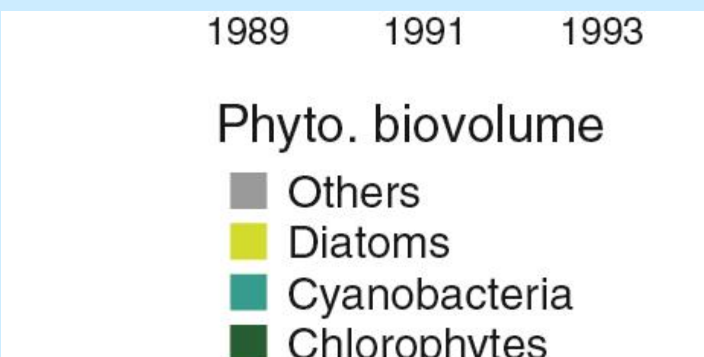
The interaction between biology and chemistry

Changed nutrient availability

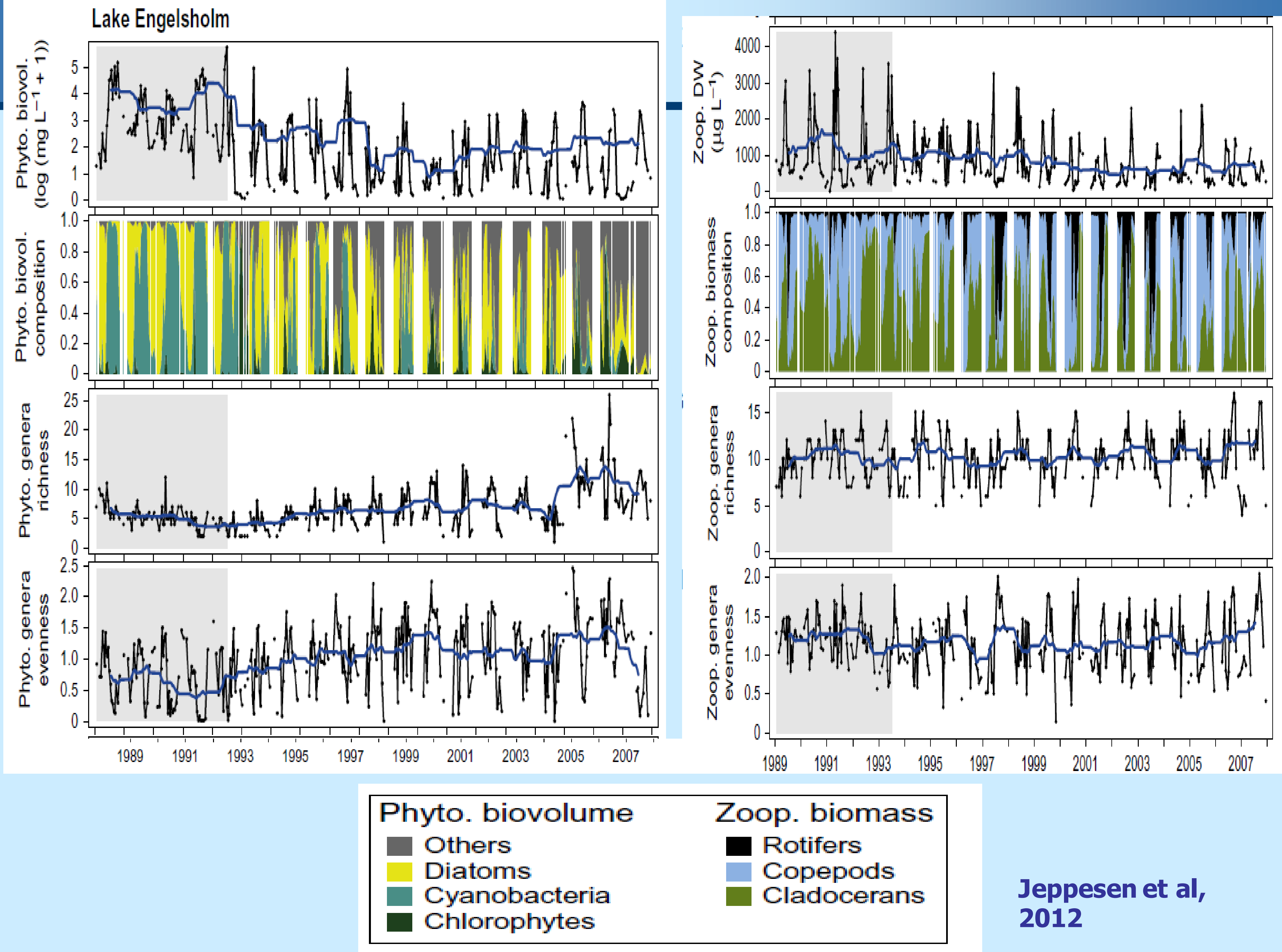
Changed biological structure

Lake Engelsholm





Jeppesen et al, 2012



Jeppesen et al, 2012

Effects of birds grazing on submerged macrophytes

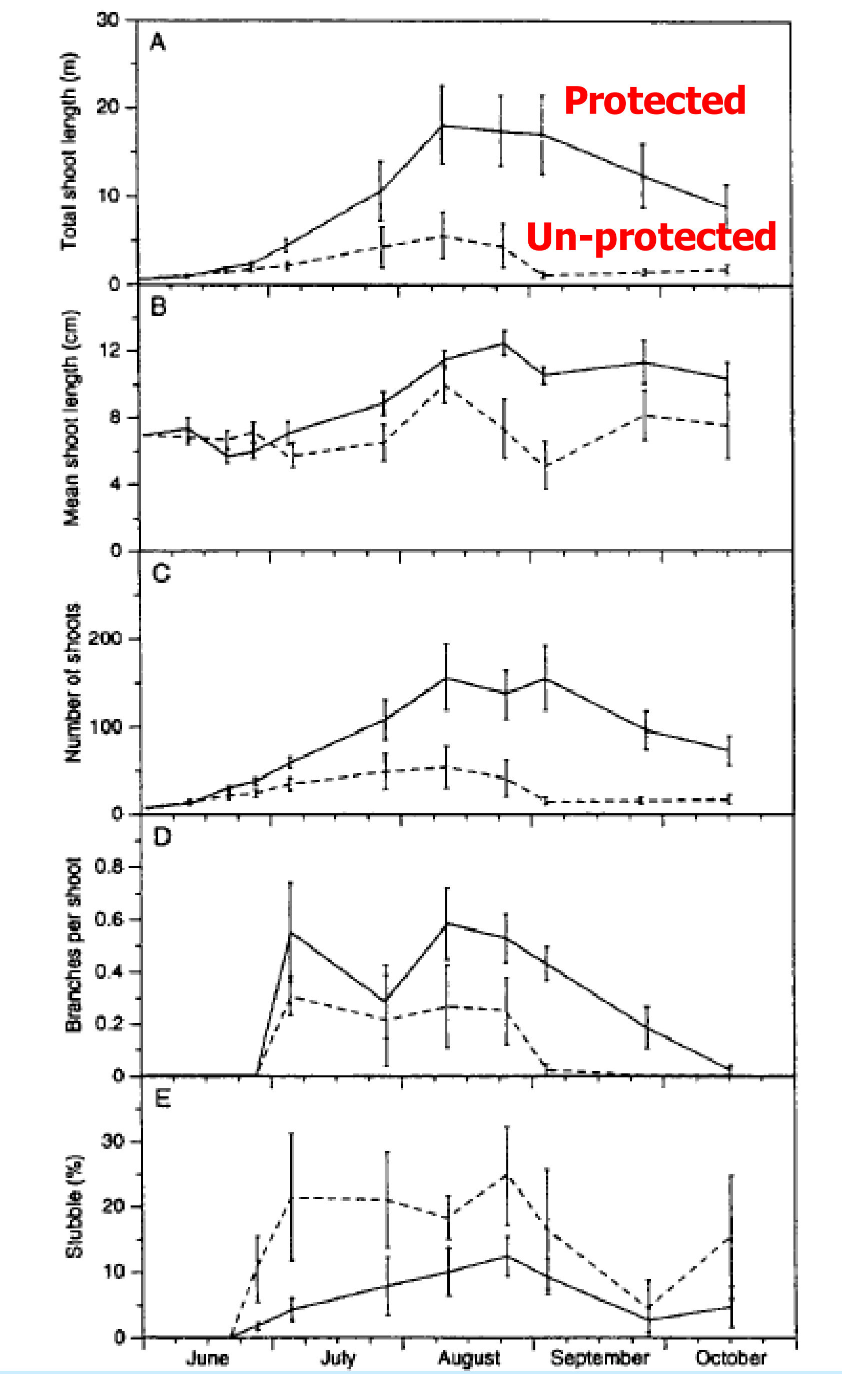
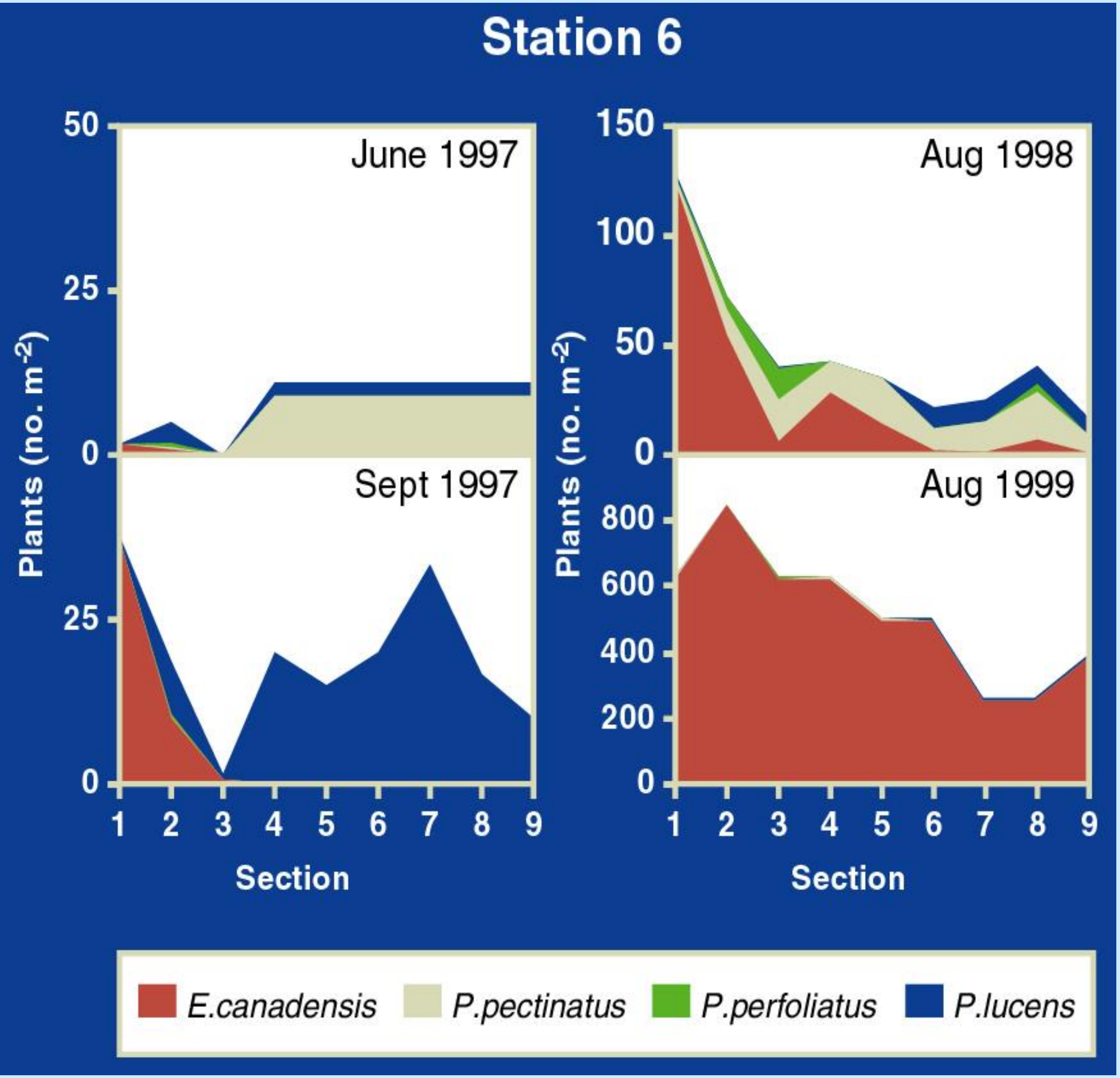


Fig. 2. Mean total shoot length (A), average shoot length (B), number of shoots per square metre (C), branches per shoot (D) and percentage of stubble (E) of the *P. crispus* planted in pots in the small-scale exclosure experiments. Unfenced exclosures are indicated by a dotted line, fenced exclosures by a solid line. Bars indicate standard error ($n = 7$).

From Søndergaard et al. 1996

Macrophyte colonisation following transplantation into protected areas



Lauridsen et al, 2003

Restoration of macrophytes has been used to restore clear water of shallow lakes

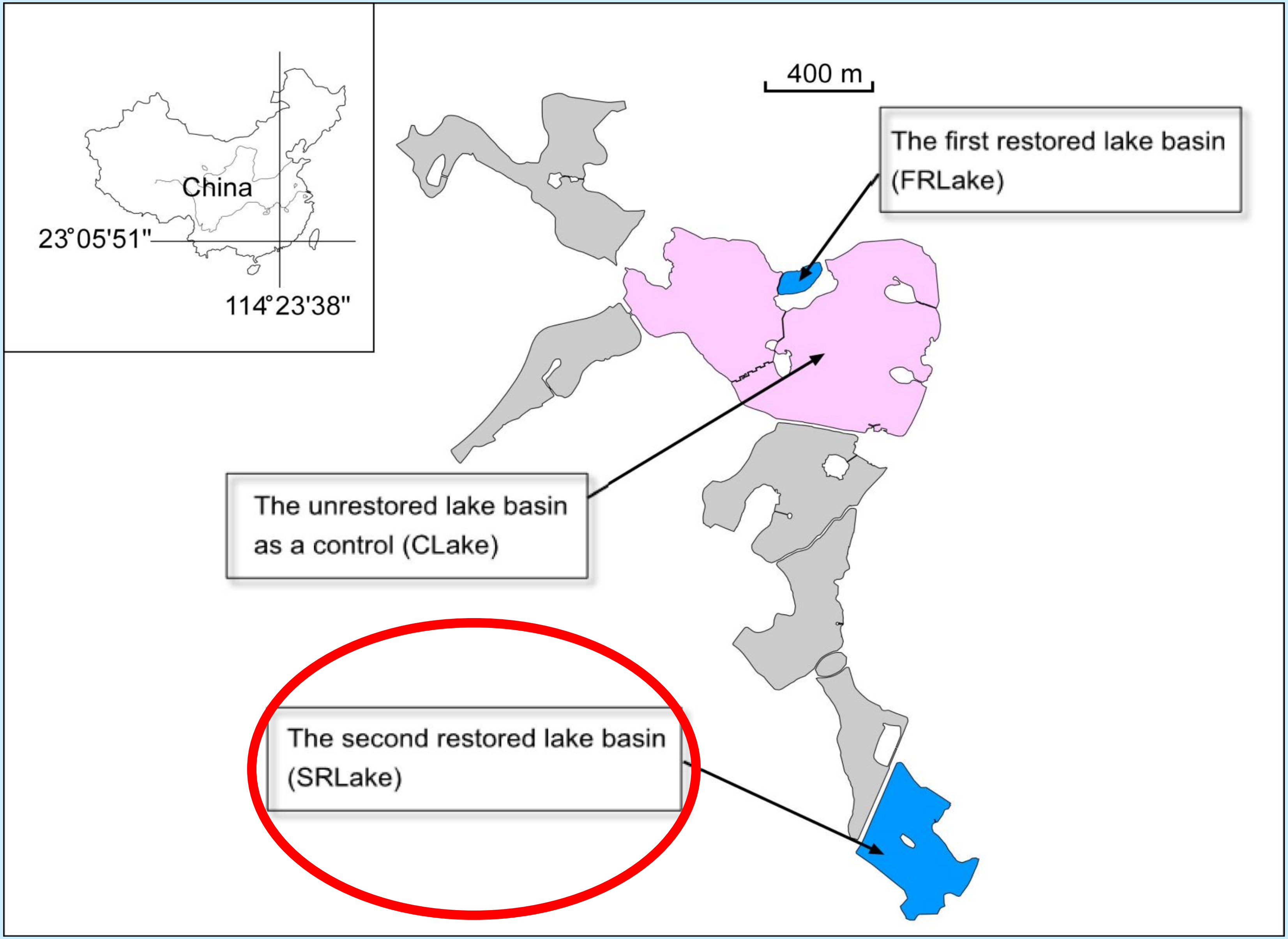
Planting macrophytes (Lake Taihu)

Soon after macrophytes disappeared again

Huizhou Westlake, China


几乎100%除去输入的营养物质!!!!
捕捞所有“坏家伙”
增加植物– Vallesneria etc.
长远眼光
Prof. Zhengwen Liu, CAS
南京+ 济南大学， 广州
?
好人
惠州西湖

Second restored lake (12 ha)



Carp removed

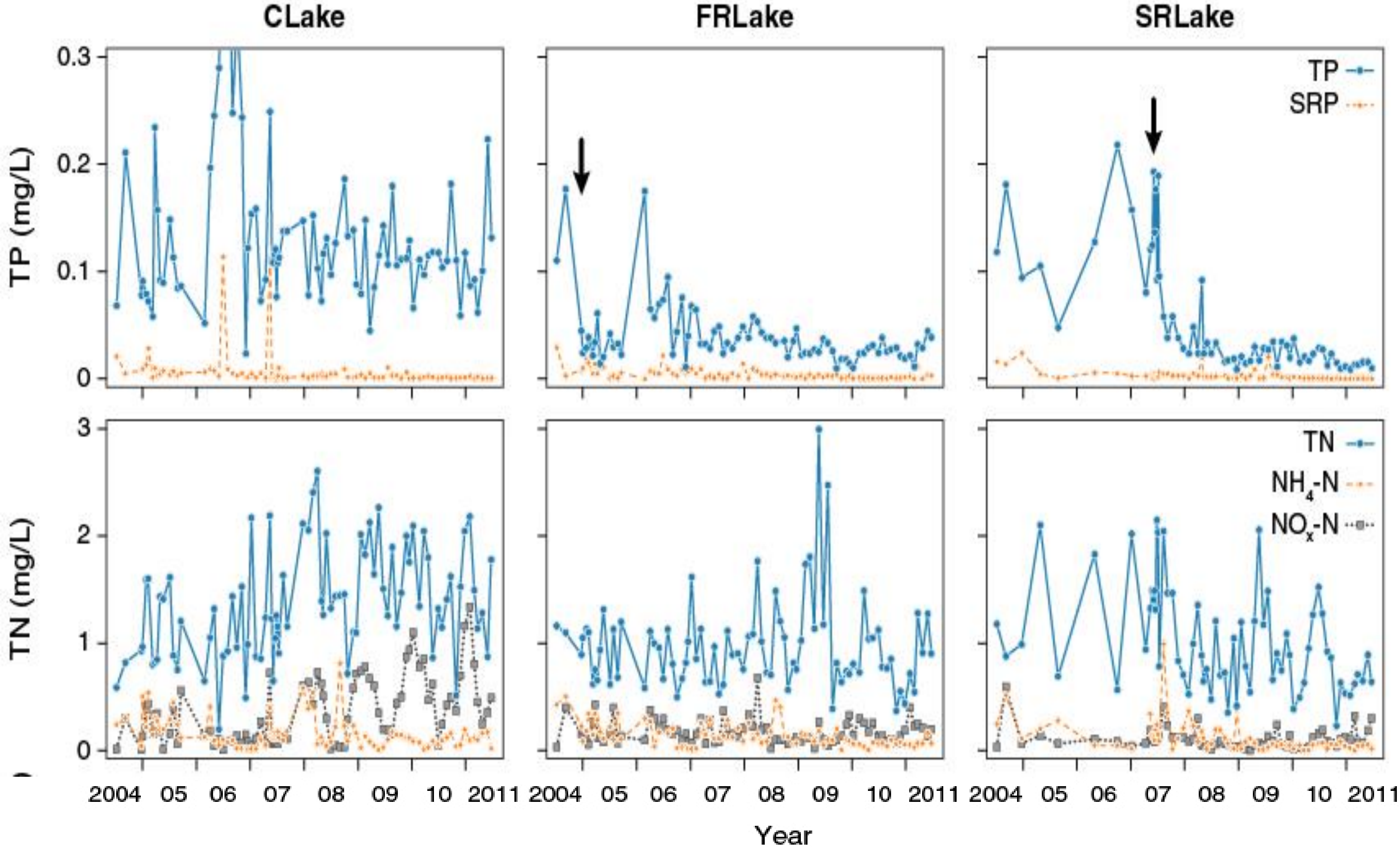
Huizhou Westlake

Huizhou West Lake (Jan. 2009)

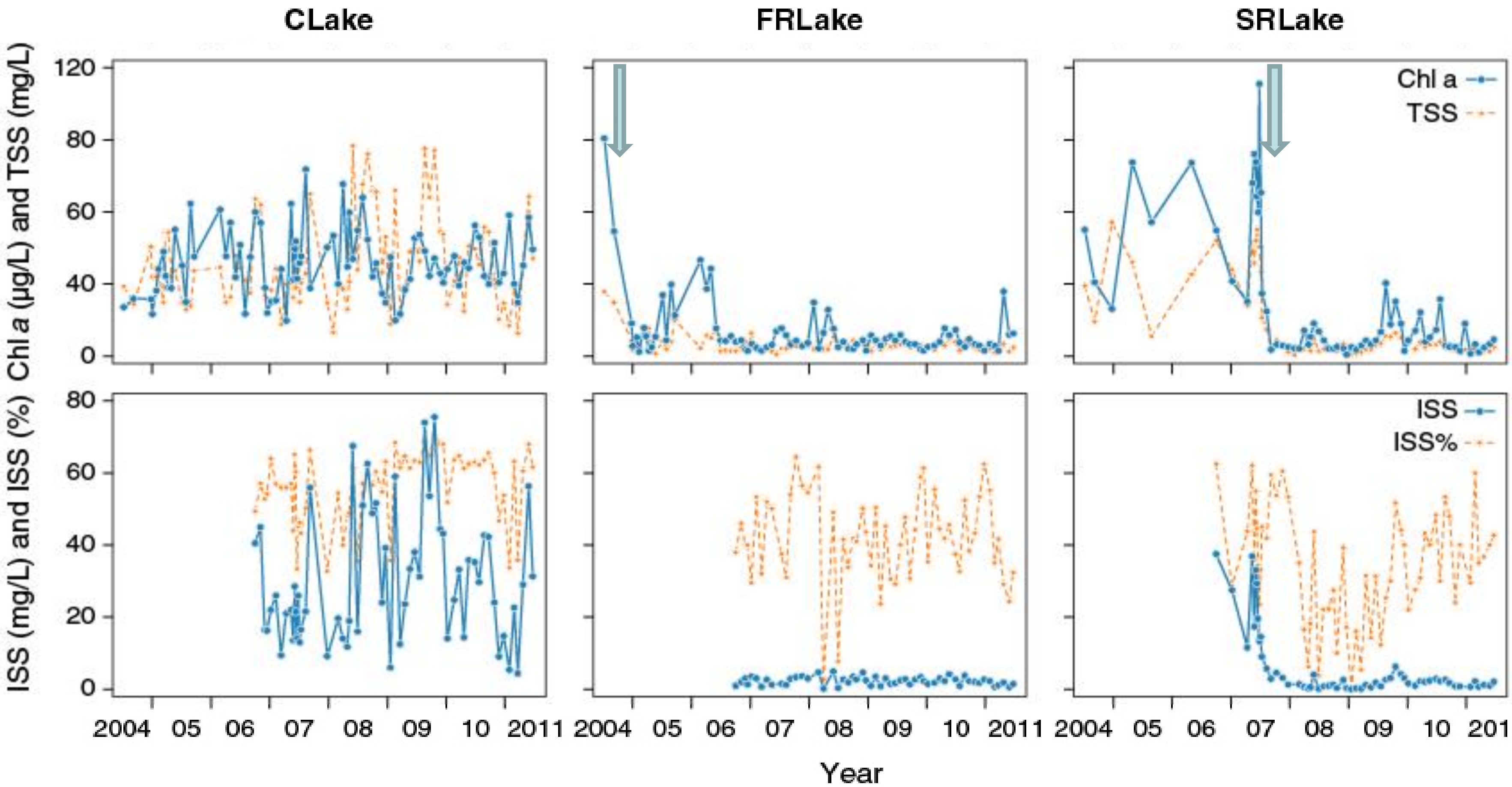
Huizhou Westlake

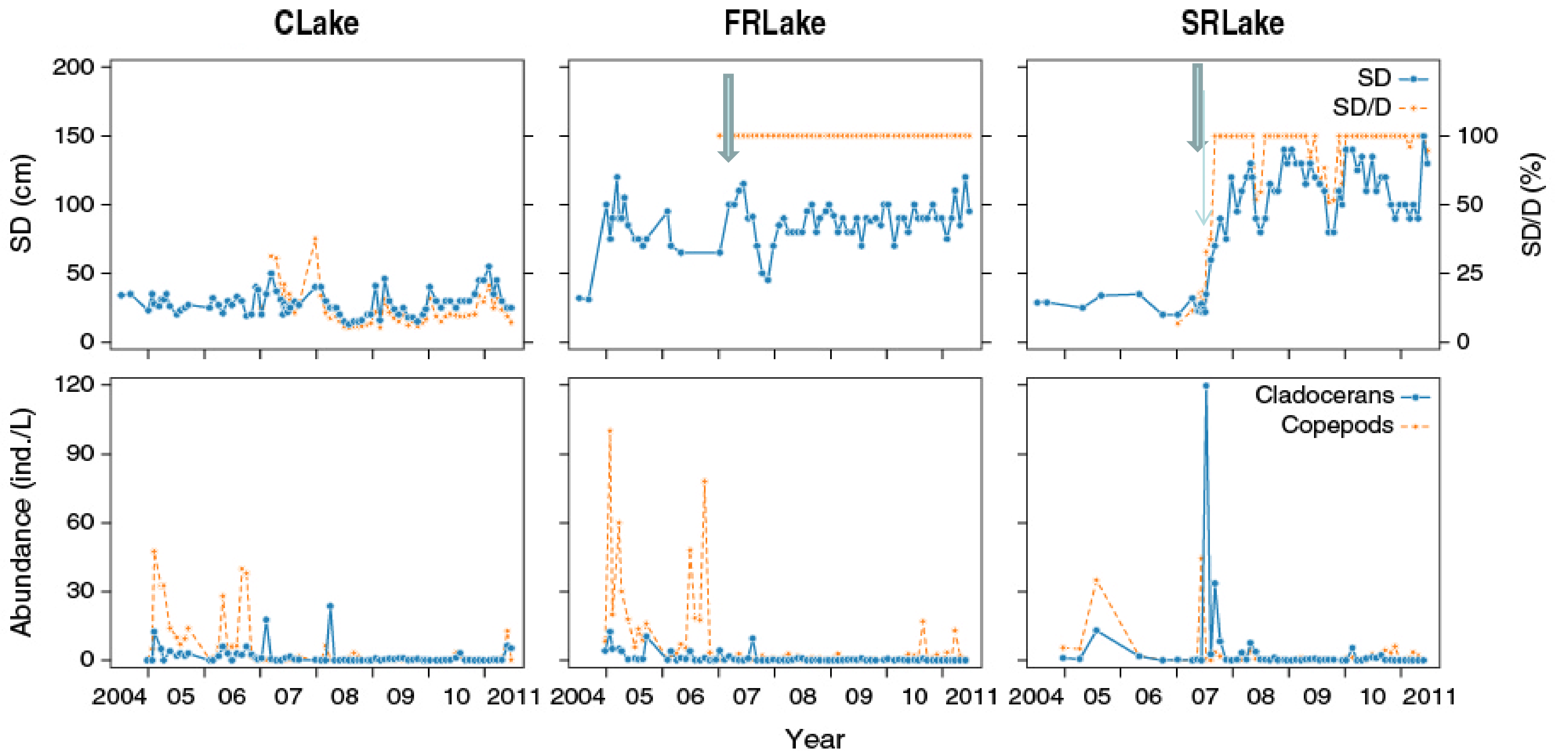
Vallesneria carpet

Huizhou Westlake



Huizhou Westlake





CLake
FRLake
SRLake
SD
SD/D
Cladocerans
Copepods
SD (cm)
SD/D (%)
Abundance (ind./L)
Year
200
150
100
50
0
120
90
60
30
2004
05
06
07
08
09
10
2011
25

Turbid state


302 m
31°32'01.64" N 120°14'13.13" E
Data SIO, NOAA, U.S. Na
Image © 2011 Di

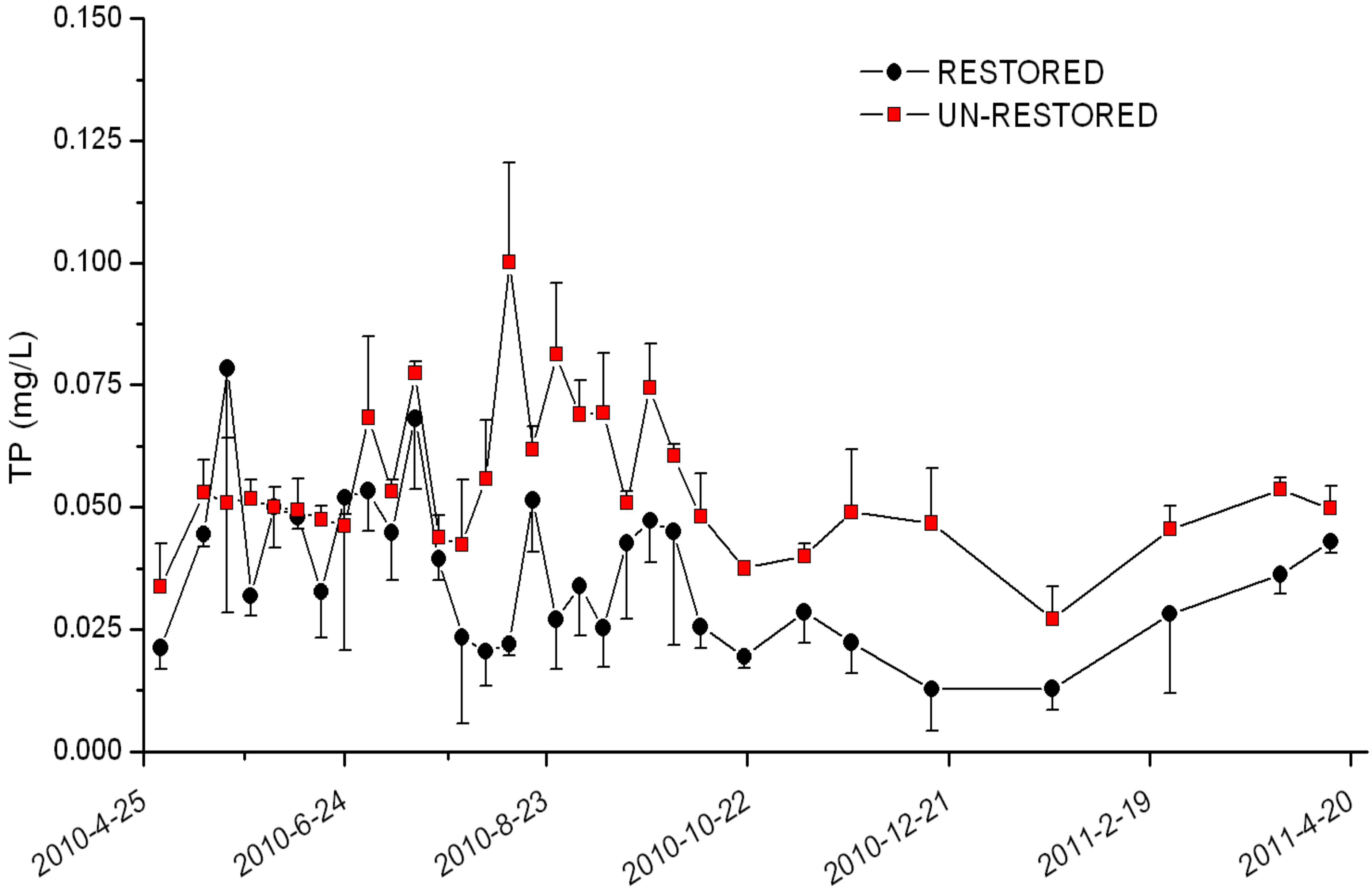
Wuli lake

May, 2010

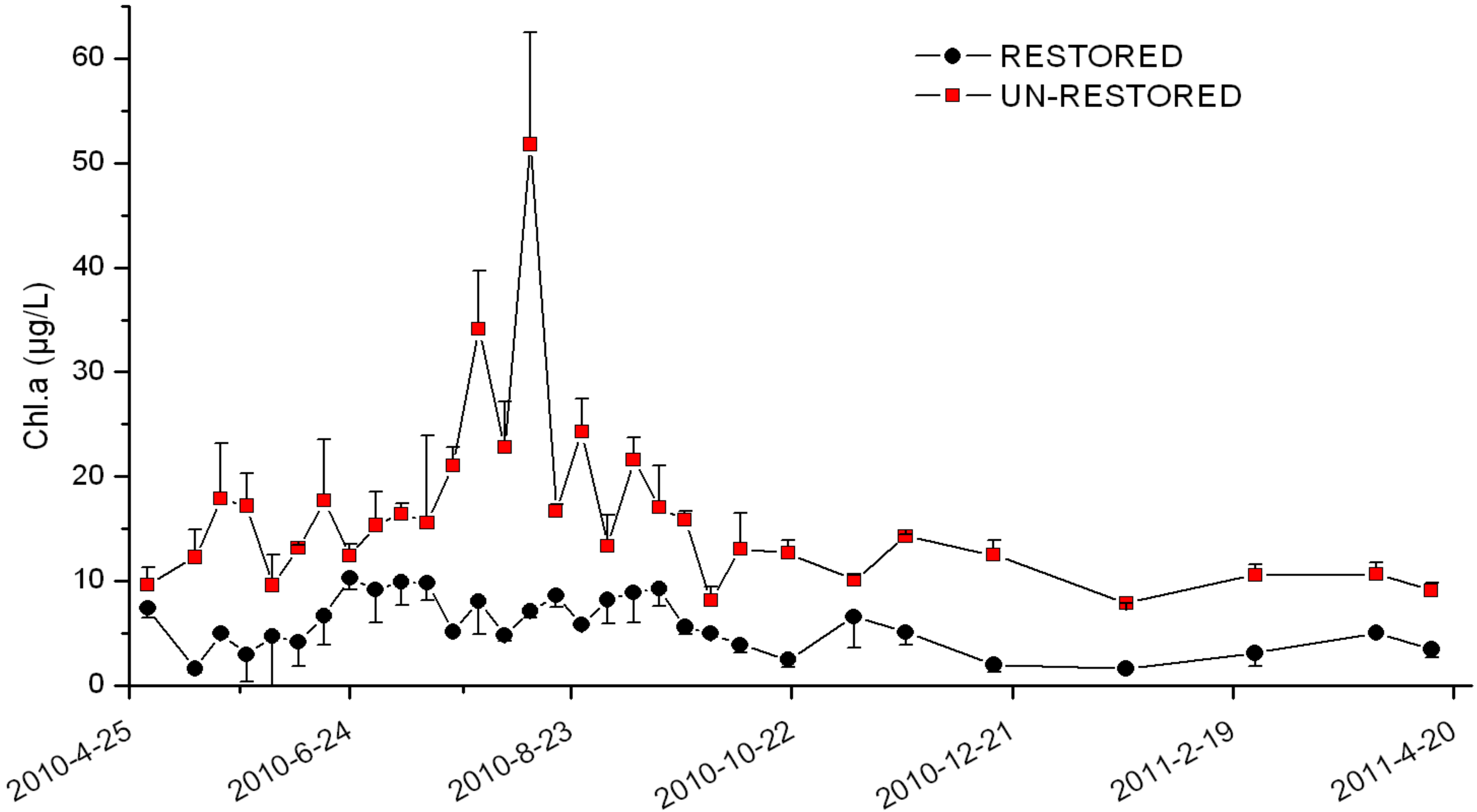
Wuli lake

Wuli lake

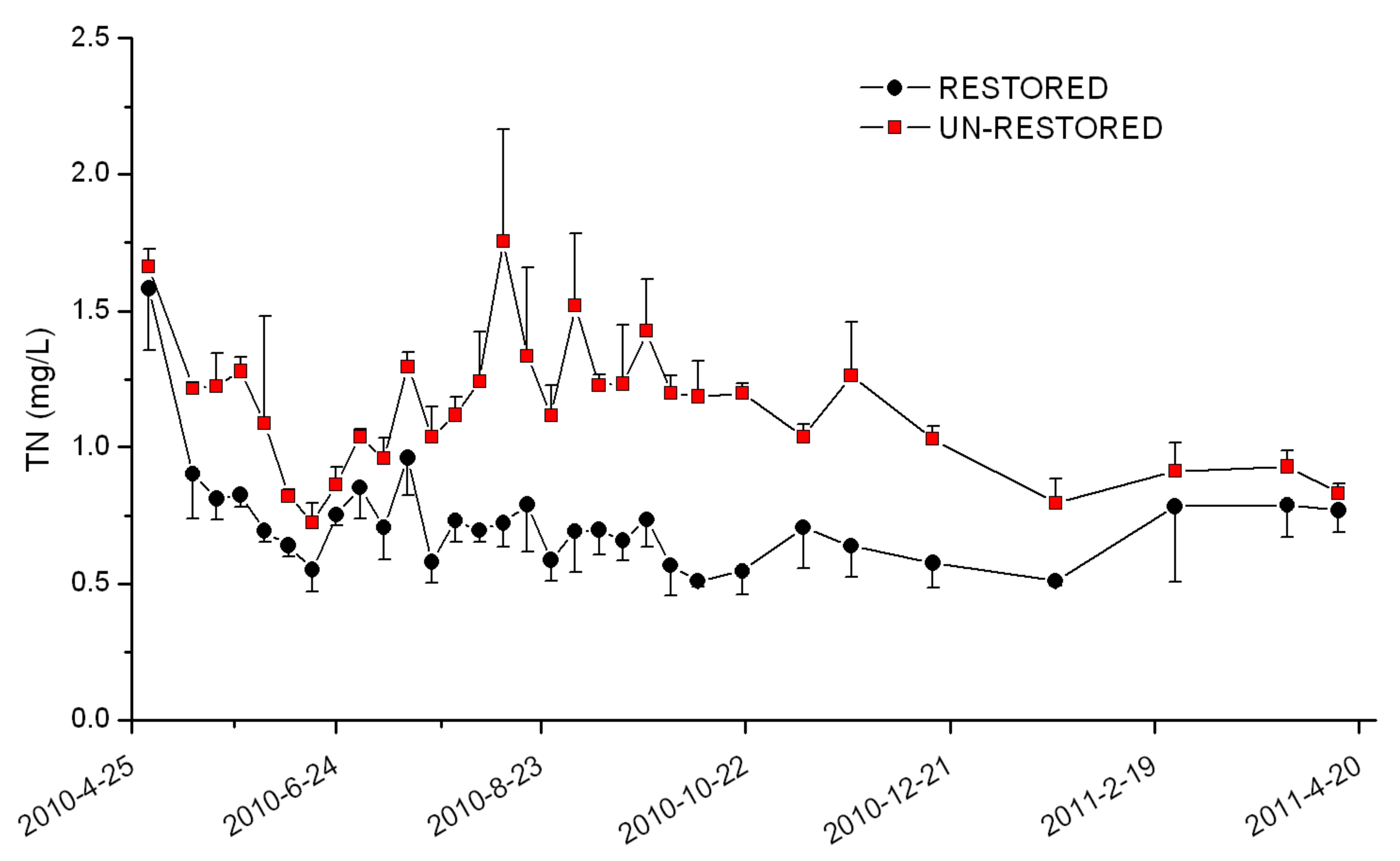
Wuli lake



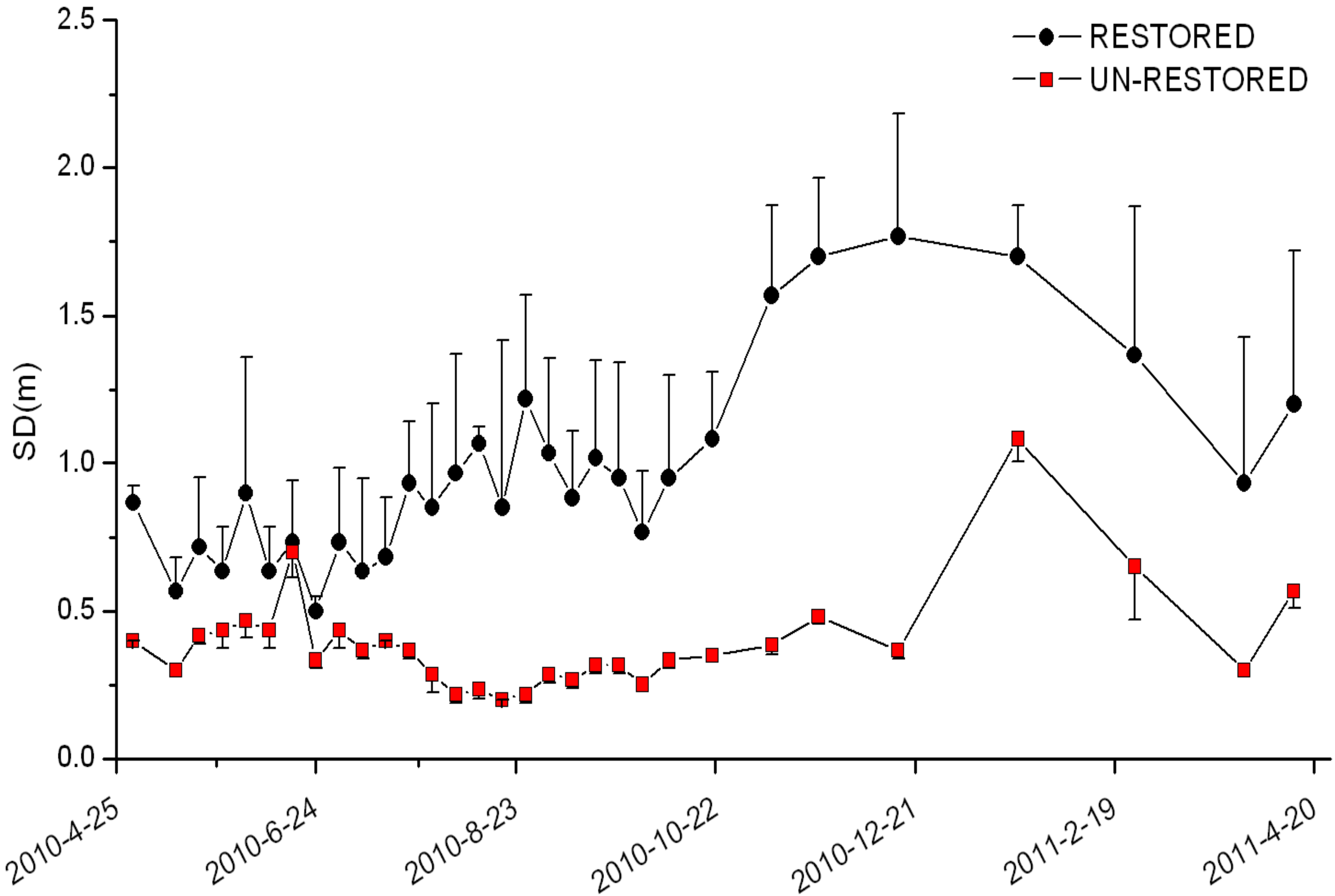
TP in restored and un-restored areas



Chla in restored and un-restored areas



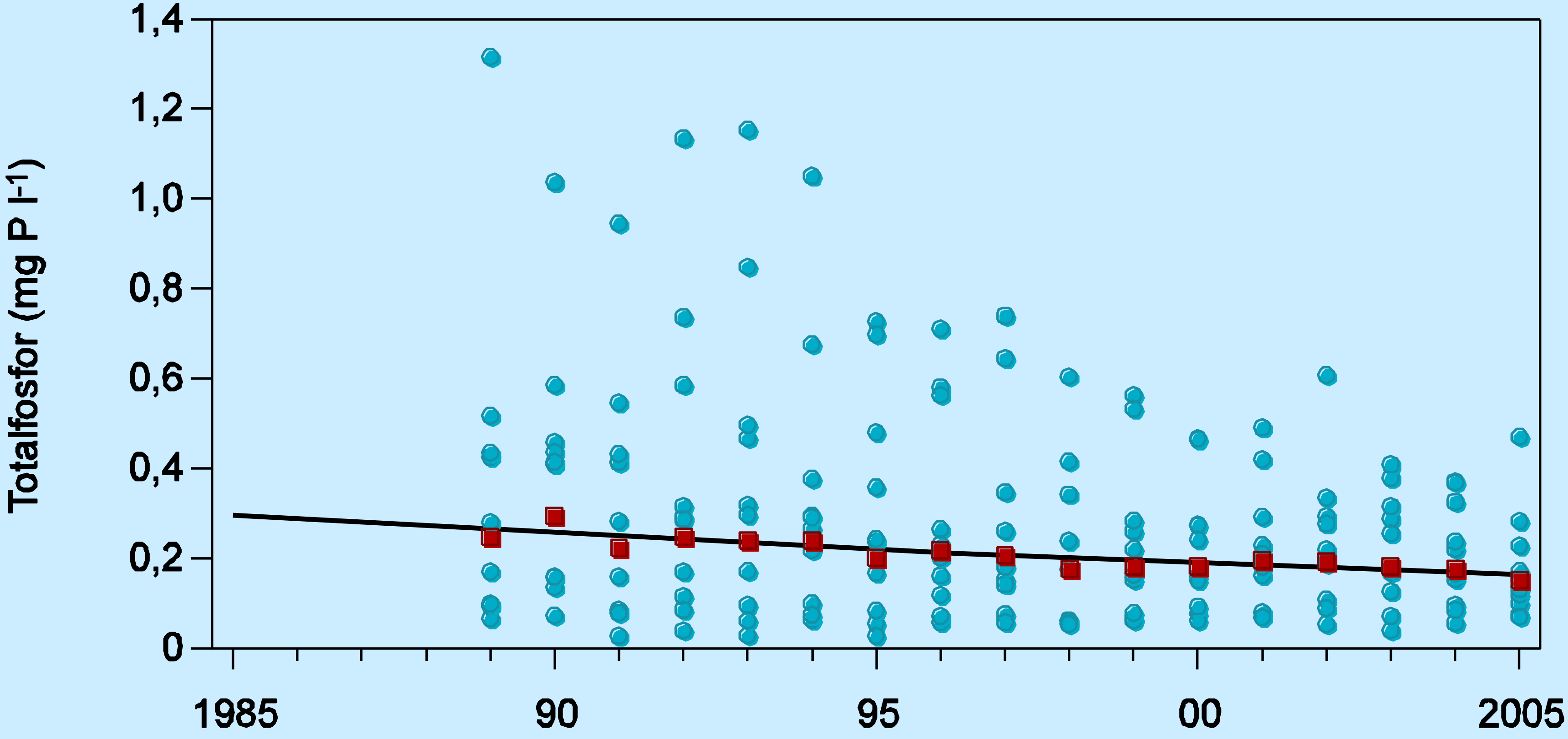
TN in restored and un-restored areas



RESTORED
UN-RESTORED
SD(m)
2.5
2.0
1.5
1.0
0.5
0.0
2010-4-25
2010-6-24
2010-8-23
2010-10-22
2010-12-21
2011-2-19
2011-4-20

- **What about the long-term effect then?**

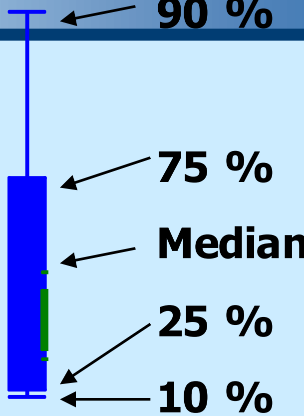
Reduced loading and concentration of TP in Danish lakes

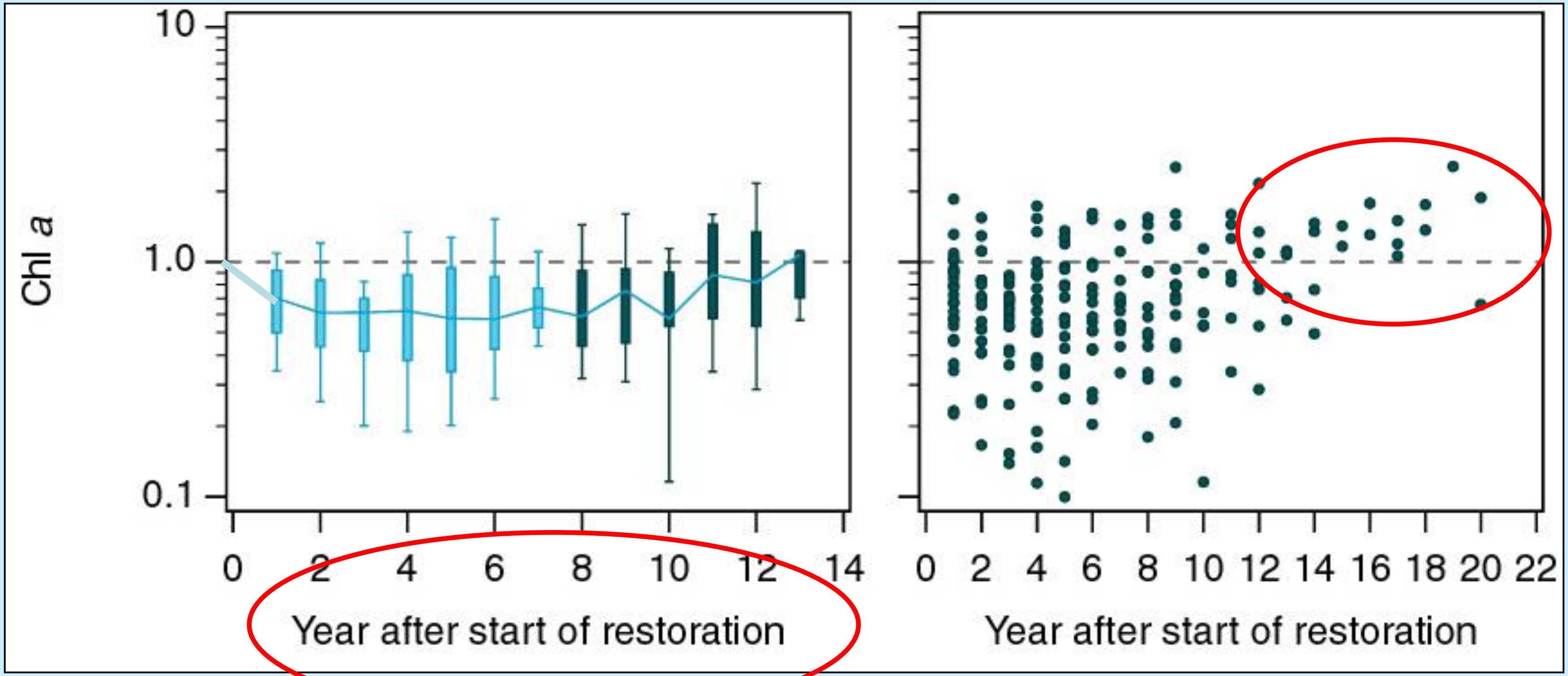


Makes it more complicated to extract the effects of fish removal contra the effect of reduced loading and internal P loading

Presentation of data

- Relative units (relative to before restoration)
- Significant difference marked with blue color
- log scale

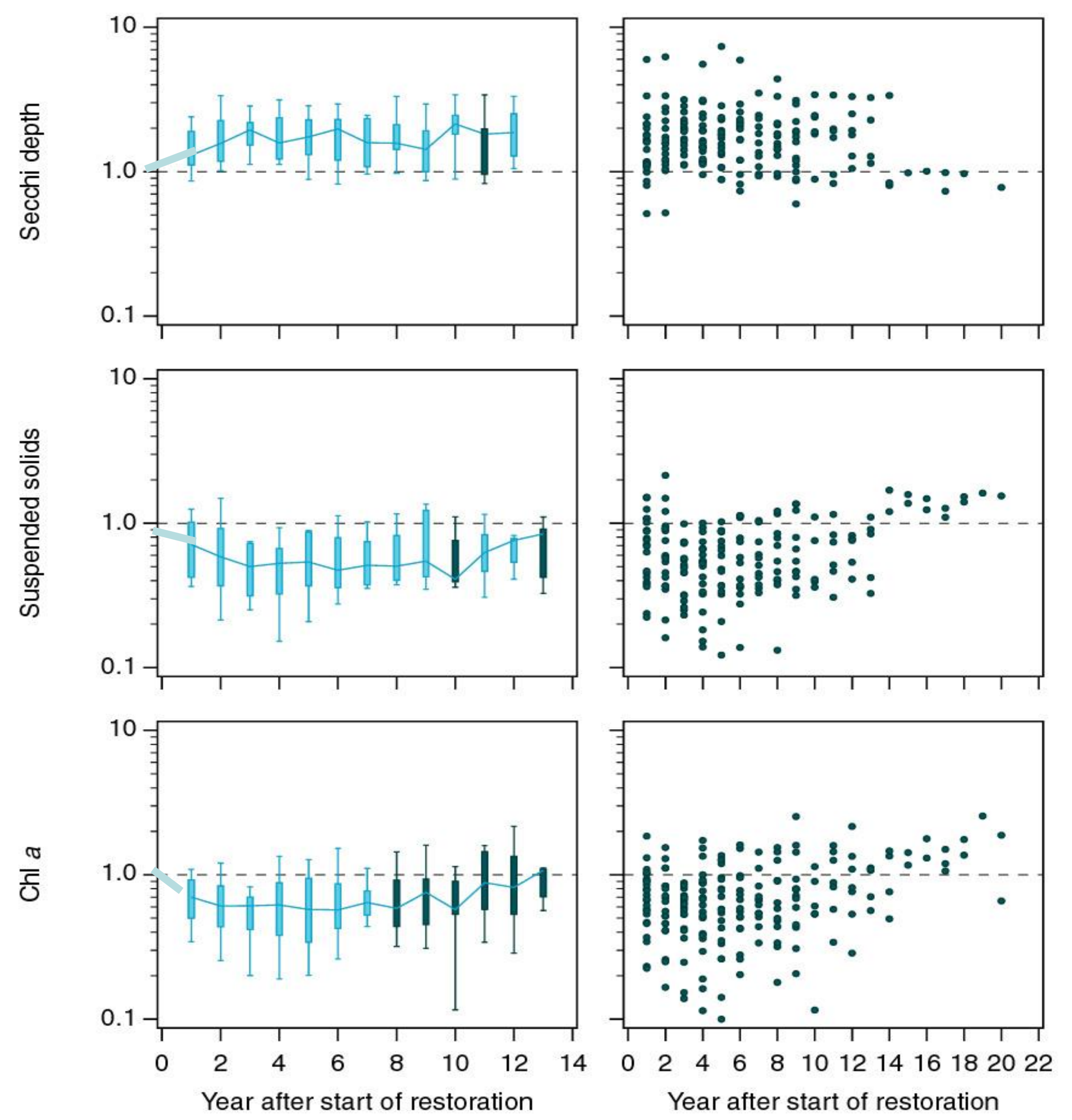




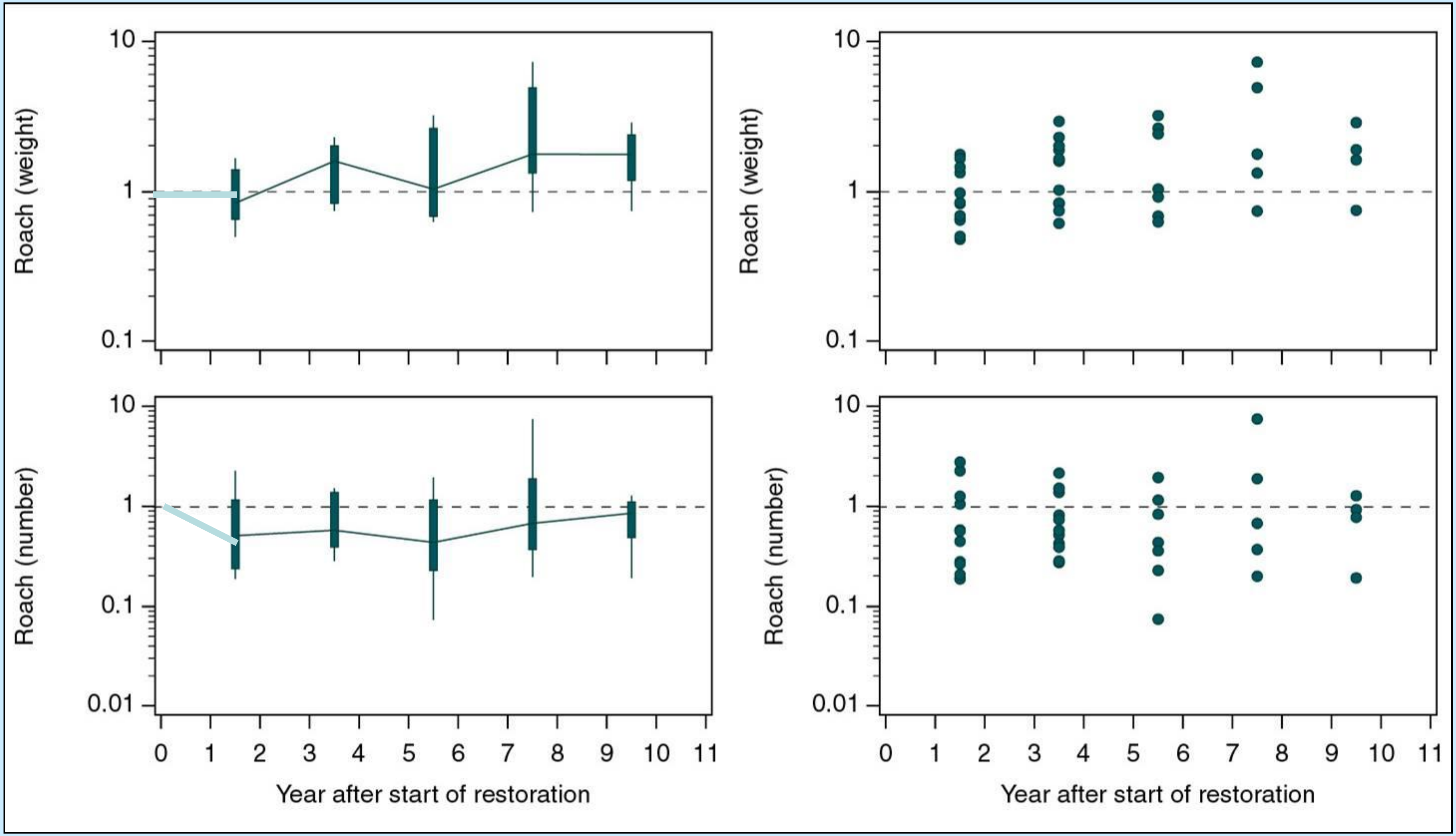
Secchi depth

Suspended solids

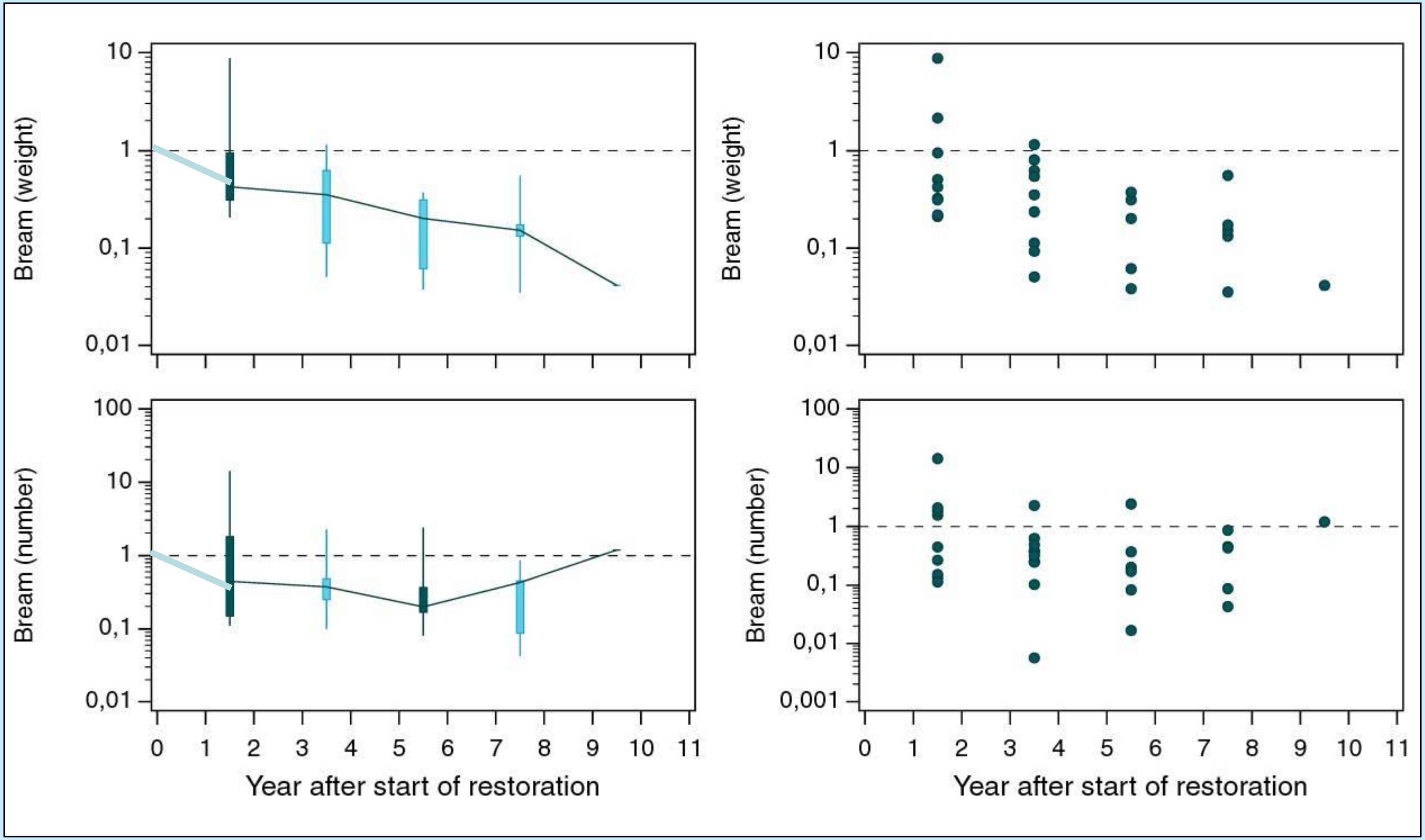
Chlorophyll a



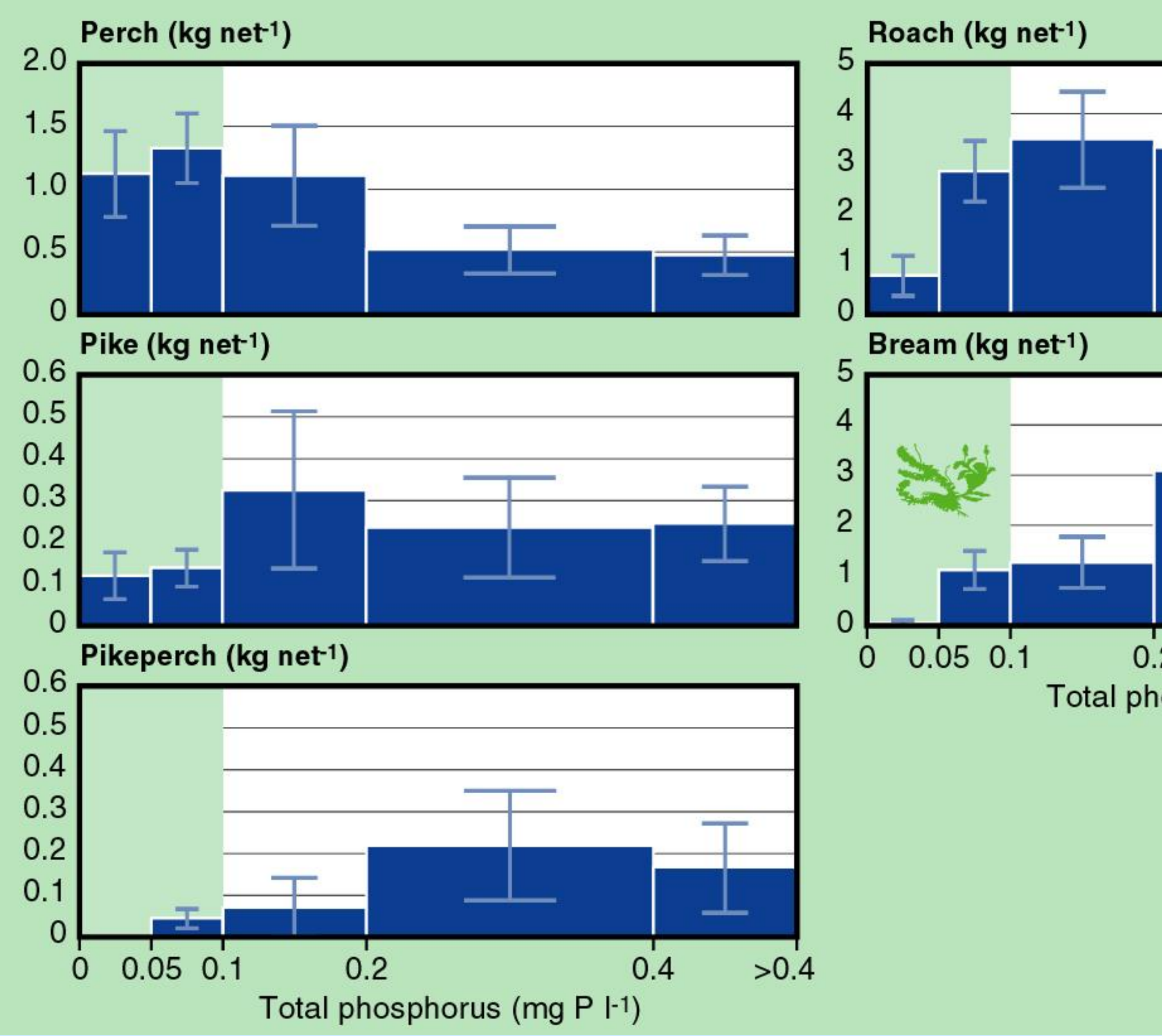
Fish (roach CPUE; weight and number)



Fish (bream CPUE; weight and number)



Fish community changes along a TP gradient

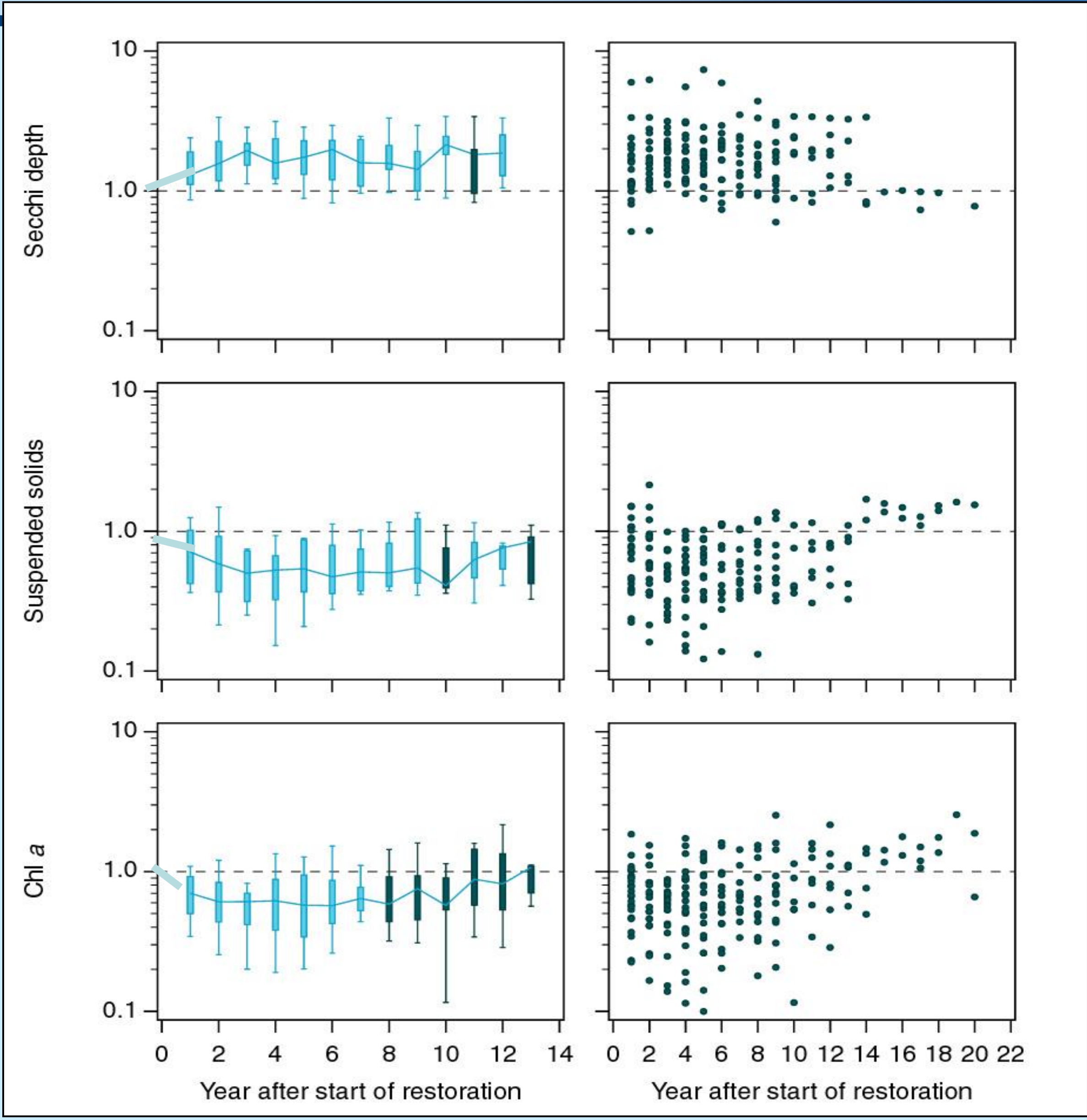


Jeppesen et al, FWB, 2000

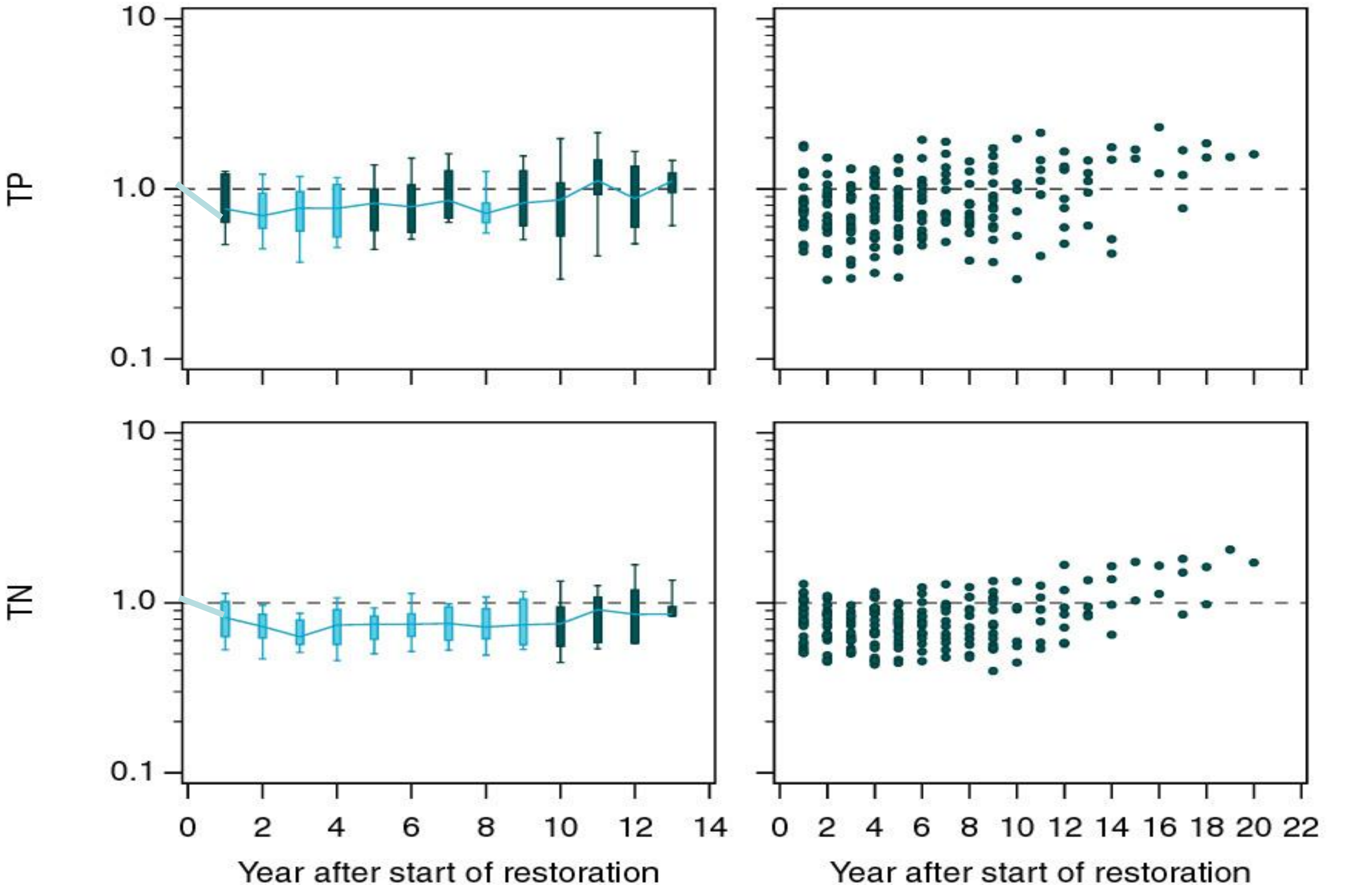
Secchi depth

Suspended solids

Chlorophyll a

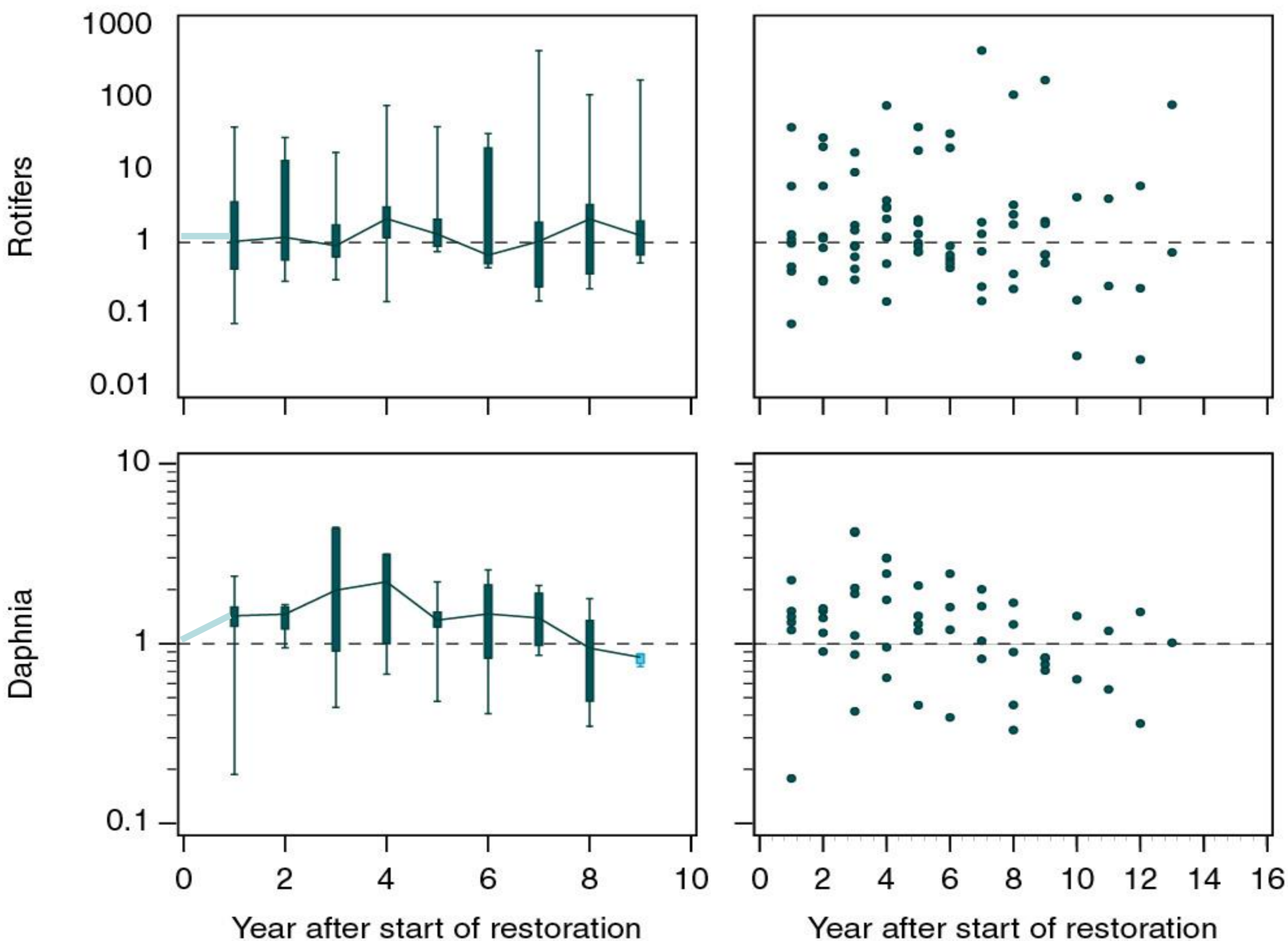


TP and TN

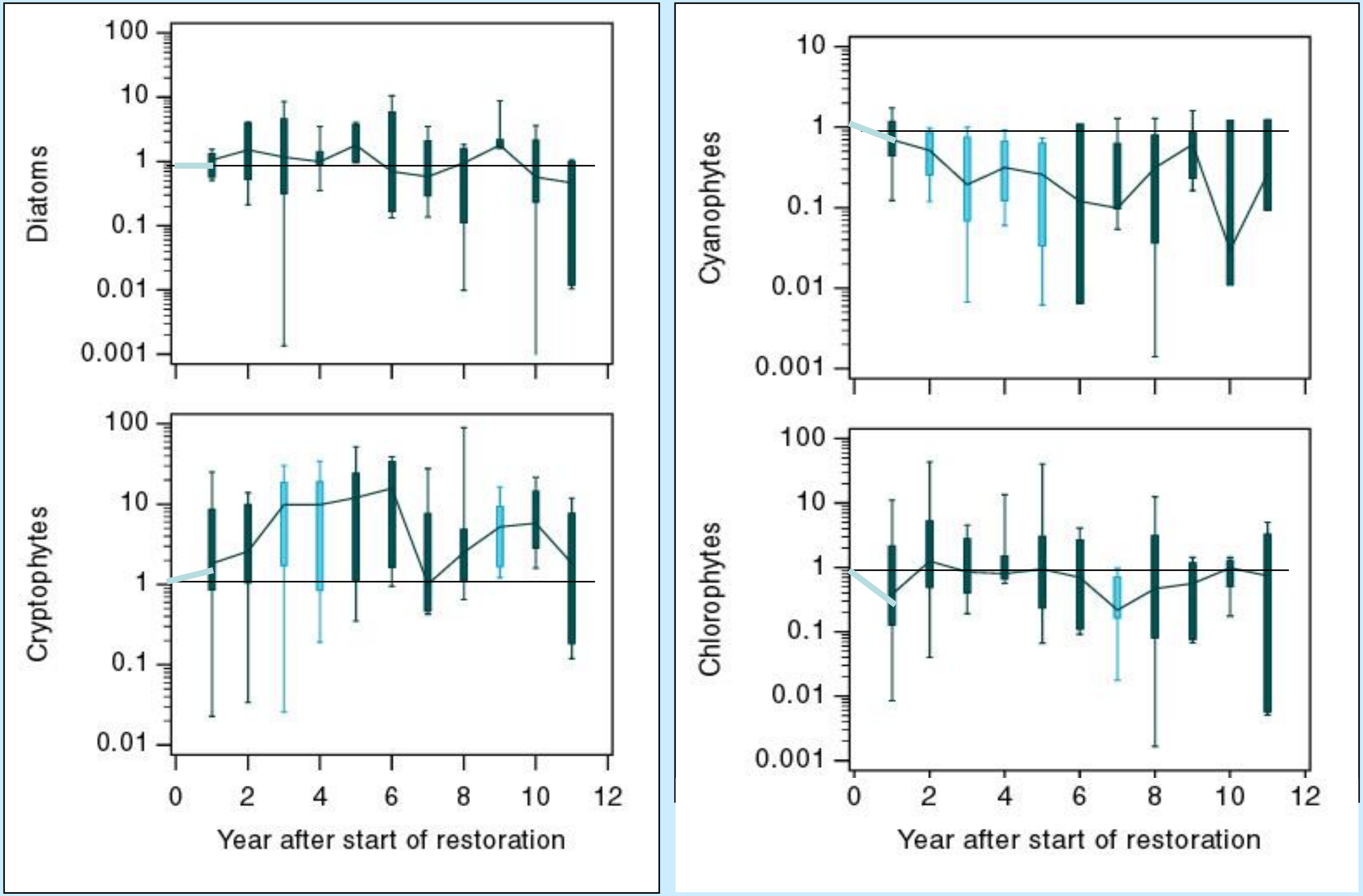


TP
TN
10
1.0
0.1
0
2
4
6
8
10
12
14
16
18
20
22
Year after start of restoration
Year after start of restoration

Zooplankton biomass



Biovolume of main phytoplankton classes



Submerged macrophytes after fish removal

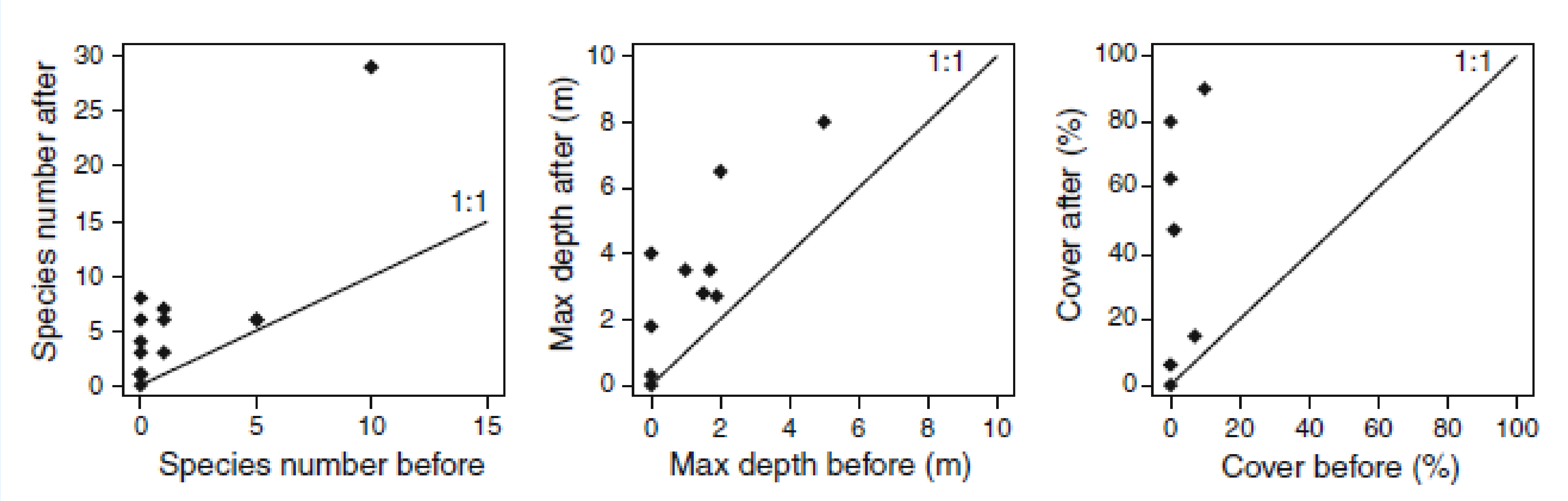
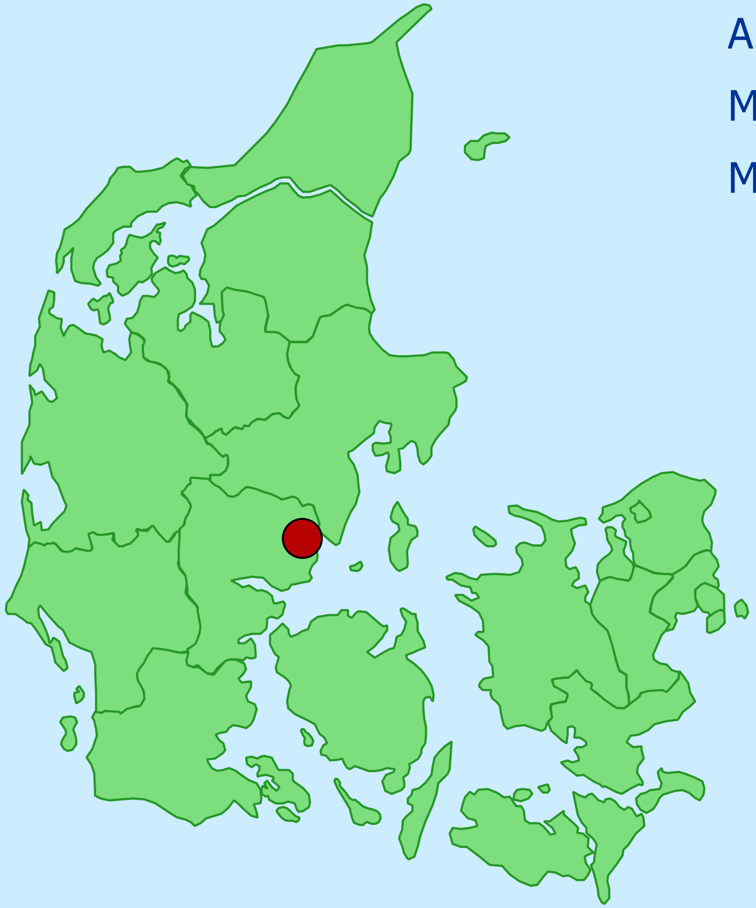


Figure 7. Changes in the number of species, maximum depth distribution, and cover of submerged macrophytes after the fish removal (number of lakes = 10–15).

Lake Væng – fish removal

180,000 (2.5 t) roach and bream removed from 1986-88

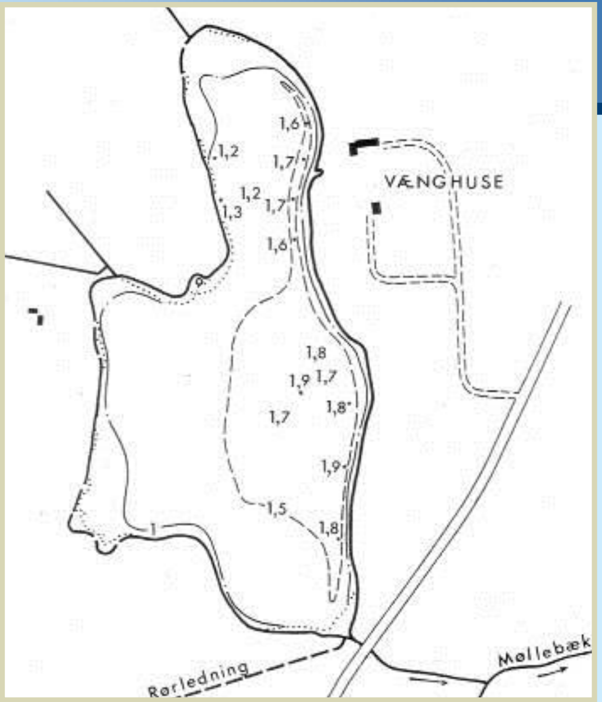
(= 50% of the total fish biomass)



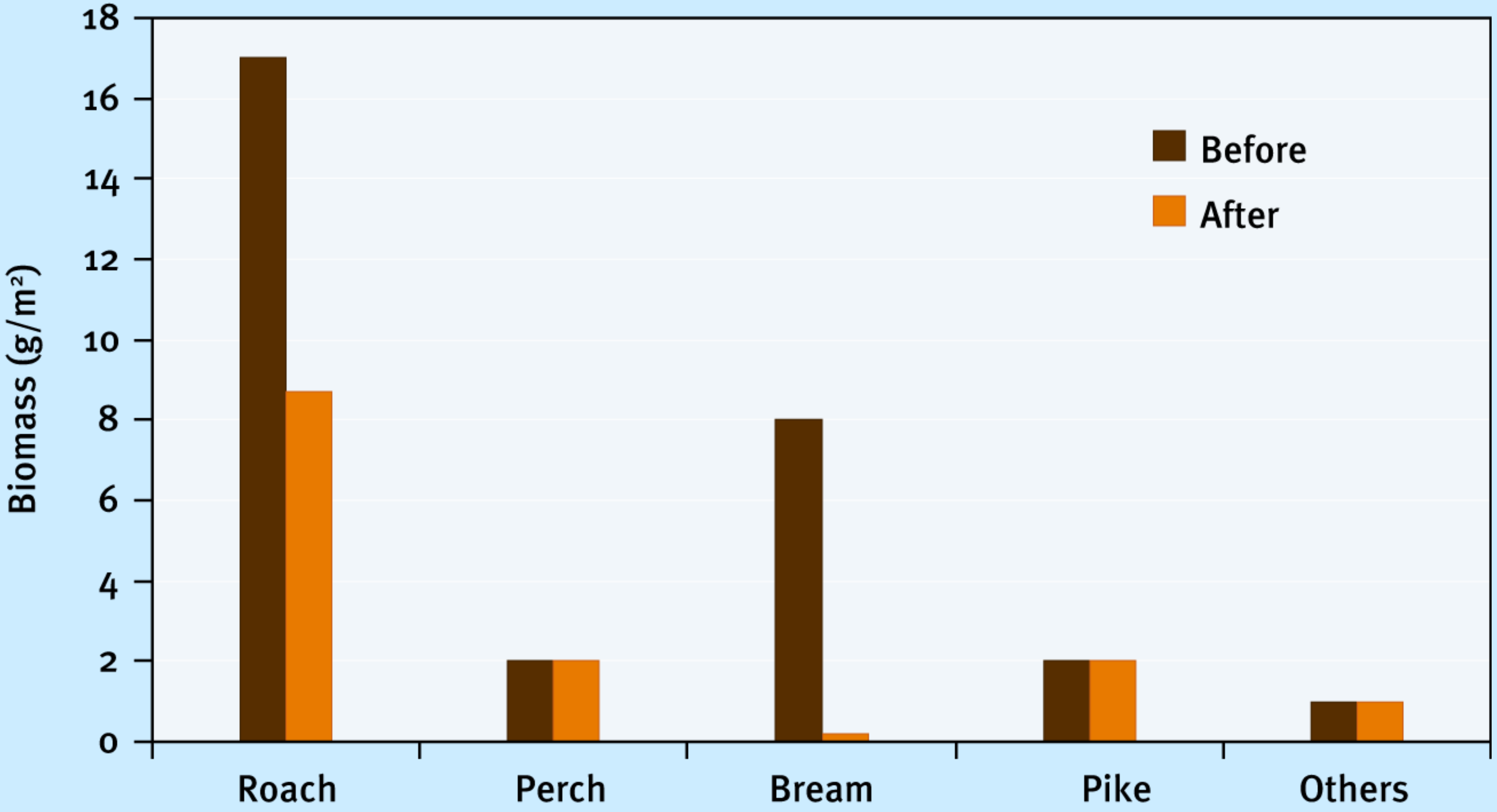
Area: 16 ha

Mean depth: 1.2 m

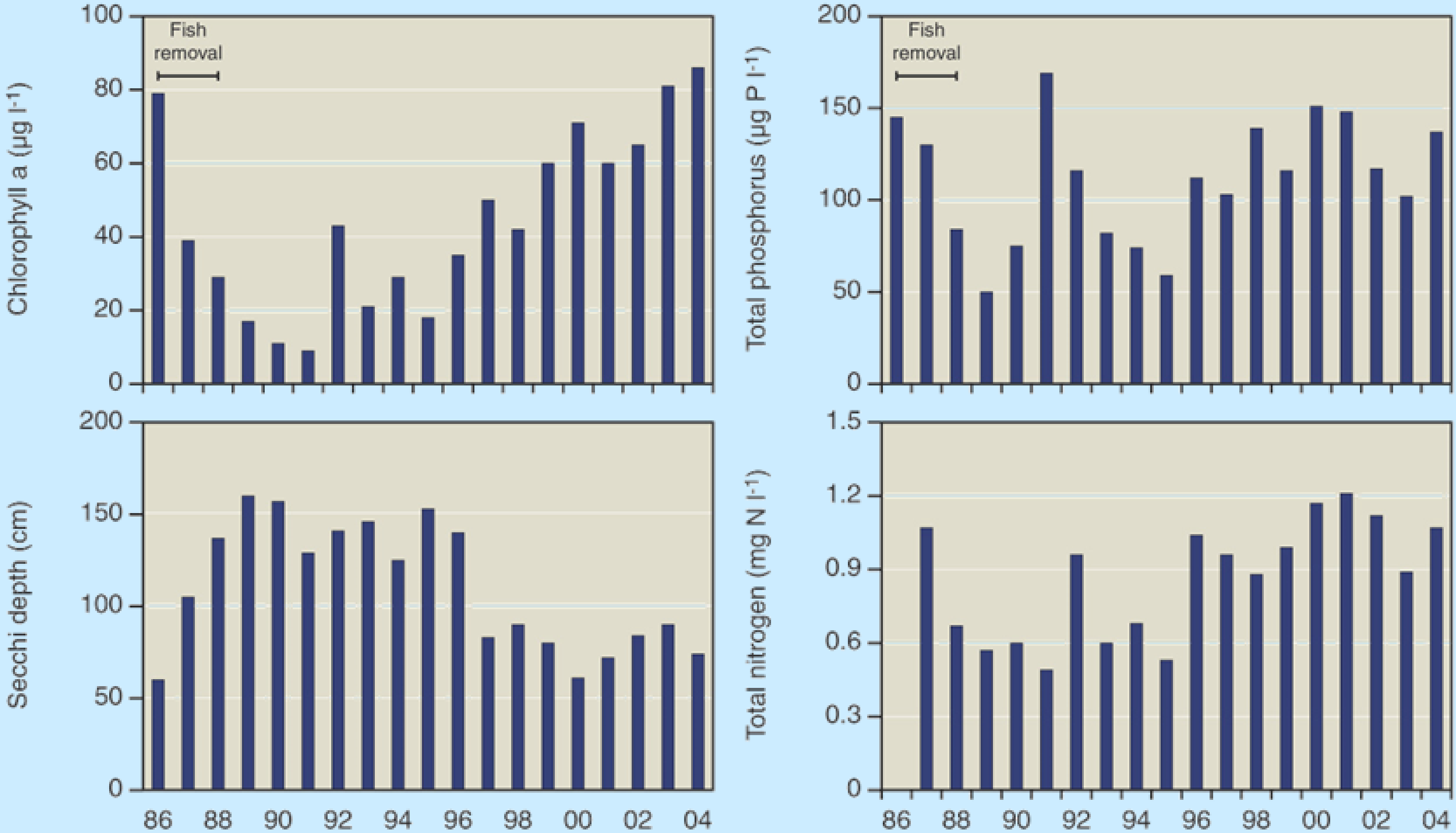
Max. depth: 1.8 m



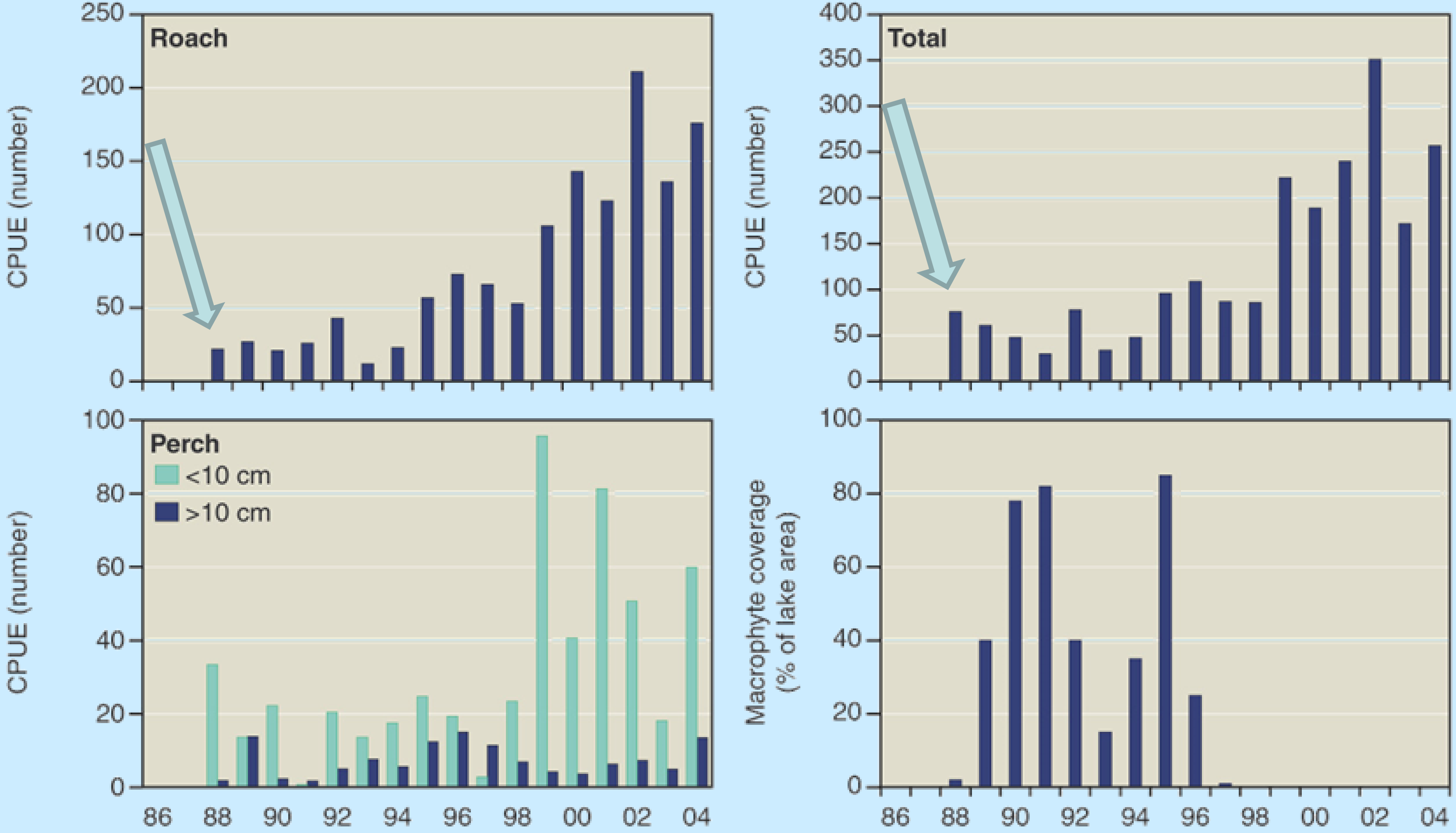
Fish biomass in Lake Væng before and after removal



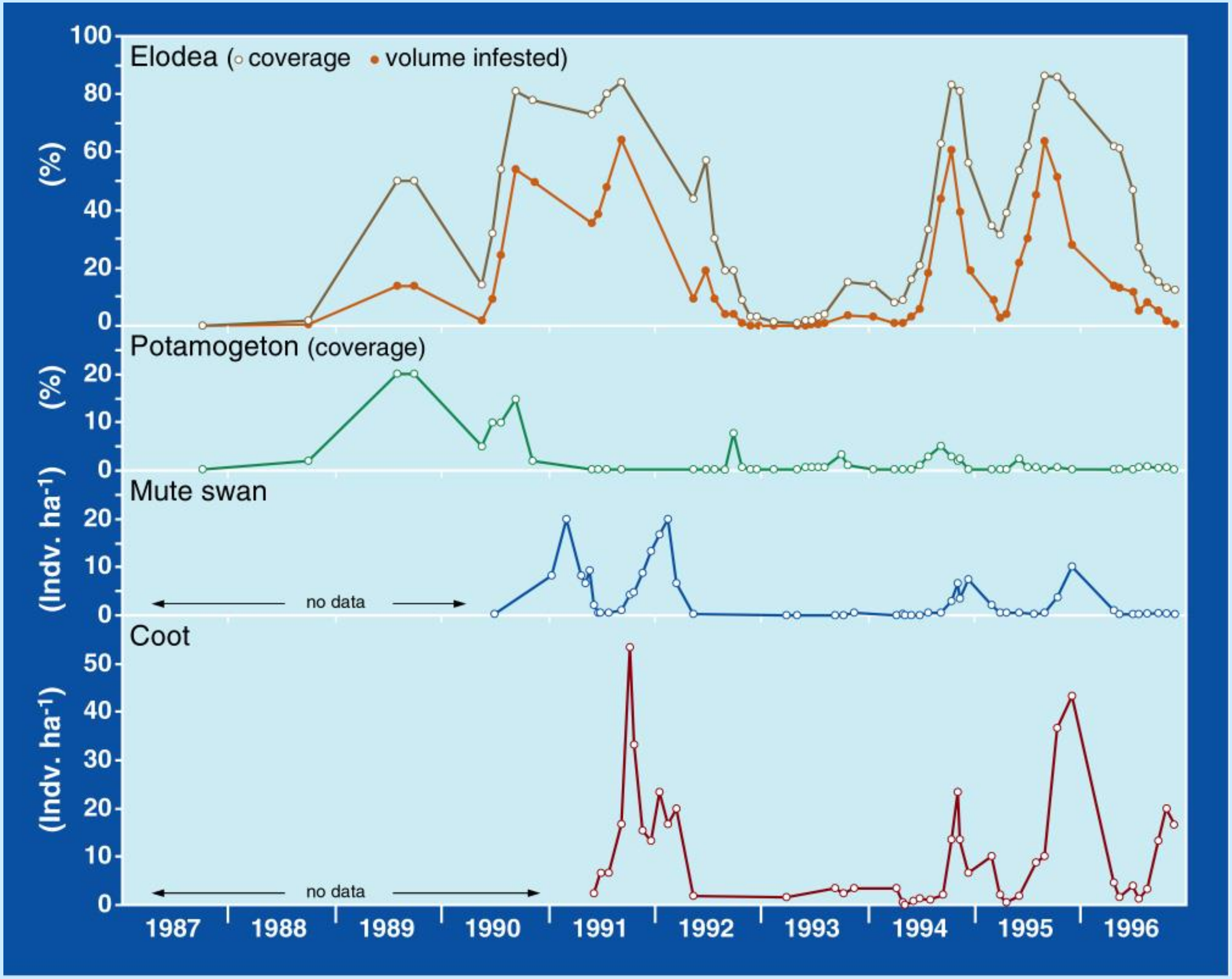
Chlorophyll, Secchi depth, TP and TN

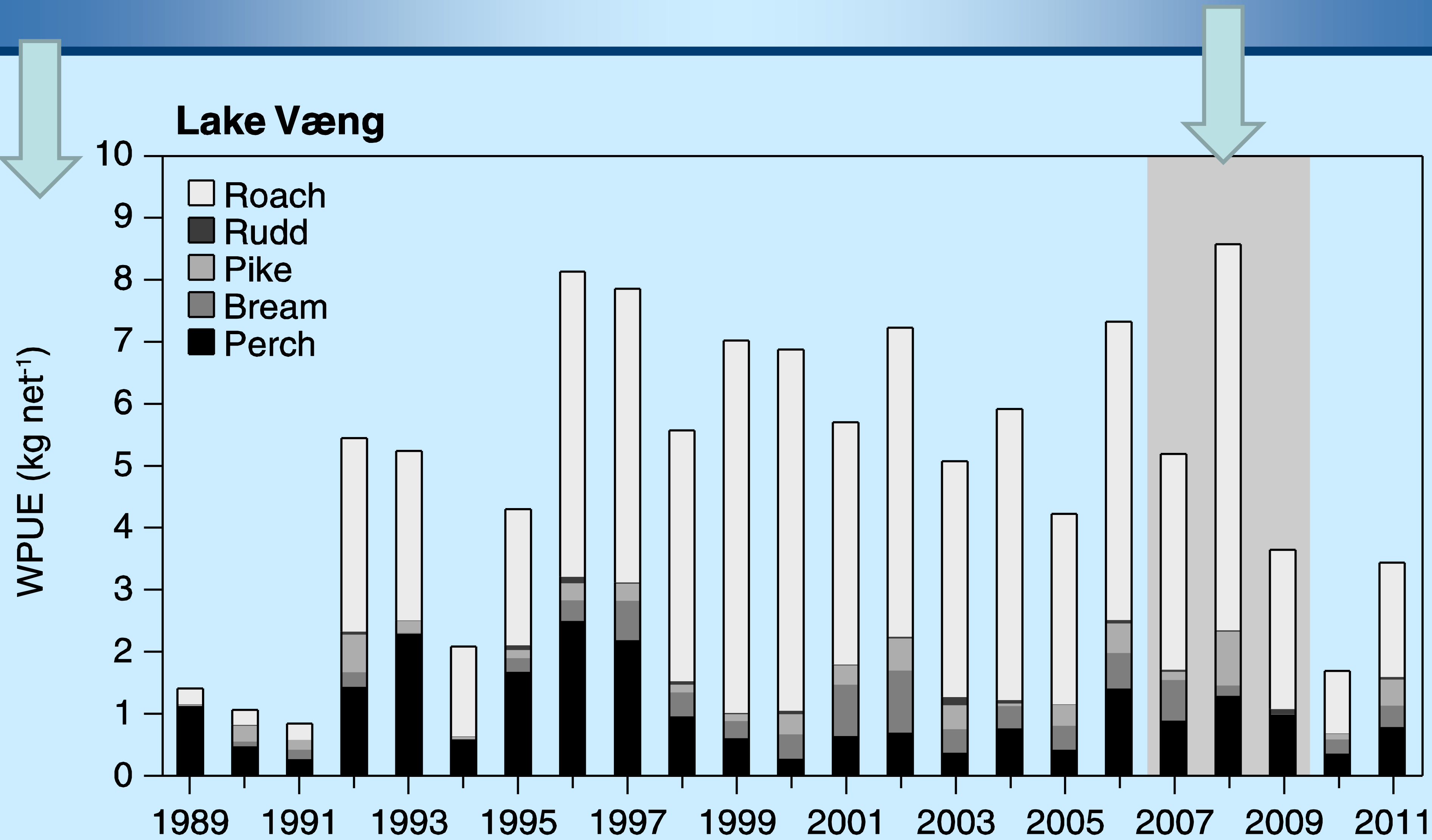


Fish and submerged macrophytes



Lake Væng: Waterfowl and macrophytes





50% less removed than first time

Jeppesen et al, 2012

Submerged macrophytes

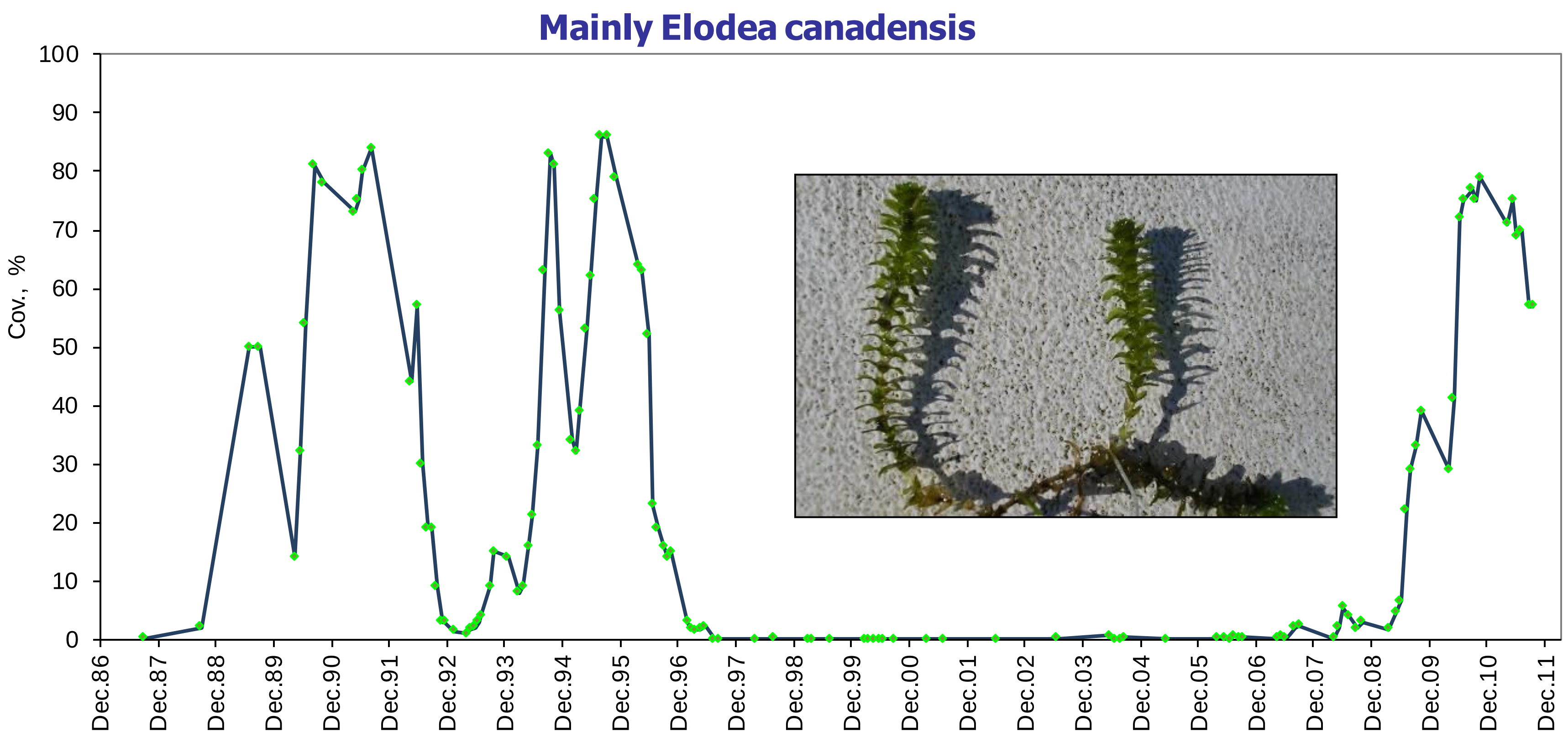
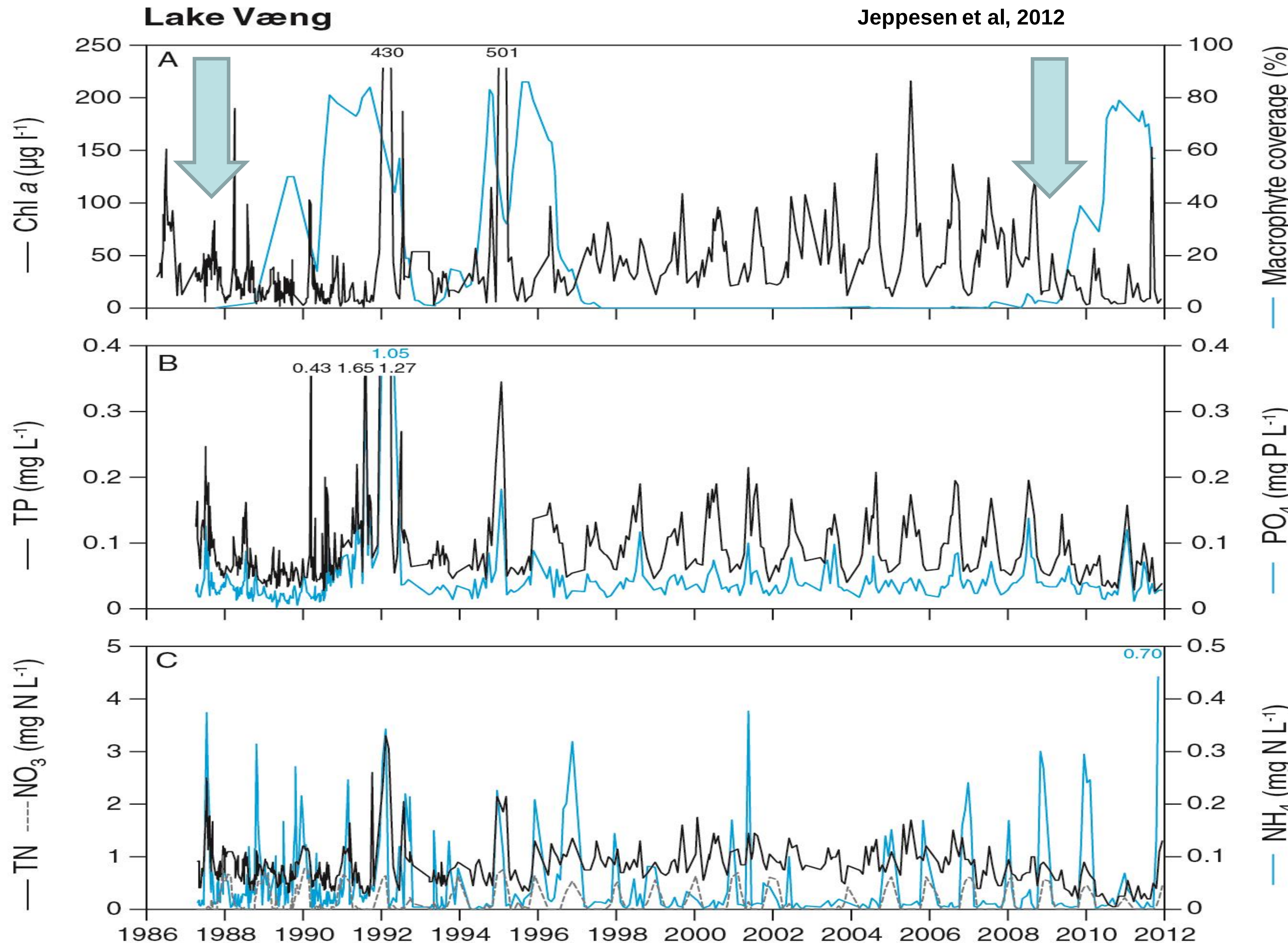
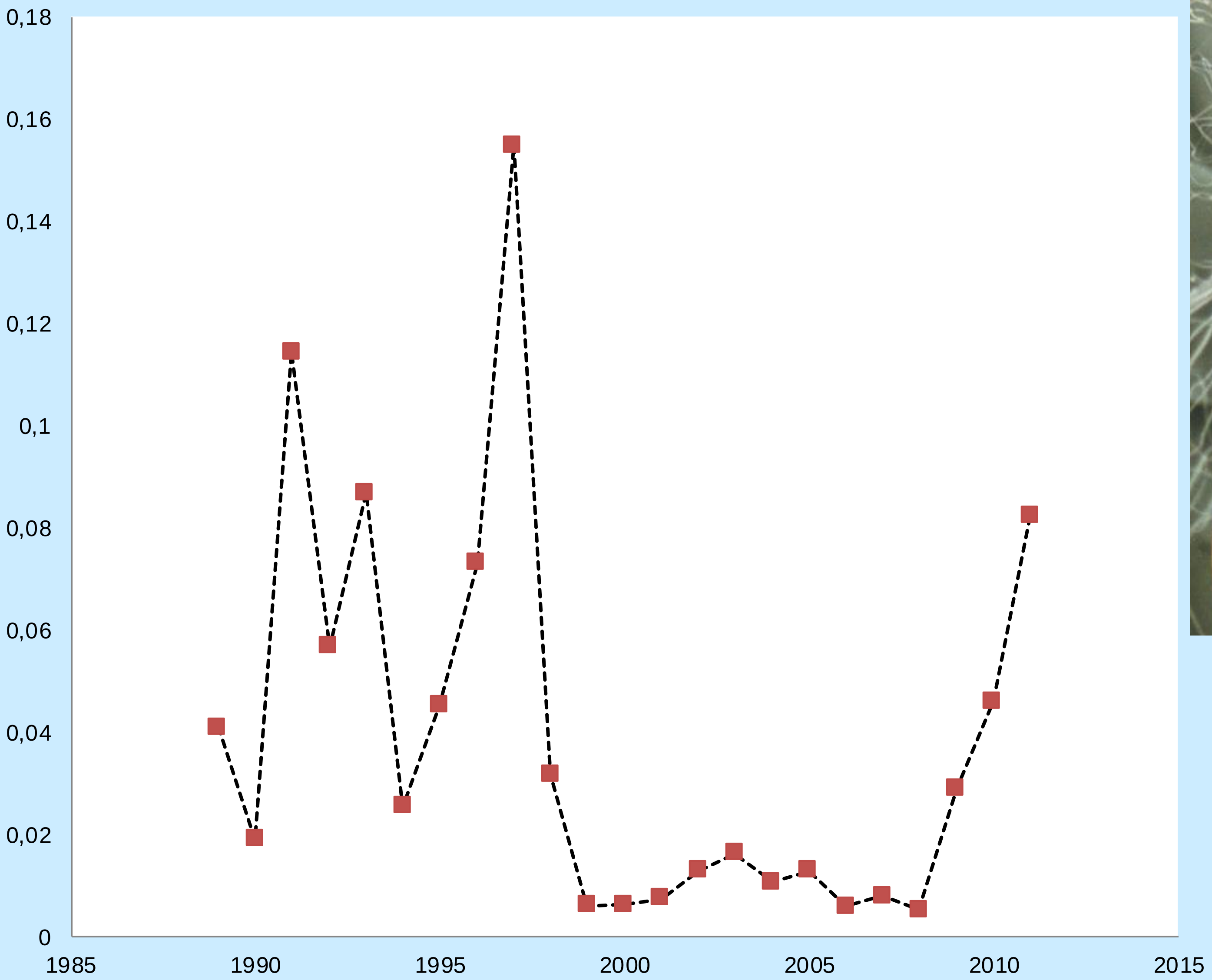


Figure 1. Macrophytes coverage in Lake Væng following the first and second biomanipulation in 1986-1988 and 2007-20009, respectively.


Lake Væng
Jeppesen et al, 2012
A
430
501
— Chl a (µg l-1)
— Macrophyte coverage (%)
B
0.43 1.65 1.27
1.05
— TP (mg L-1)
— PO4 (mg P L-1)
C
0.70
—TN ----NO3 (mg N L-1)
— NH4 (mg N L-1)
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012

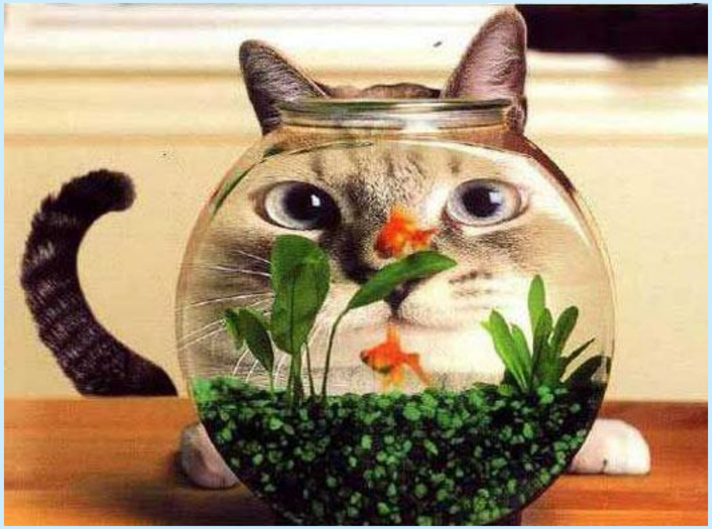
Individual mean body weight (kg) of perch in Lake Væng.



Fish removal: conclusions ?

Fish removal: conclusions

- If sufficent number of fish removed large effects on most trophic levels and nutrient concentrations.
- Clear effects in most lakes for 6-10 years.
- Thereafter less clear effects in most of the lakes (but only few long term data available).
- Repeated fish removal needed in most lakes to maintain effects (at least in nutrient rich lakes in this study).



Prerequisites for a successful restoration

- External loading reduced sufficiently, lake TP reduced to below 50 ug P/l in shallow lakes.
- Establishment of a high coverage of submerged macrophytes in shallow lakes.
- Internal P loading not controlling lake water TP
- Long term stability ?
- Sufficient action in restoration, i.e. high proportion of fish removed.

Reasons for failures (fish removal)

- Insufficient loading reduction
- Rapid return of zooplanktivorous fish, particularly roach
- Invertebrate predators (*Neomysis*)
- High resuspension of loose sediment
- Internal P loading from a sediment pool
- Instability due to low macrophyte coverage

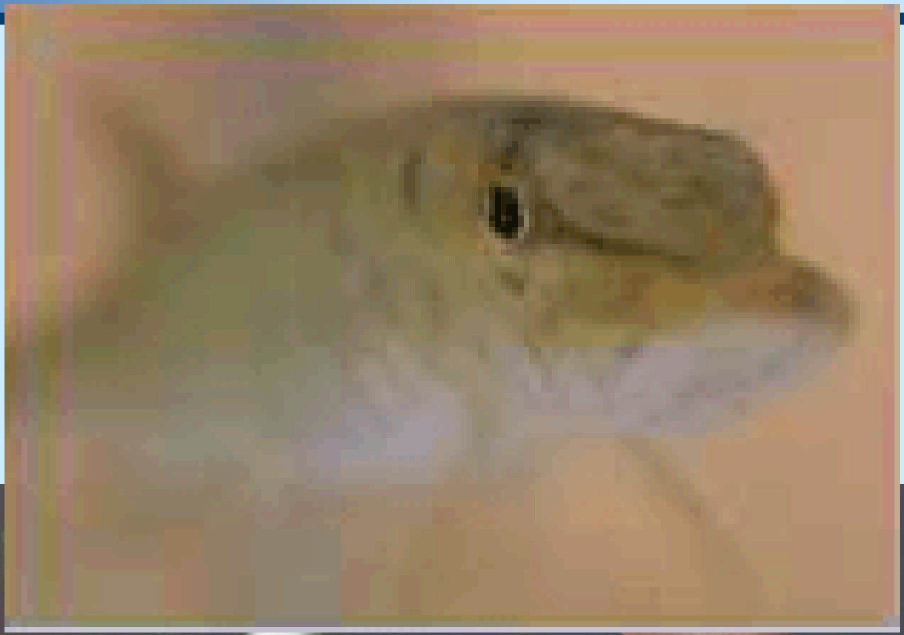
Next

Your lake----Østensjøvann

Reduce the external loading and biomanipulate it - and follow the development

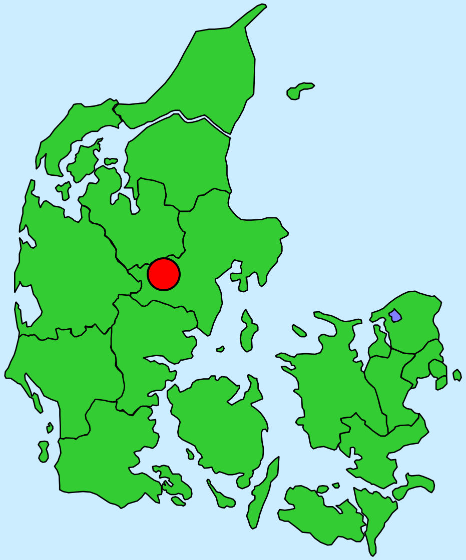
Be prepared that some less intensive follow- up removal might be needed

Pike stocking



Lyng Sø   pike stocking

- During 4 year stocked with 500-3600 pike fingerlings pr. ha.



Area: 10 ha

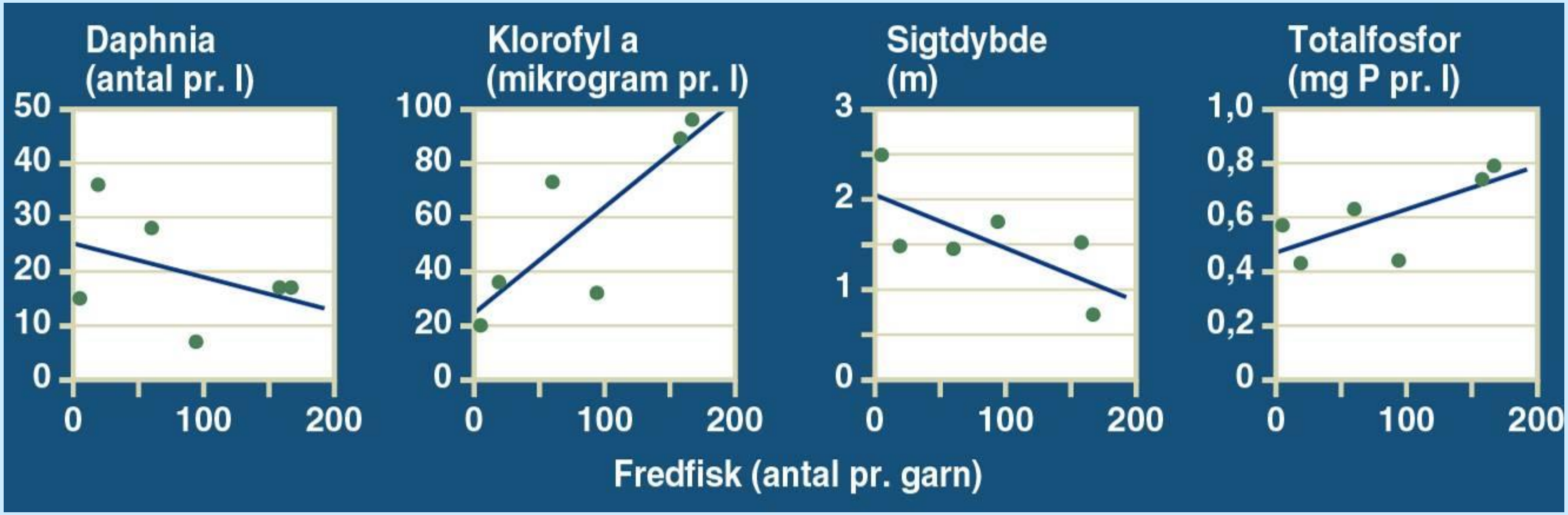
Mean depth: 2.4 m

Max. depth: 7.6 m

***Aim*: Stocking with piscivores to remove YOY-fish and improve zooplankton conditions**

Lyng Sø – results: pike stocking

- **Manipulation of the trophic cascade from YOY-fish to zooplankton and phytoplankton level.**
- **High stocking densities and multiple stockings needed to achieve top-down effects (> 1000 ind./ha)**



Overall results from 34 lakes, does however not show promissing results (report from DTU-AQUA)

- Only in very few lakes results can be seen.
- As a consequence it is now longer recommended as a seperate restoration method in Denmark

Yes	Maybe	Unknown	Likely not	No
1	3	22	8	0

Overall effects/conclusions

Type	Number of lakes	Ecological effect	Remarks/buts
Pike stocking	50		Few effects, timing very important
Fish removal	40		Clear effects, but repeated removal after 5-10 years often needed
Al treatment	6		Very clear short term effects, but long term effects ?
Oxygenation	6		Some effect, but long term treatment needed, permanent effects?
Sediment removal	1		Depends on loading, very expensive