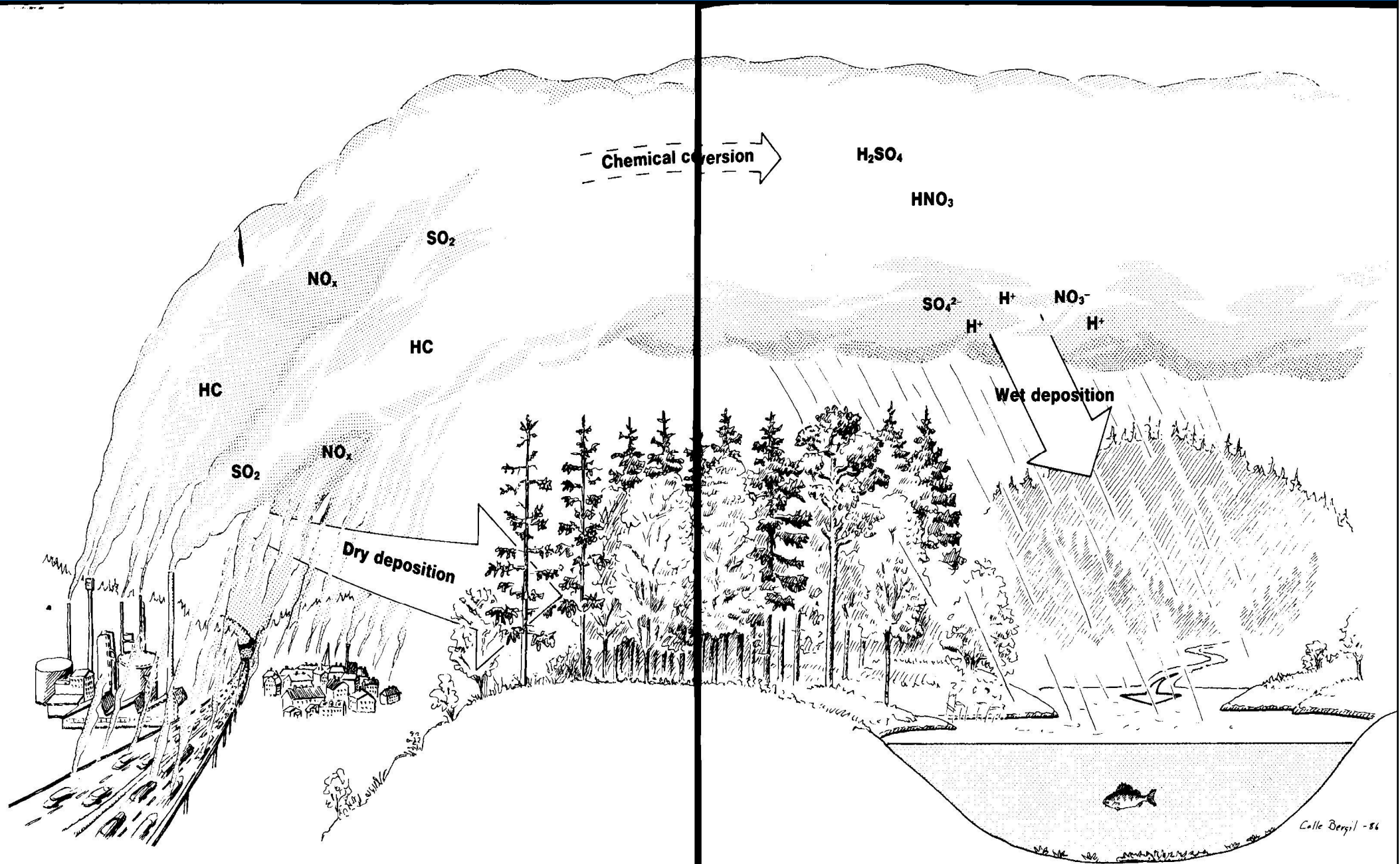


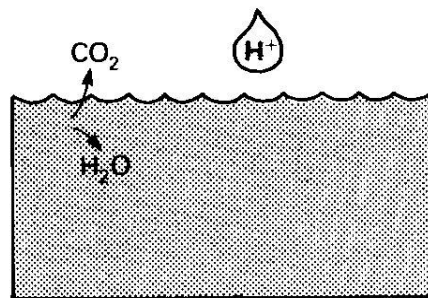
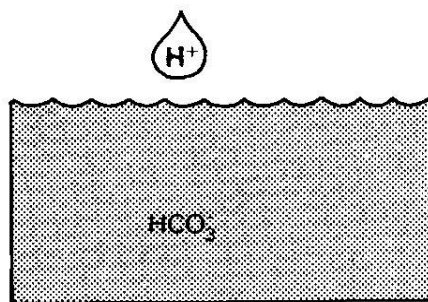
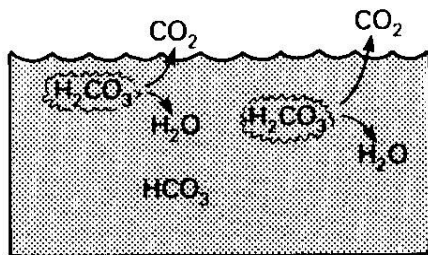
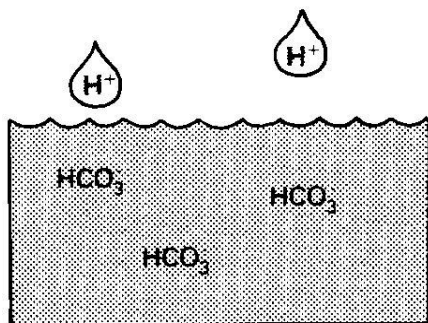
Acidifikace a zotavování jezer

- **Atmosférická depozice a acidifikace** povrchových vod
- **Černé jezero** – historie acidifikace na Šumavě
- **Dlouhodobé změny diverzity** v šumavských jezerech
- **Jedinečný plankton šumavských jezer**
- **Klíčová role hliníku** pro dostupnost fosforu a plankton
- **Plešné jezero** – dostupnost fosforu a zotavení planktonu
- **Plešné jezero** – model acidifikace a zotavení
- **Současné zotavování šumavských jezer**
- **Vápnění ... není řešení**
- **Teoretické předpoklady biologického zotavování**

Atmosférická acidifikace



Acidifikace

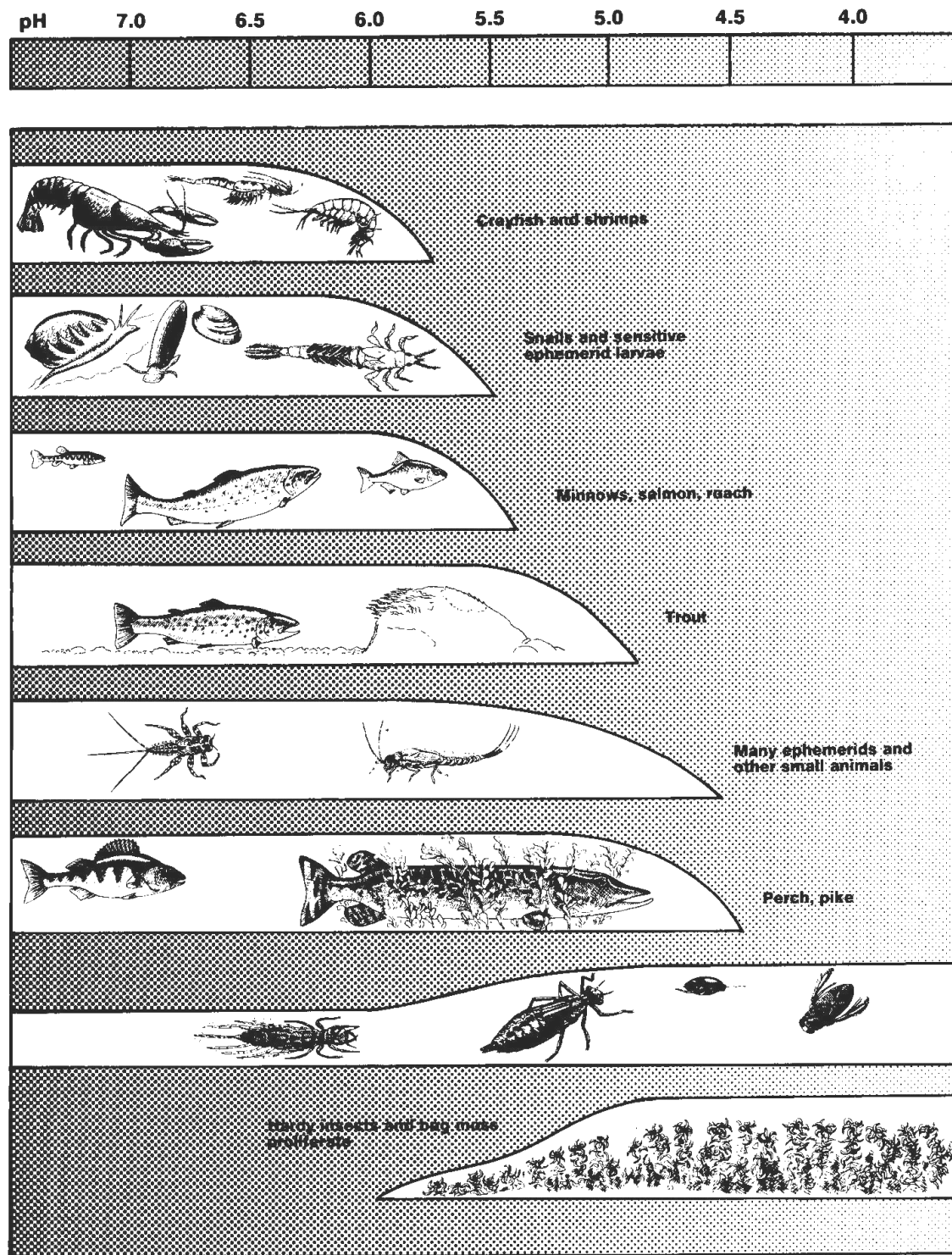


vyčerpání
uhlíčanového
pufrčního
systému

$SO_4 > NO_3 > CO_3$

nedostatek Ca

toxická Al



Acidifikace povrchových vod

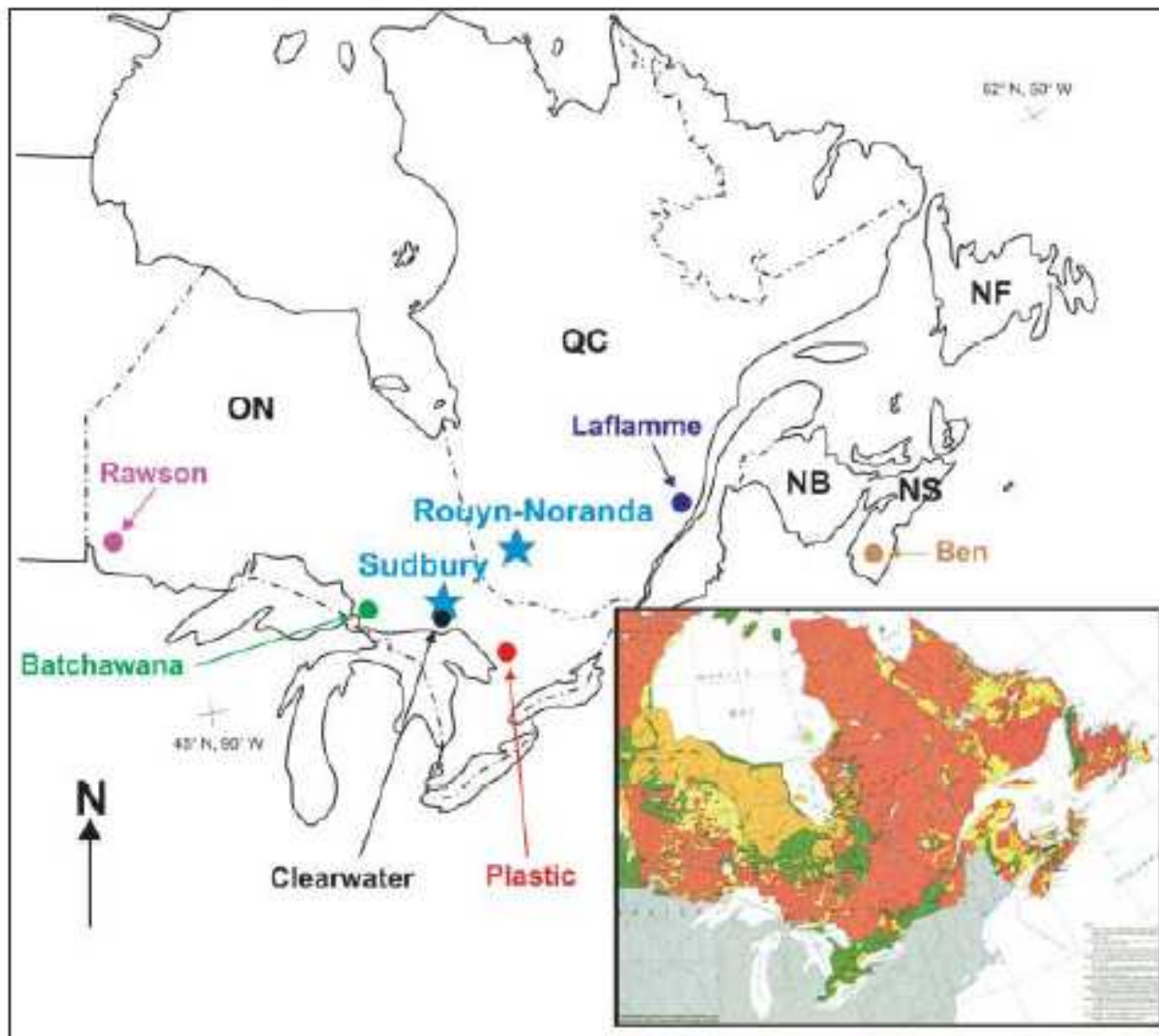
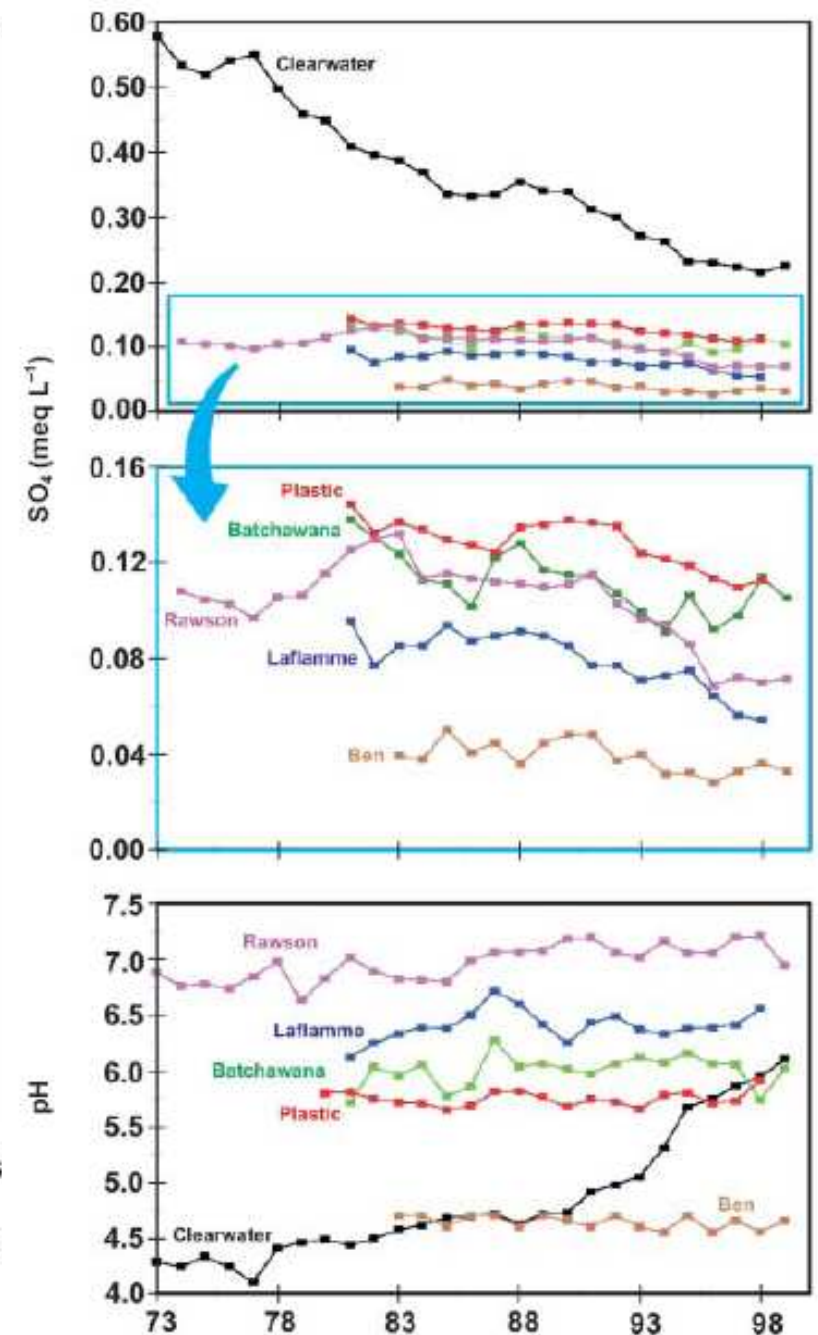
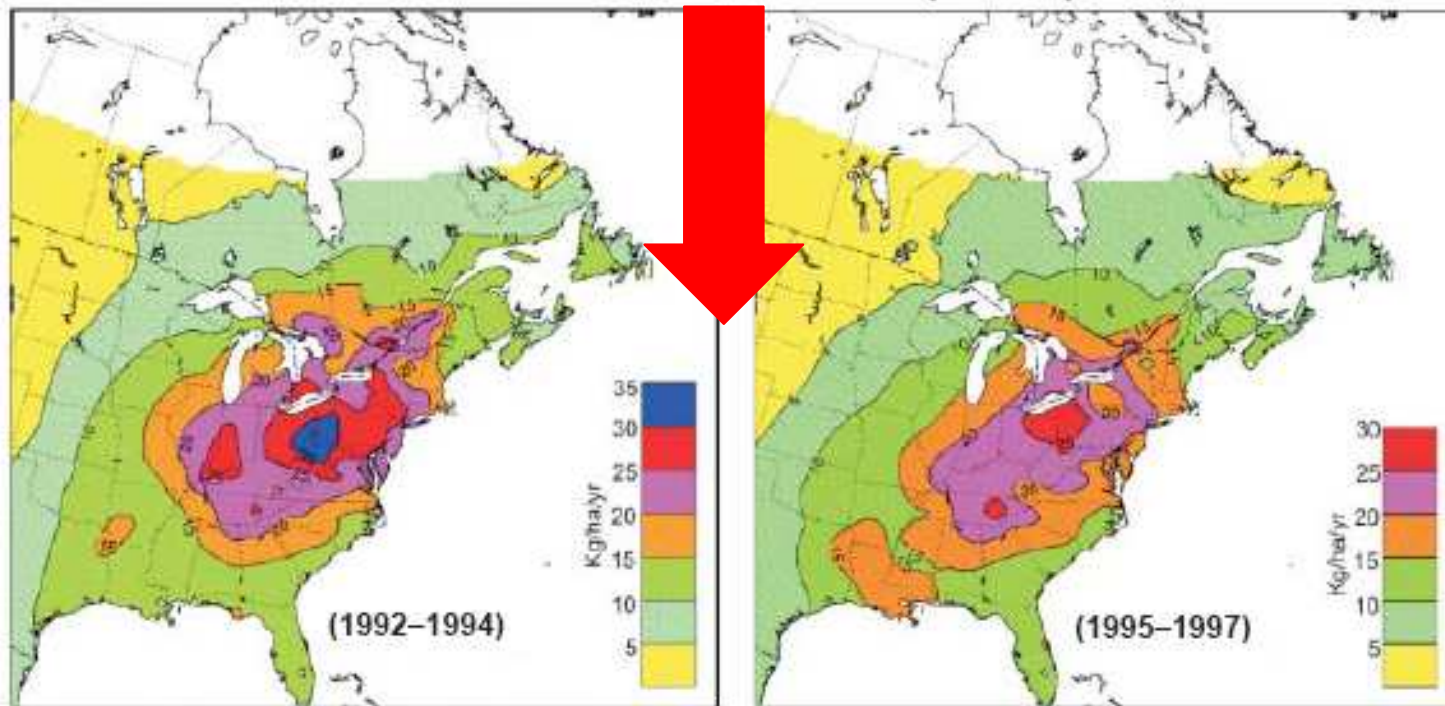


Figure 1. Map of southeastern Canada showing the location of provinces, smelters and the 6 lakes mentioned in the text (provincial abbreviations: Newfoundland = NF, Nova Scotia = NS, New Brunswick = NB, Quebec = QC, and Ontario = ON). Red coloration in the inset map denotes terrain that is sensitive to acidic deposition based on bedrock and soil characteristics (7).



Sea-salt Corrected Wet Sulfate Deposition



Wet Nitrate Deposition

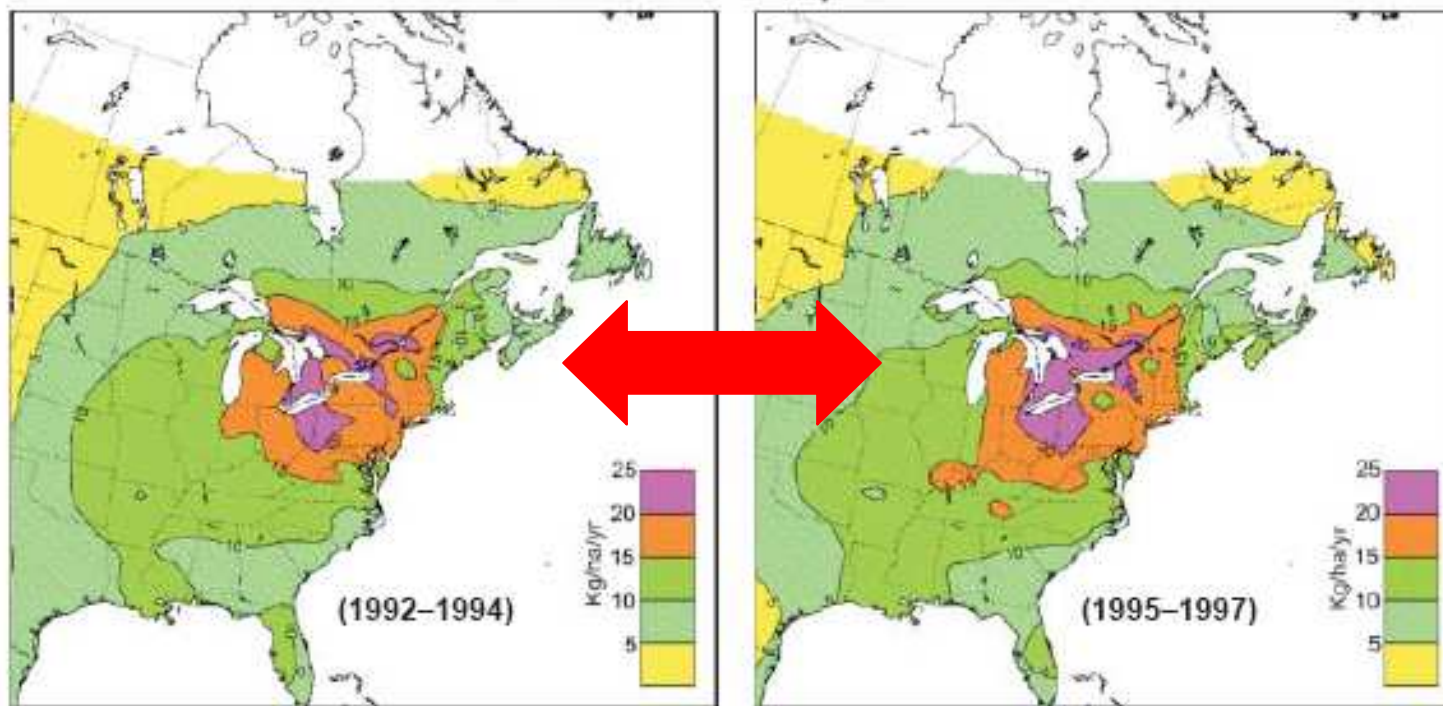


Table 1. Emissions of sulphur dioxide by regions: Current legislation (CLE) and maximum technically feasible reduction (MFR) scenarios. Million tonnes SO₂. Emissions from biomass burning, international shipping and aircraft are not included.

| Region | Emissions | | CLE scenario | | | MFR scenario | | |
|-------------------------------------|------------|------------|--------------|-----------|------------|--------------|-----------|-----------|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| Western Europe | 17.9 | 7.9 | 3.8 | 3.1 | 2.9 | 1.4 | 1.3 | 1.2 |
| Central and Eastern Eur. | 11.1 | 5.9 | 4.1 | 2.6 | 2.3 | 0.8 | 0.6 | 0.6 |
| Newly Independent States | 19.5 | 11.1 | 7.8 | 6.0 | 6.3 | 1.8 | 1.7 | 1.7 |
| Centrally Planned Asia ¹ | 22.0 | 28.4 | 30.9 | 31.1 | 29.4 | 6.7 | 6.6 | 6.4 |
| South Asia | 4.8 | 7.6 | 11.0 | 17.3 | 22.5 | 1.9 | 2.6 | 3.3 |
| Pacific OECD | 2.7 | 2.6 | 2.8 | 2.1 | 1.5 | 0.6 | 0.5 | 0.5 |
| Other Pacific Asia | 5.1 | 4.3 | 5.4 | 6.9 | 8.7 | 1.5 | 1.8 | 2.0 |
| North America | 24.4 | 18.5 | 16.4 | 15.9 | 17.5 | 2.9 | 3.2 | 3.3 |
| Latin Am. and Caribbean | 6.7 | 6.2 | 6.8 | 5.8 | 5.3 | 1.8 | 1.8 | 1.7 |
| M. East and N. Africa | 3.1 | 5.0 | 3.5 | 2.8 | 2.4 | 0.8 | 0.7 | 0.7 |
| Sub-Saharan Africa | 4.8 | 5.4 | 4.9 | 5.2 | 5.8 | 1.3 | 1.3 | 1.3 |
| World Total | 122 | 103 | 97 | 99 | 104 | 22 | 22 | 23 |

¹ Including China.

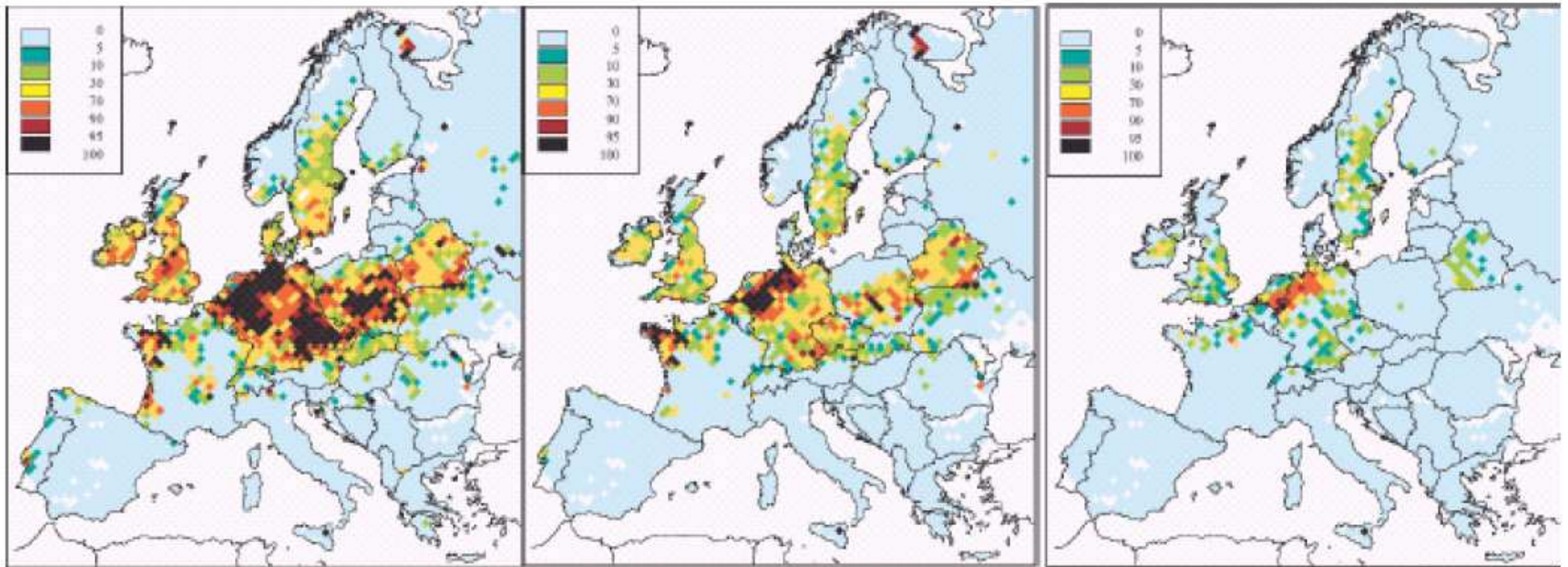
Table 2. Emissions of nitrogen oxides by regions: Current legislation (CLE) and maximum technically feasible reduction (MFR) scenarios. Million tonnes NO₂. Emissions from biomass burning, international shipping and aircraft are not included.

| Region | Emissions | | CLE scenario | | | MFR scenario | | |
|-------------------------------------|-----------|-----------|--------------|-----------|-----------|--------------|-----------|-----------|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| Western Europe | 14.1 | 10.8 | 7.5 | 6.0 | 6.1 | 2.8 | 3.0 | 3.1 |
| Central and Eastern Eur. | 3.5 | 2.8 | 2.0 | 1.7 | 1.8 | 0.6 | 0.6 | 0.7 |
| Newly Independent States | 11.2 | 7.2 | 6.7 | 5.9 | 6.7 | 1.5 | 1.6 | 1.8 |
| Centrally Planned Asia ¹ | 7.8 | 12.3 | 13.8 | 15.0 | 16.2 | 3.7 | 4.2 | 4.5 |
| South Asia | 3.1 | 5.4 | 7.6 | 9.7 | 11.6 | 1.9 | 2.4 | 2.9 |
| Pacific OECD | 3.7 | 3.7 | 3.4 | 3.2 | 2.8 | 1.2 | 1.1 | 1.0 |
| Other Pacific Asia | 3.5 | 5.6 | 5.8 | 6.9 | 8.2 | 1.6 | 2.0 | 2.4 |
| North America | 23.4 | 19.9 | 18.3 | 20.8 | 22.2 | 5.7 | 6.3 | 6.8 |
| Latin Am. and Caribbean | 5.5 | 6.4 | 6.0 | 5.8 | 6.3 | 1.3 | 1.5 | 1.7 |
| M. East and N. Africa | 2.6 | 3.3 | 2.6 | 2.8 | 3.1 | 0.7 | 0.8 | 0.8 |
| Sub-Saharan Africa | 2.6 | 3.7 | 3.7 | 4.8 | 6.7 | 1.1 | 1.2 | 1.4 |
| World Total | 81 | 81 | 77 | 82 | 92 | 22 | 25 | 27 |

¹ Including China.

N = acid

Figure 3. Percentage of forest area receiving acid deposition above the critical loads for acidification. For the emission levels in the year 2000 (left), and for two projected emission levels for 2020: CLE (centre) and MTR (right).



2000

2020 CLE

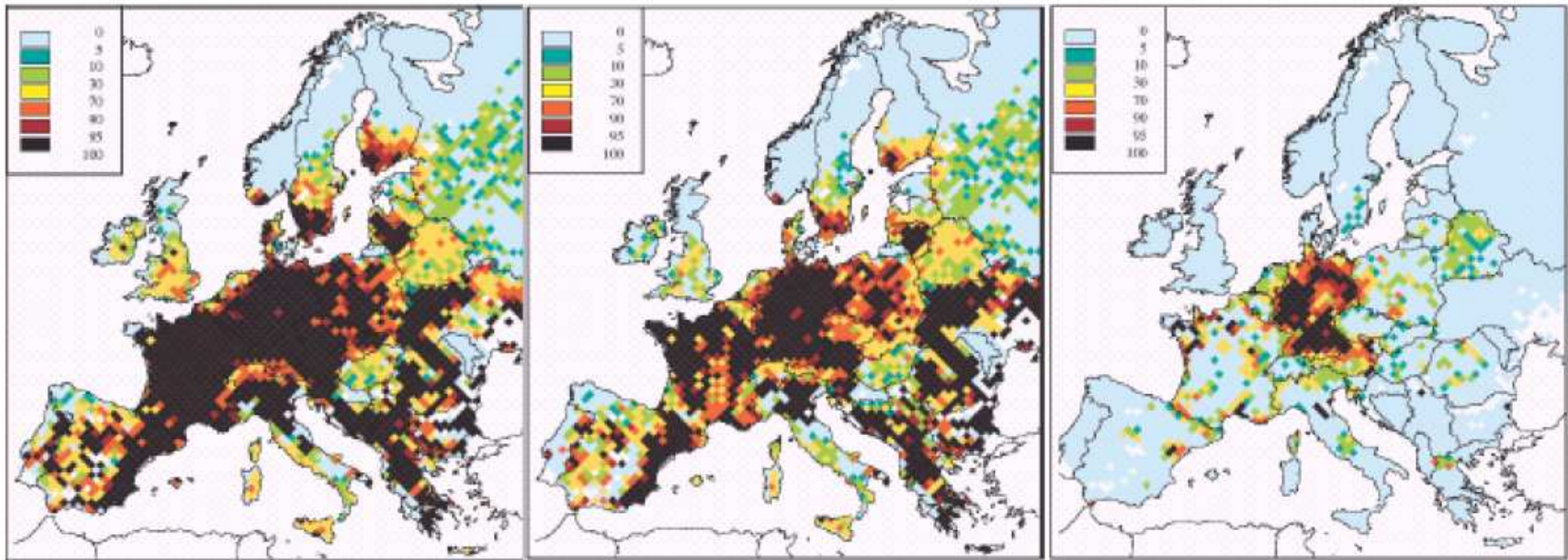
2020 MTR

Current legislation
scenario

Maximum technically
feasible reduction

N = nutrient

Figure 4. Percentage of total ecosystems receiving nitrogen deposition above the critical loads for eutrophication. For the emission levels in the year 2000 (left), and for two projected emission levels for 2020: CLE (centre) and MTRF (right).



2000

2020 CLE

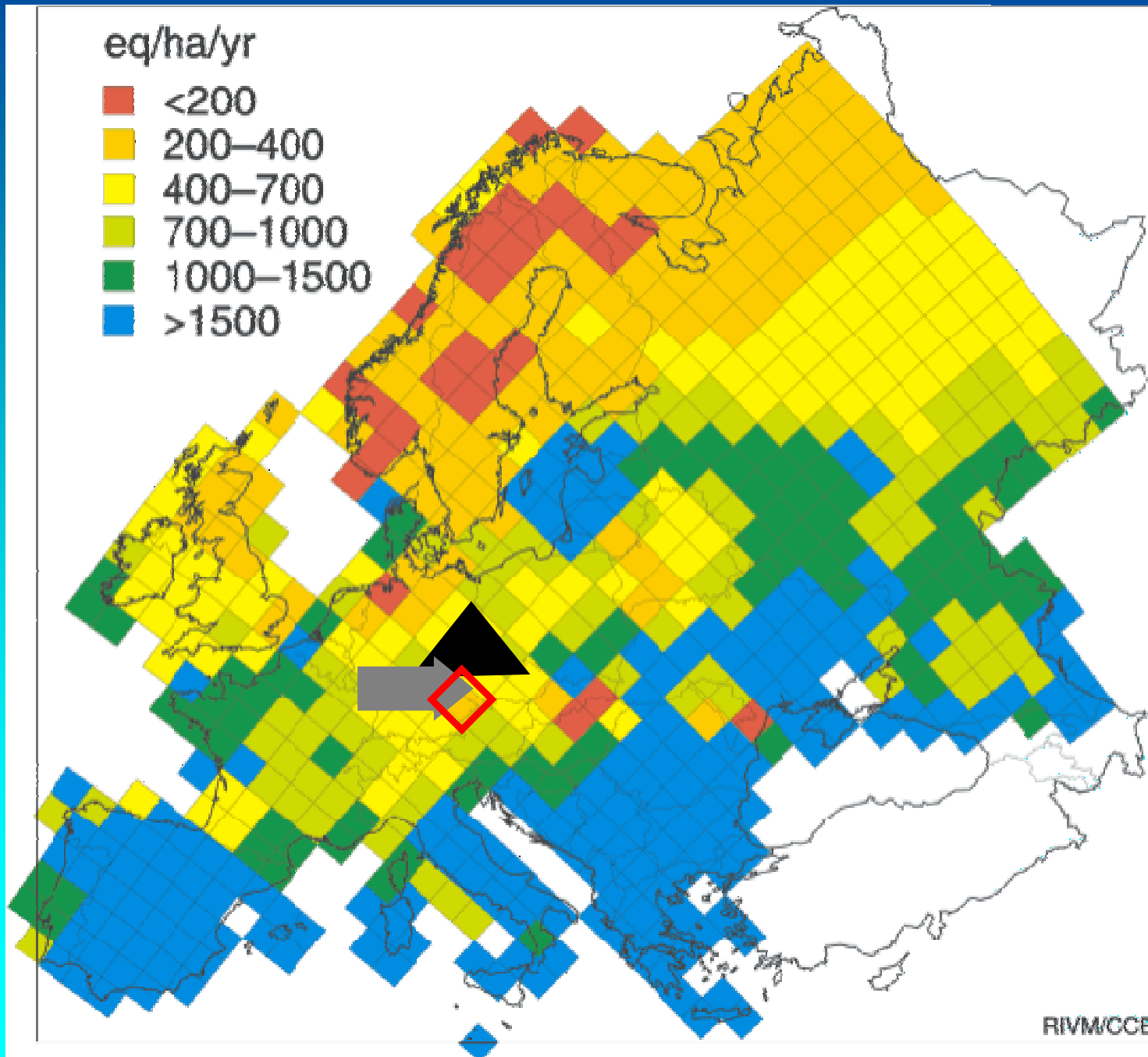
2020 MTRF

Current legislation
scenario

Maximum technically
feasible reduction

Critical loads for acid deposition in Europe

http://www.acidrain.org/cl_acid.htm



Dlouhodobý limnologický výzkum šumavských jezer...

- 1871–1872: A. Frič & B. Hellich
- 1893–1896: A. Frič & V. Vávra (létající stanice); P. Wagner
- 1903–1912: V. Švambera; A. Černý
- 1935–1936: O. Jírovec, R. Šrámek-Hušek & J. Šámal
- 1947: J. Weiser
- od 1956: V. Landa a kol., T. Soldán a kol. (ENTÚ)
- 1960–1961: J. Hrbáček a kol. (HBL); M. Novák
- od 1979: J. Fott a kol., E. Stuchlík a kol. (PřF UK)
- od 1984: J. Veselý (ČGÚ)
- od 1985: V. Sraškrábová a kol., J. Kopáček a kol. (HBÚ)
- po 1990: J. Lukavský a kol. (BÚ); B. Jánský a kol. (PřF UK)
- po 2000: M. Čtvrtlíková a kol. (PřF UP)

1. Hydrobiologický výzkum šumavských jezer – od 1871

- zooplankton – redukce, vyhynutí, zotavení
- ryby – původní stav, introdukce, vyhynutí
- barva vody & průhlednost
- jezerní chemismus – citlivé měkké vody
- fytoplankton – složení, biomasa

2. Historická data

např. průzkum a těžba rud, sklárny, pastva, těžba dřeva, lesní hospodářské plány, stavba hrází a plavení dříví, vysazování ryb atd.

3. Paleolimnologie

např. pylové analýzy, rozsivkové pH, chemismus, těžké kovy, organické polutanty atd.

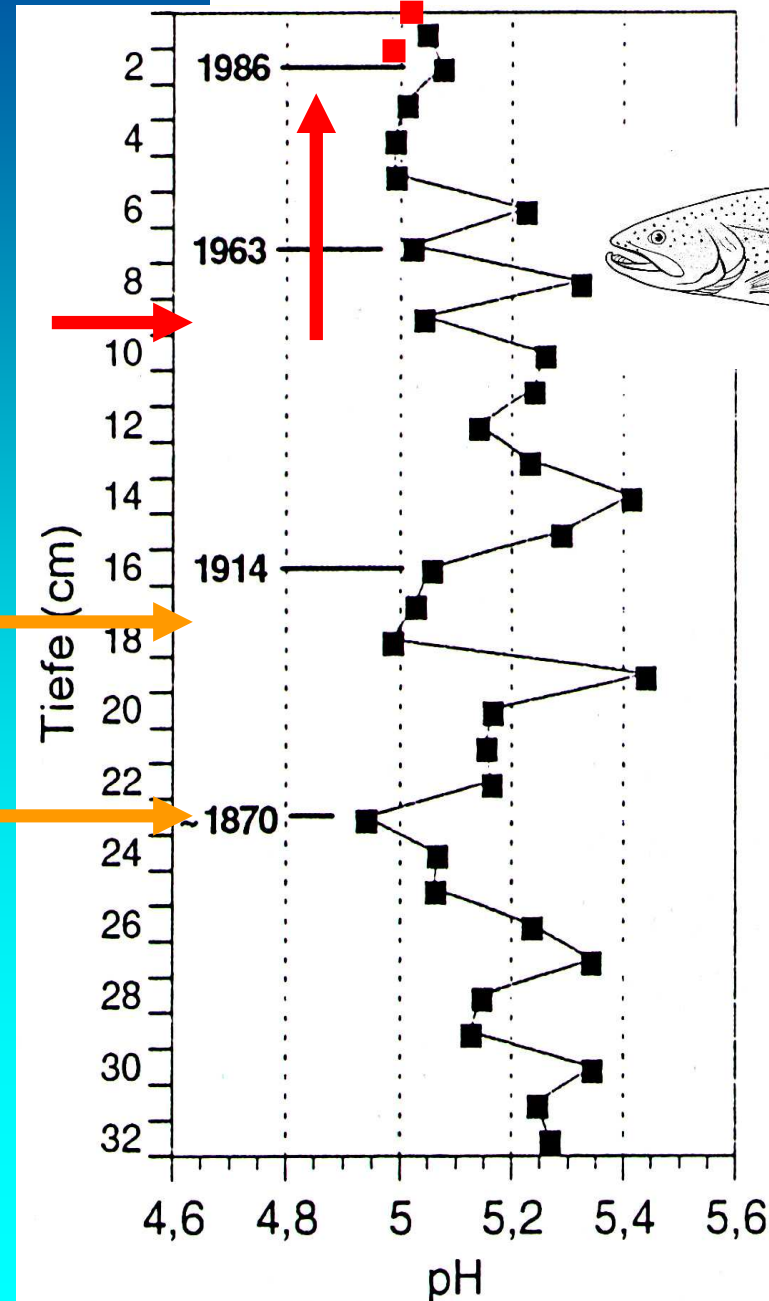


Großer Arbersee, diatom-inferred pH from the lake sediment (Steinberg et al. 1998)

Atmospheric acidification
(due to remote pollution)

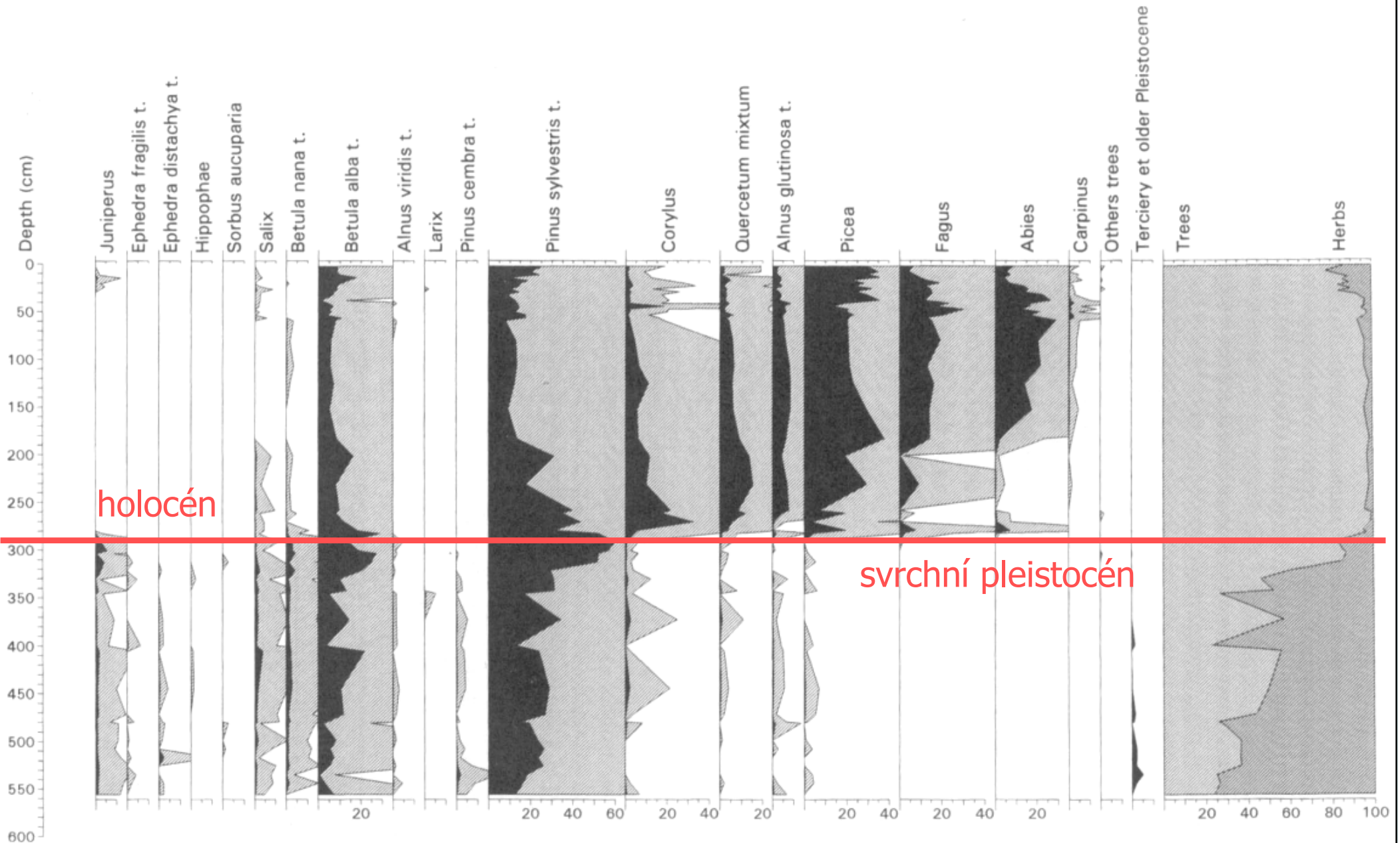
Temporary acidification
(due to local pollution
from Bodenmais)

Reversal ■
(present lakewater pH ~6)



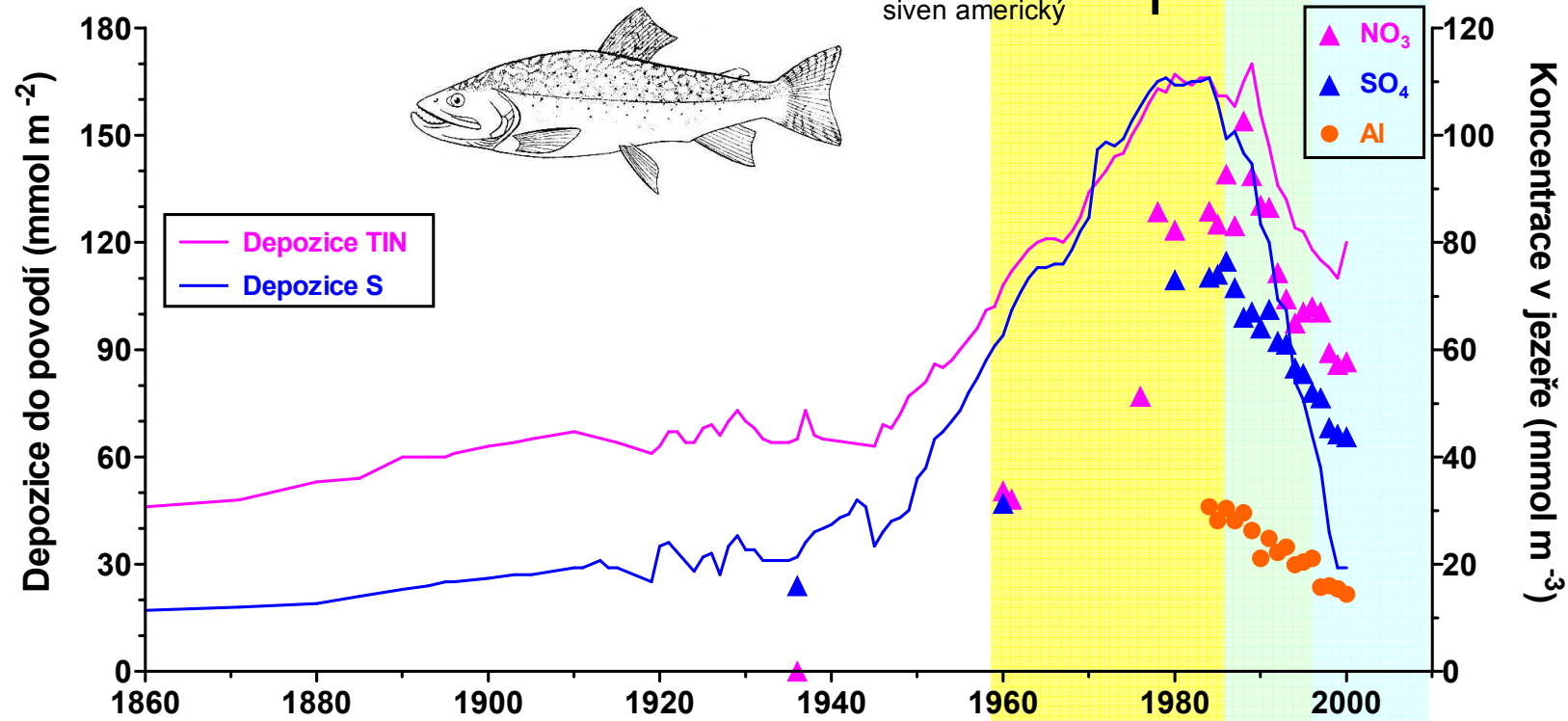
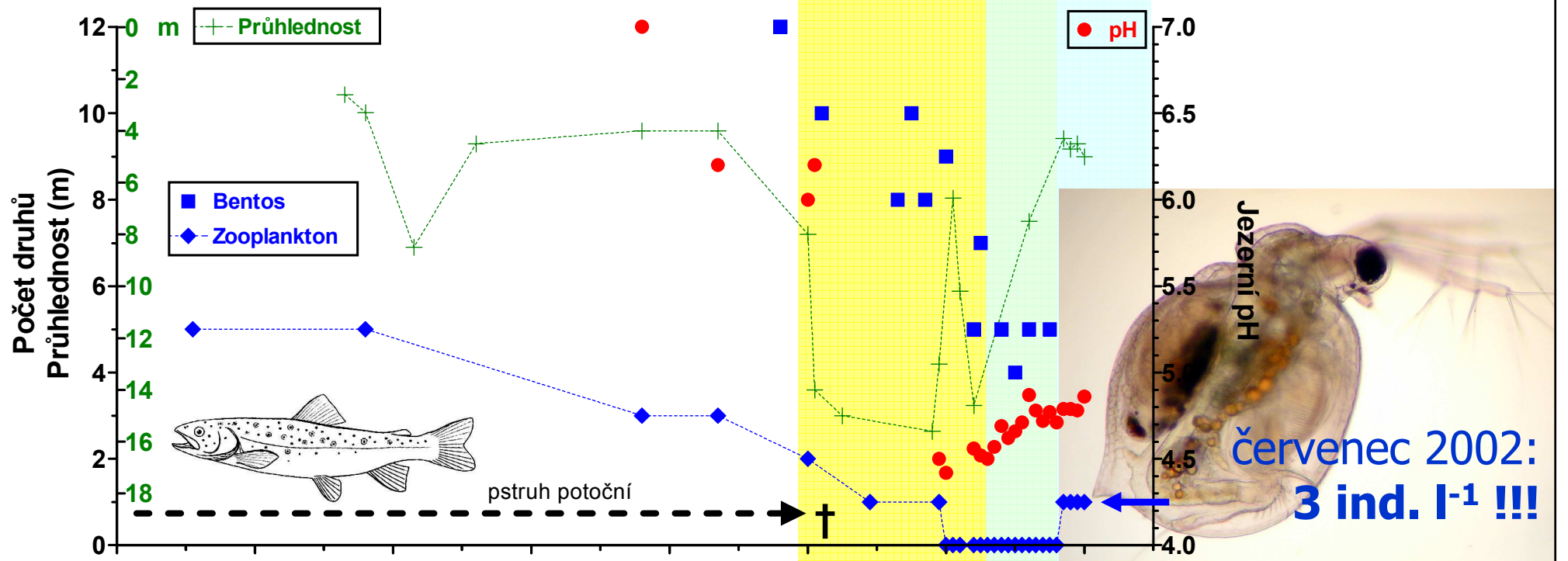
Plešné jezero, pylový diagram (Jankovská 2004)

PLEŠNE JEZERO-Lake, Sumava Mts., S Bohemia
1090 m asl., 48°47'N, 13°52'E
CZECH REPUBLIC



Černé jezero 1871 – 2003

historie (nejen) jedné acidifikace

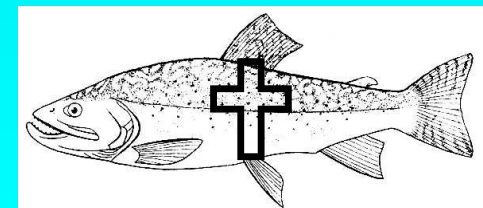
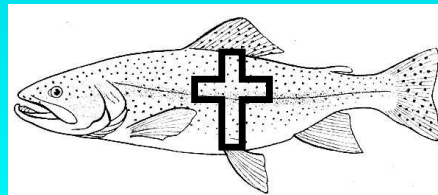
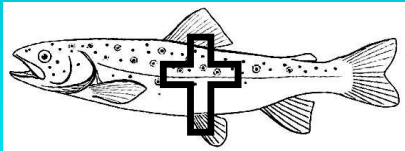


Historický výskyt (vysazování) ryb v jednotlivých šumavských jezerech

Pstruh potoční (původní)
Pstruh potoční (vysazovaný)
Pstruh duhový
Siven americký

| CN | CT | RA | PL | KA | PR | GA | LA |
|----|----|----|----|----|----|----|----|
| ■ | ■ | ? | ? | ■ | ? | ■ | ■ |
| □ | □ | ■ | ■ | □ | ■ | □ | ■ |
| □ | □ | □ | □ | ■ | □ | ■ | □ |
| ■ | □ | □ | ■ | □ | ■ | □ | ■ |

VYHYNULÝ
NEPŘÍTOMNÝ
NEJASNÝ



Historický výskyt nápadných druhů koryšů v zooplanktonu jednotlivých šumavských jezer



- Bosmina longispina*
- Ceriodaphnia quadrangula*
- Daphnia longispina* (*D. rosea*)
- Holopedium gibberum*
- Polyphemus pediculus*
- Acanthodiaptomus denticornis*
- Cyclops abyssorum*
- Heterocope saliens*



- PŘEŽÍVAJÍCÍ
- VYHYNULÝ
- NEPŘÍTOMNÝ
- PALEOLIMNOGICKY OVĚŘEN V SEDIMENTECH

| CN | CT | RA | PL | KA | PR | GA | LA |
|------------------|-------|-------|-------|------------------|----------------------------|------------------|------------------|
| Red | Red | White | White | White | Red | Red | White |
| Blue with smiley | Red | White | White | Blue with smiley | Blue with smiley | Blue with smiley | Blue with smiley |
| Red | Red | Red | Red | White | Blue with exclamation mark | Red | Blue |
| Red | Red | White | White | Red | White | Blue | White |
| Red | Red | White | White | Red | Blue | Blue | Blue |
| Red | Red | White | Red | Red | Red | Red | White |
| Red | Red | Red | Red | White | Blue with exclamation mark | Blue | White |
| White | White | Red | Blue | White | White | White | White |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 3 | 4 | 3 |
| 6 | 7 | 3 | 3 | 3 | 3 | 3 | 0 |

Dnes na Šumavě:

- NE
- ANO
- ANO
- ANO
- ANO
- NE
- ANO
- ANO



potenciální druhy pro zotavení



Historický výskyt jepic a pošvatek v makrozoobentosu jednotlivých šumavských jezer (50. léta 20. stol.)

- Siphonurus lacustris*
- Siphonurus alternatus*
- Ameletus inopinatus*
- Cloeon dipterum*
- Leptophlebia vespertina*
- Amphinemura triangularis*
- Protonemura auberti*
- Protonemura montana* + *P. hrabei*
- Nemoura cinerea*
- Nemurella picteti*
- Leuctra aurita*
- Leuctra autumnalis*
- Leuctra digitata*
- Leuctra fusca*
- Leuctra handlirschi*
- Leuctra nigra*

| | CN | CT | RA | PL | KA | PR | GA | LA |
|---|--------|--------|--------|--------|--------|--------|--------|--------|
| <i>Siphonurus lacustris</i> | Red | Red | Yellow | Red | Yellow | Red | Yellow | Blue |
| <i>Siphonurus alternatus</i> | Red | White | Yellow | Red | Yellow | Red | Yellow | Red |
| <i>Ameletus inopinatus</i> | Red | Red | Yellow | Red | Yellow | Red | Yellow | Red |
| <i>Cloeon dipterum</i> | White | White | Yellow | White | Yellow | White | Yellow | Red |
| <i>Leptophlebia vespertina</i> | Smiley | Smiley | Yellow | Smiley | Yellow | Smiley | Yellow | Smiley |
| <i>Amphinemura triangularis</i> | Blue | White | Yellow | Blue | Yellow | Red | Yellow | Blue |
| <i>Protonemura auberti</i> | Red | Red | Yellow | Red | Yellow | Red | Yellow | Red |
| <i>Protonemura montana</i> + <i>P. hrabei</i> | Blue | Blue | Yellow | Blue | Yellow | Red | Yellow | Blue |
| <i>Nemoura cinerea</i> | Red | Red | Yellow | Red | Yellow | Red | Yellow | Red |
| <i>Nemurella picteti</i> | White | Red | Yellow | Red | Yellow | Red | Yellow | Red |
| <i>Leuctra aurita</i> | Blue | White | Yellow | Blue | Yellow | Red | Yellow | Blue |
| <i>Leuctra autumnalis</i> | White | White | Yellow | Red | Yellow | Red | Yellow | White |
| <i>Leuctra digitata</i> | Blue | Blue | Yellow | Blue | Yellow | Blue | Yellow | Blue |
| <i>Leuctra fusca</i> | Red | White | Yellow | White | Yellow | Red | Yellow | Red |
| <i>Leuctra handlirschi</i> | White | Red | Yellow | Red | Yellow | White | Yellow | White |
| <i>Leuctra nigra</i> | Red | White | Yellow | Red | Yellow | Red | Yellow | Red |

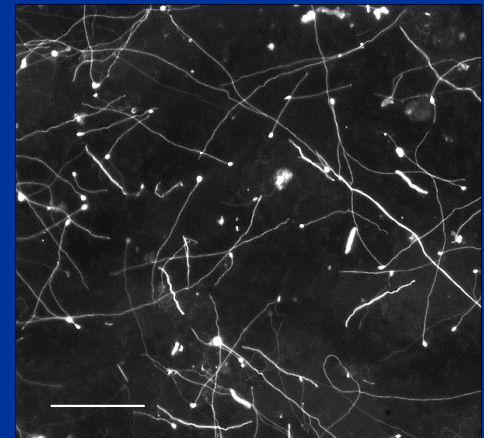
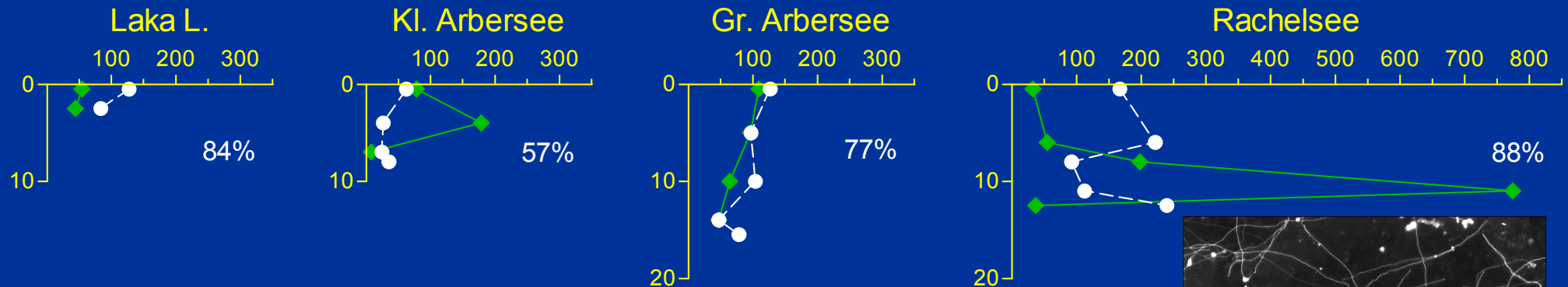
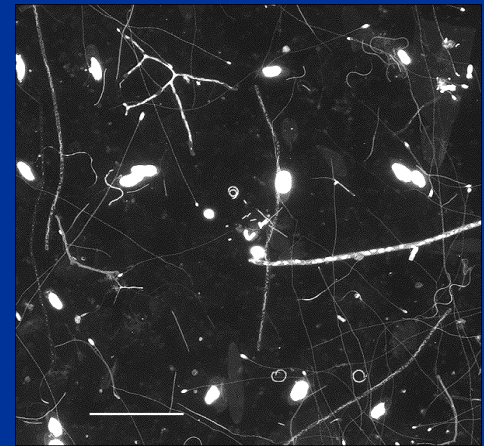
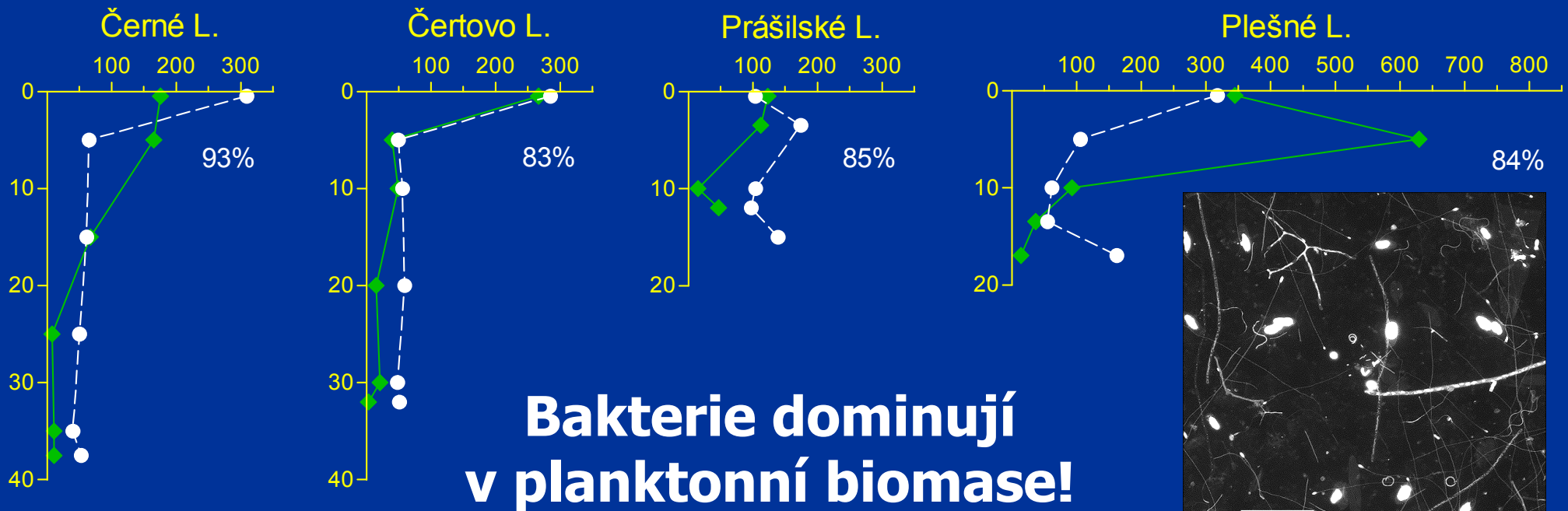


PŘEŽÍVAJÍCÍ
 VYHYNULÝ
 NEPŘÍTOMNÝ

| | | | | |
|---|---|---|------|---|
| 5 | 3 | 5 | 2 | 6 |
| 7 | 6 | 9 | 12 ? | 8 |



Nanoplankton biomass ($\mu\text{g C l}^{-1}$) in acidified lakes in the Bohemian Forest (September 1999)



-●- Heterotrophic biomass (HB)
 -◆- Phytoplankton biomass (PB)

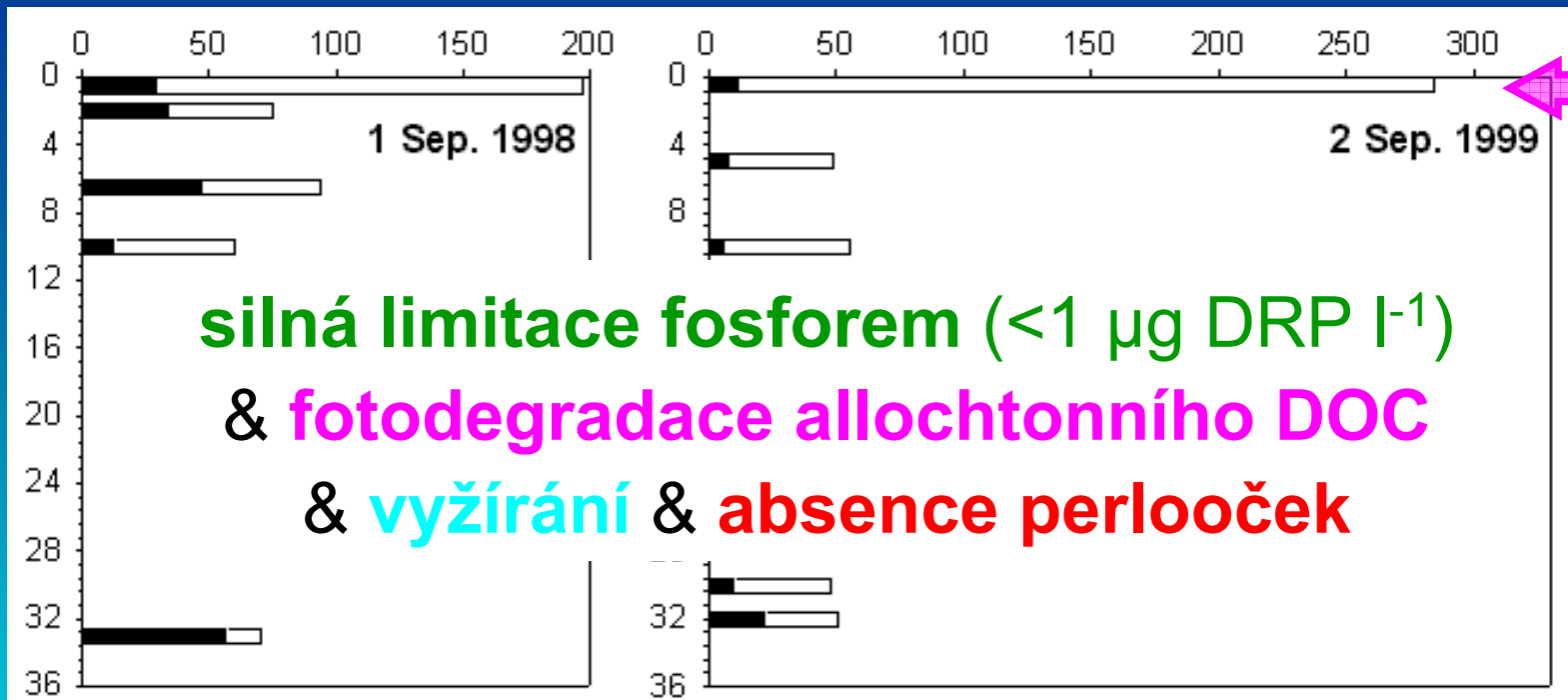
% of heterotrophic filaments (mean) in HB

Vertikální profily heterotrofní biomasy ($\mu\text{g C l}^{-1}$)

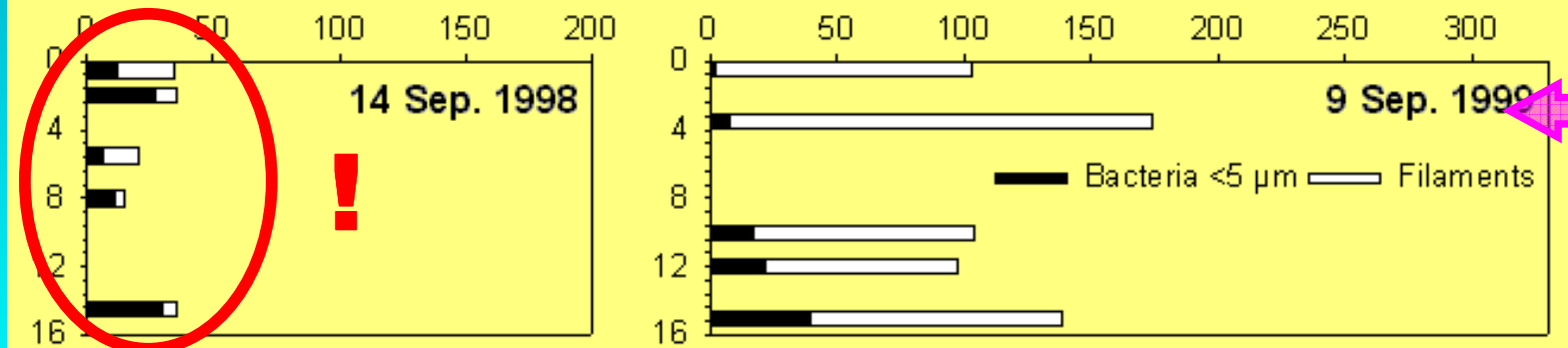
Čertovo
jezero

?

metry

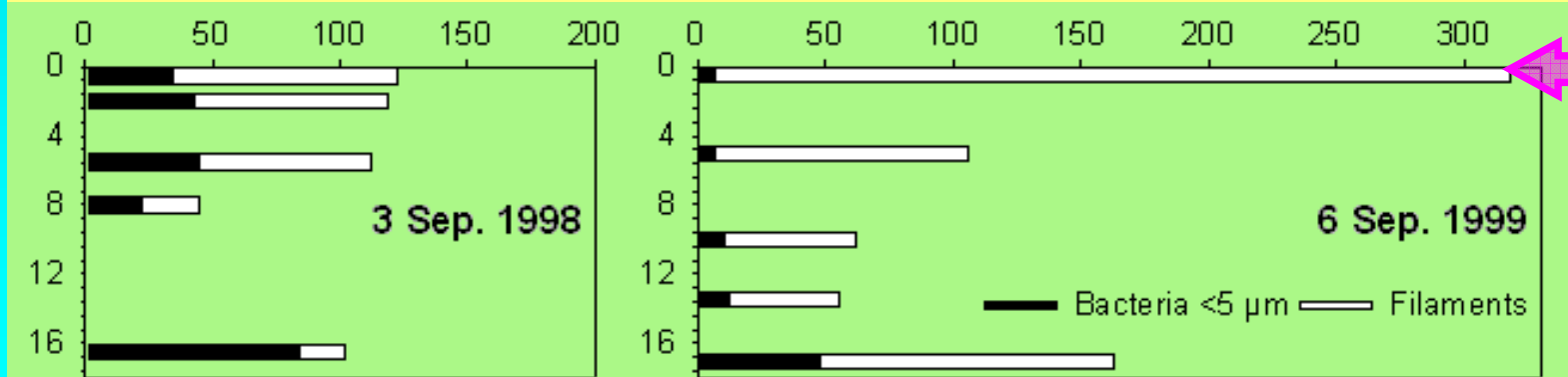


Prášilské
jezero

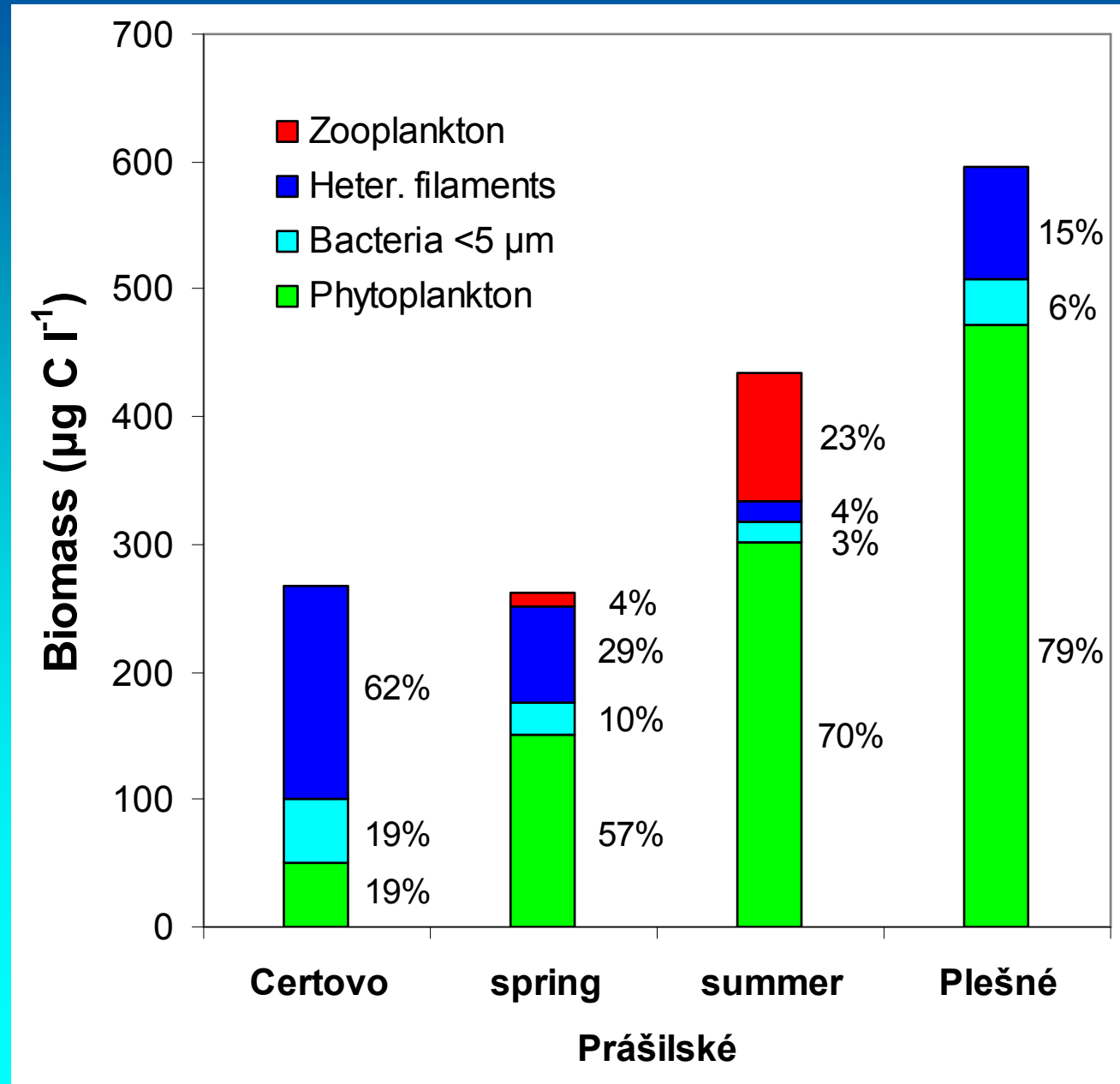


Plešné
jezero

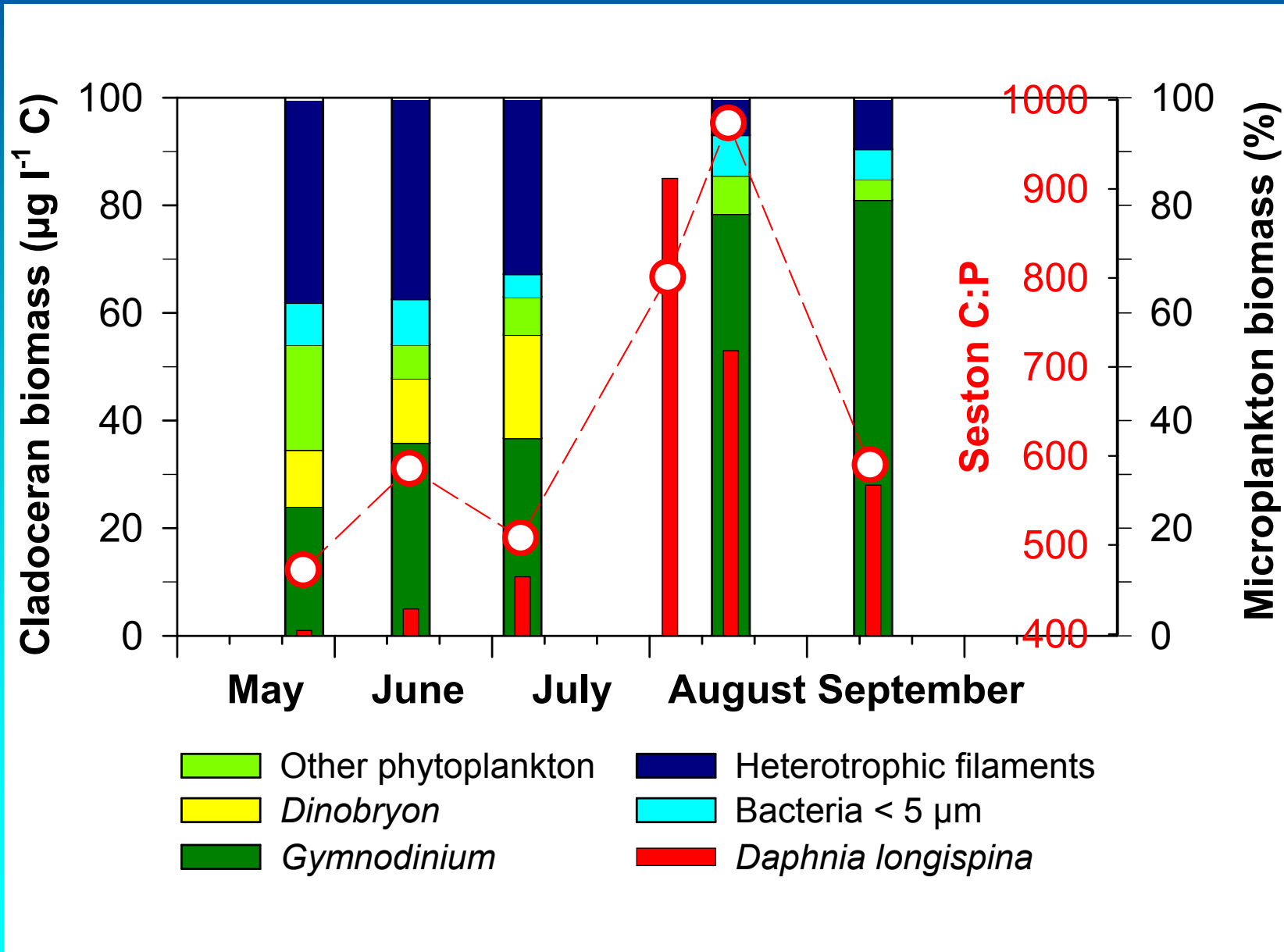
?

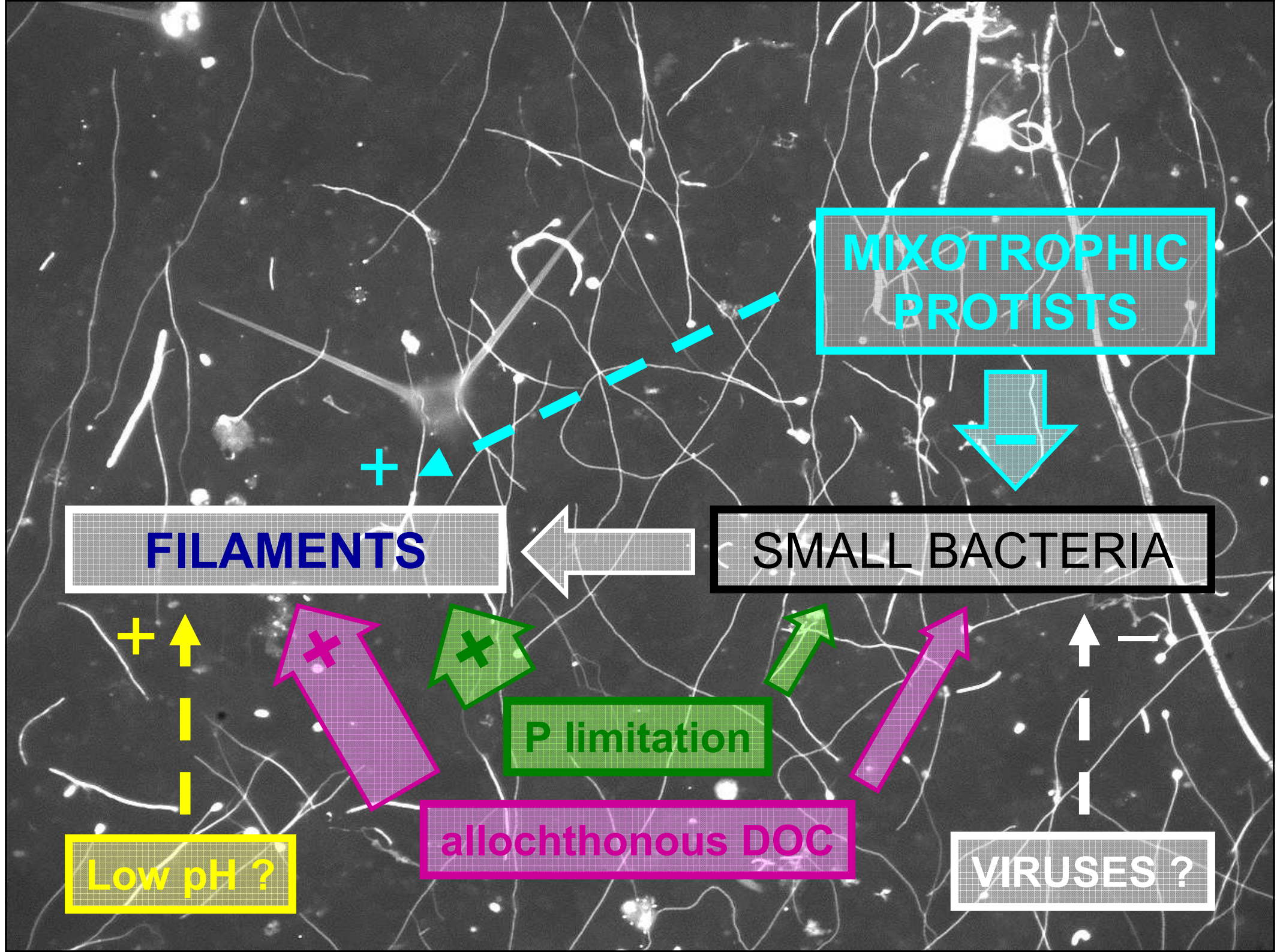


Typické složení planktonu ve třech šumavských jezerech (průměr květen–září 1998 – epilimnion)



Sezónní složení planktonu v Prášilském jezeře (květen–září 1998 – epilimnion)





MIXOTROPHIC
PROTISTS

FILAMENTS

SMALL BACTERIA

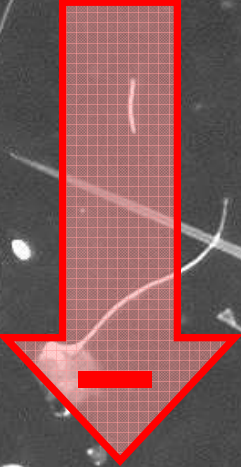
Low pH ?

P limitation

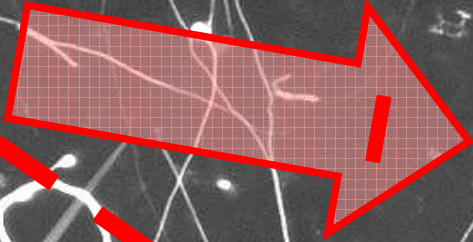
allochthonous DOC

VIRUSES ?

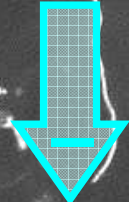
**CLADOCERAN
ZOOPLANKTON**



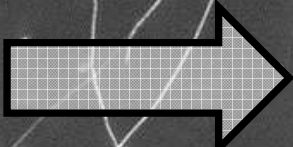
FILAMENTS



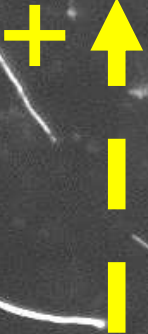
**MIXOTROPHIC
PROTISTS**



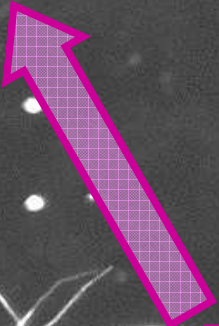
SMALL BACTERIA



Low pH ?



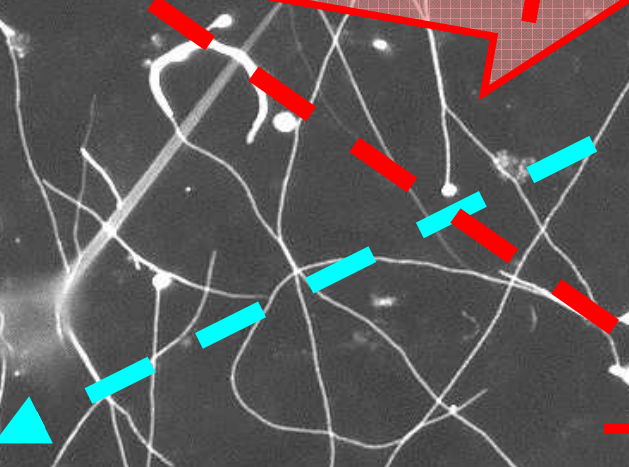
allochthonous DOC



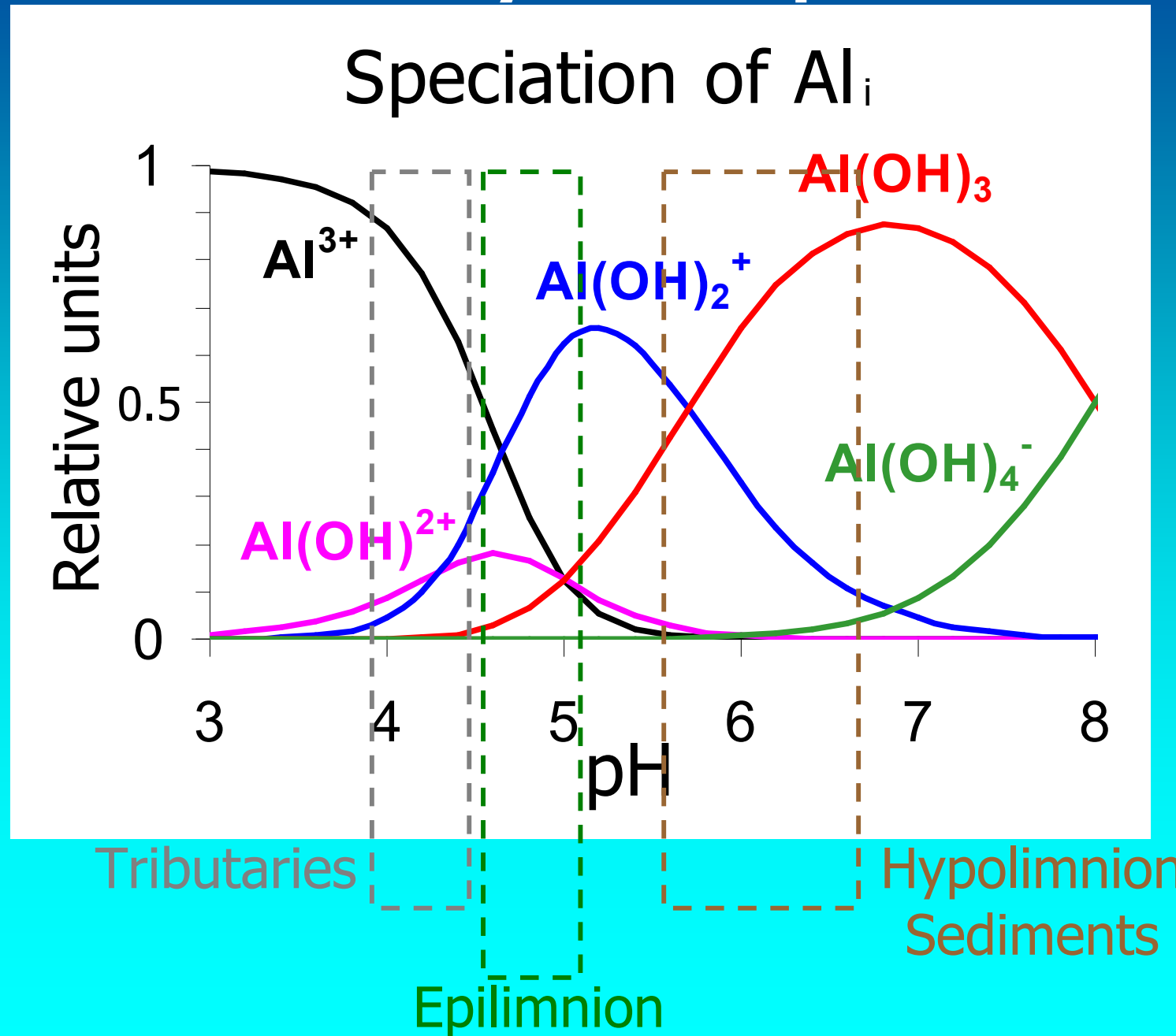
P limitation



VIRUSES ?

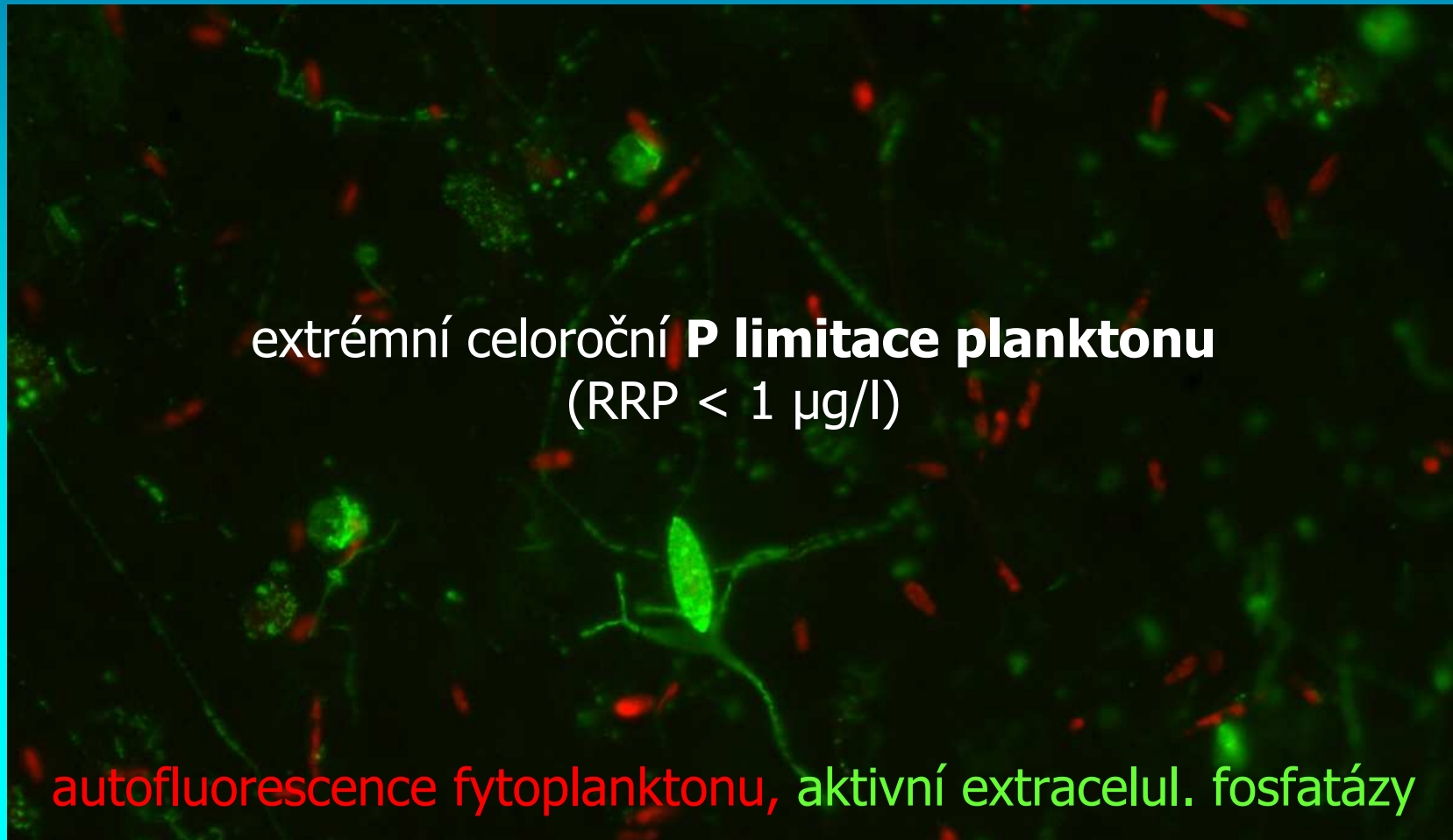


Klíčová role hliníku pro dostupnost fosforu, strukturu a dynamiku planktonu



Plešné jezero: (hladina)

relativně vysoký přísun P
přítoky (RRP > 20 µg/l)

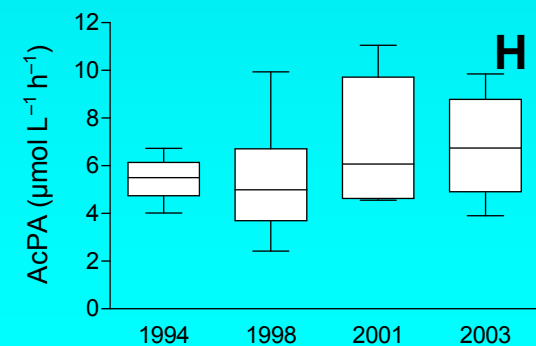
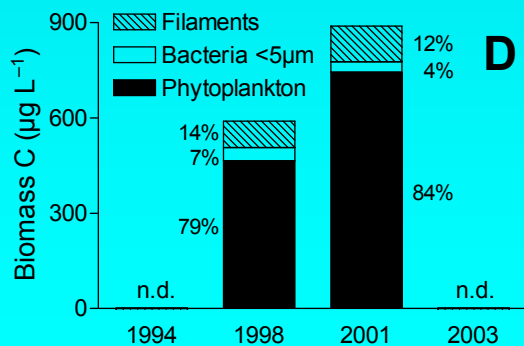
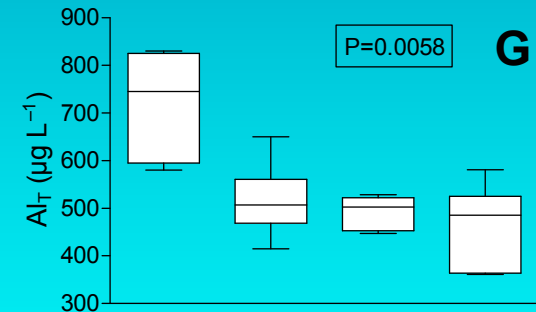
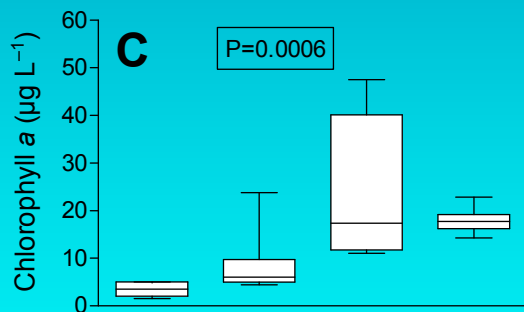
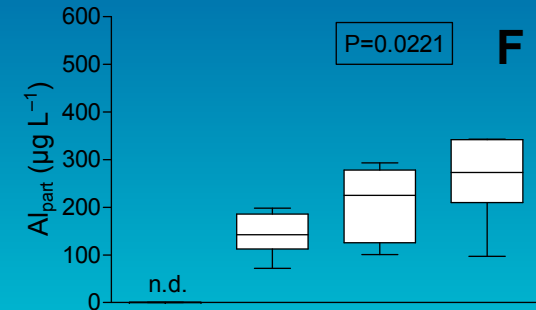
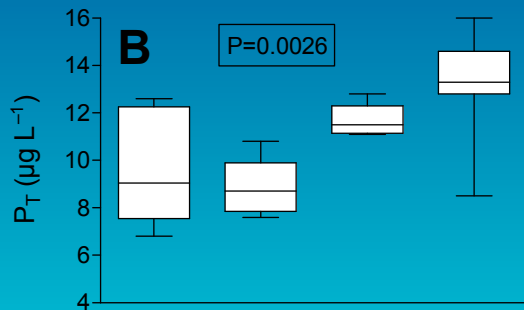
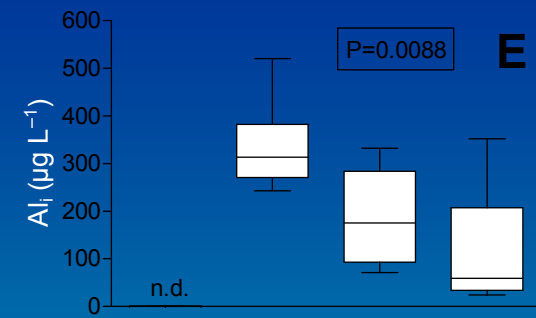
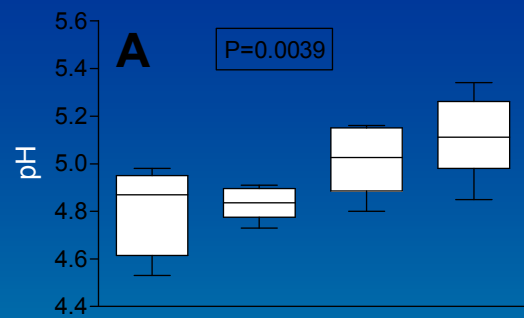


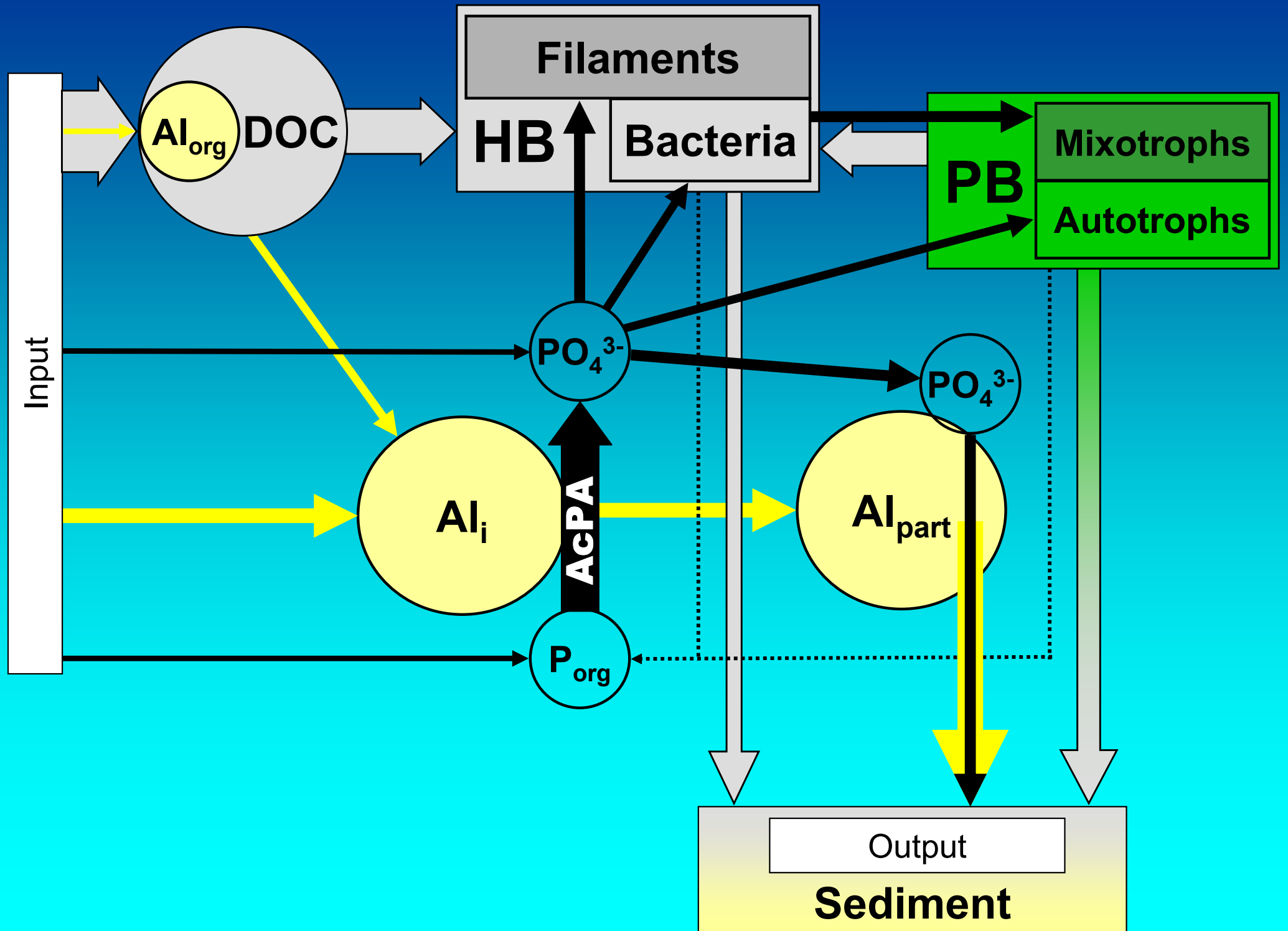
extrémní celoroční **P limitace planktonu**
(RRP < 1 µg/l)

autofluorescence fytoplanktonu, aktivní extracelul. fosfatázy

Plešné jezero: (hladina)

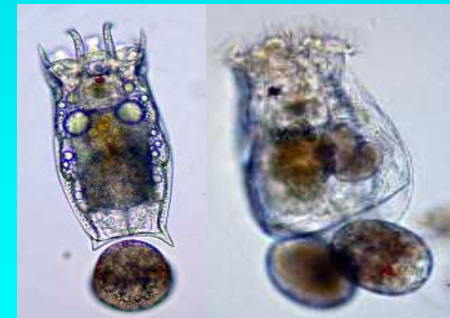
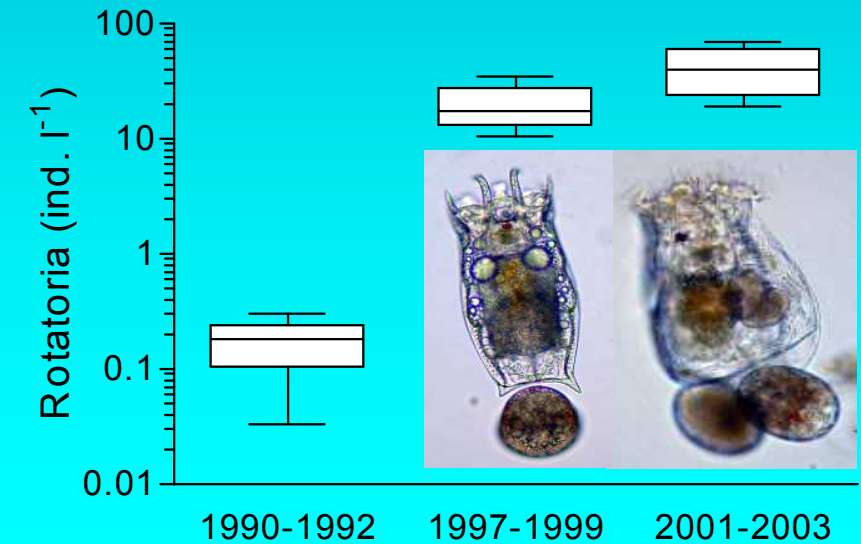
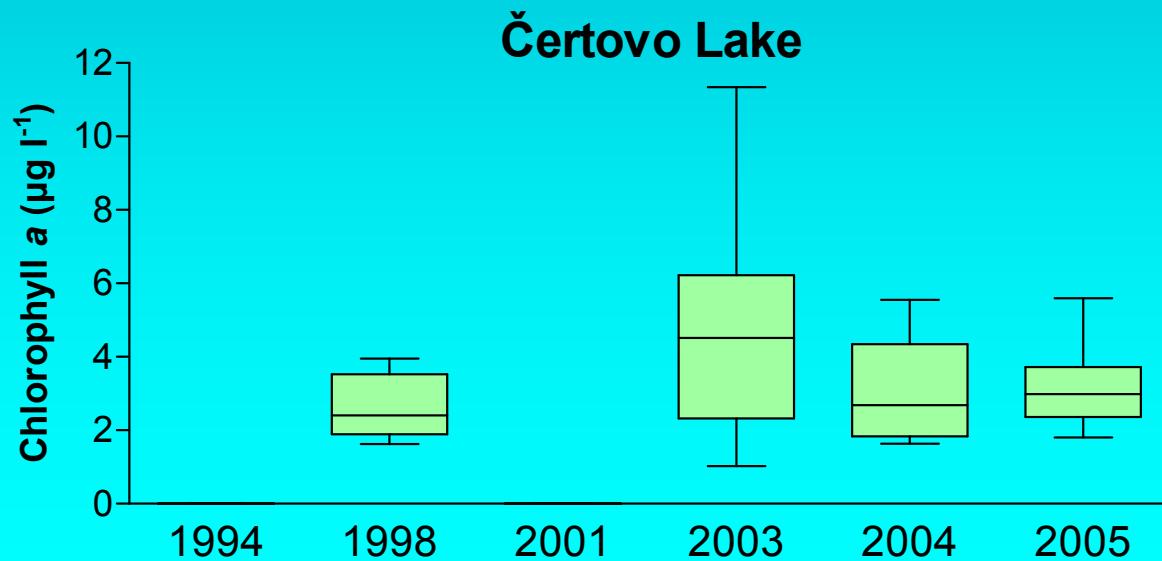
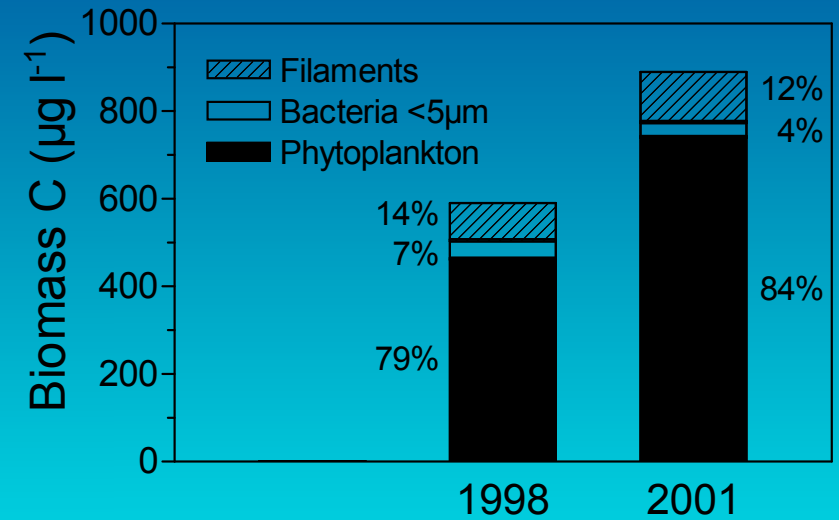
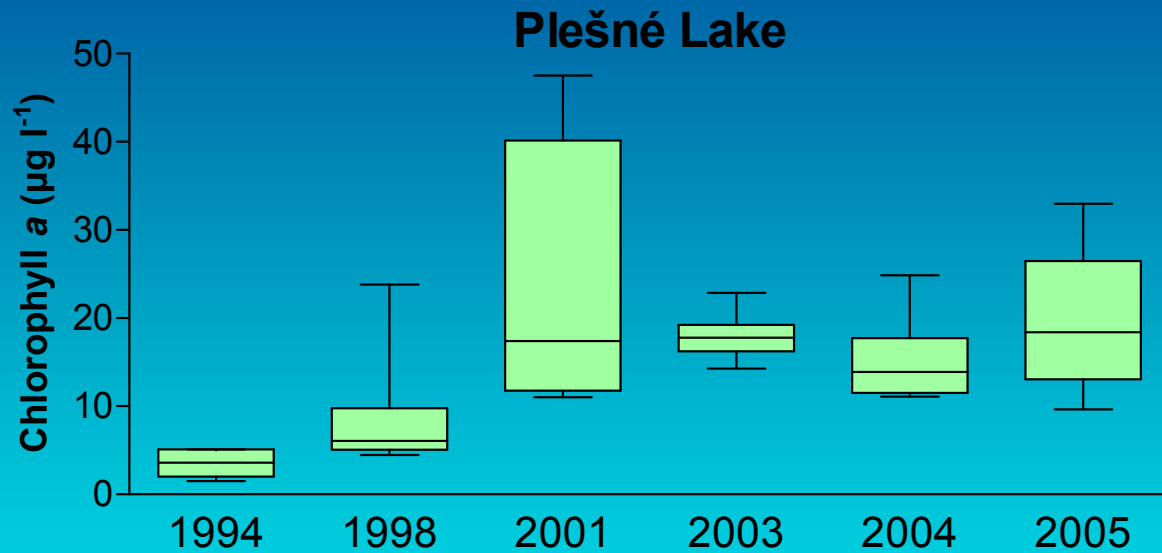
relativně vysoký přísun P
přítoky (RRP > 20 $\mu\text{g}/\text{l}$)





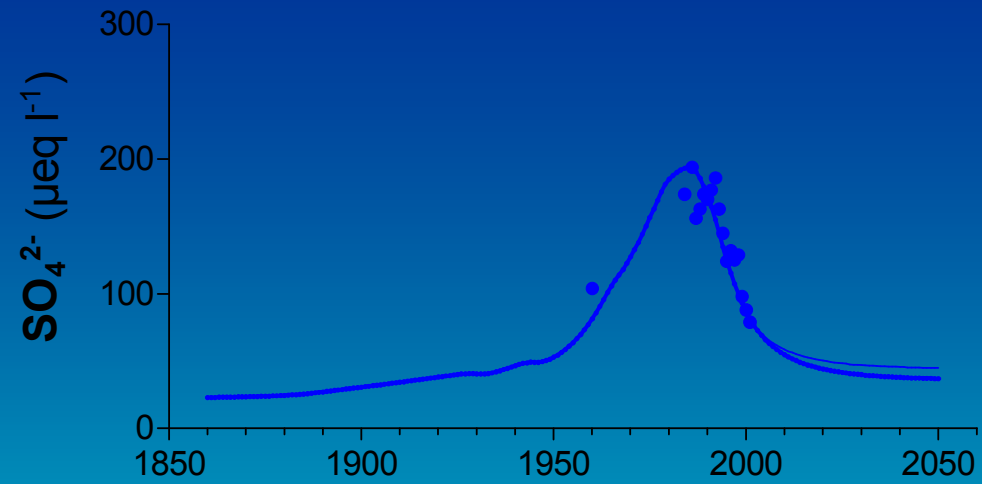
Zotavení planktonu v šumavských jezerech ?

Proč má biologické zotavení zpoždění ?



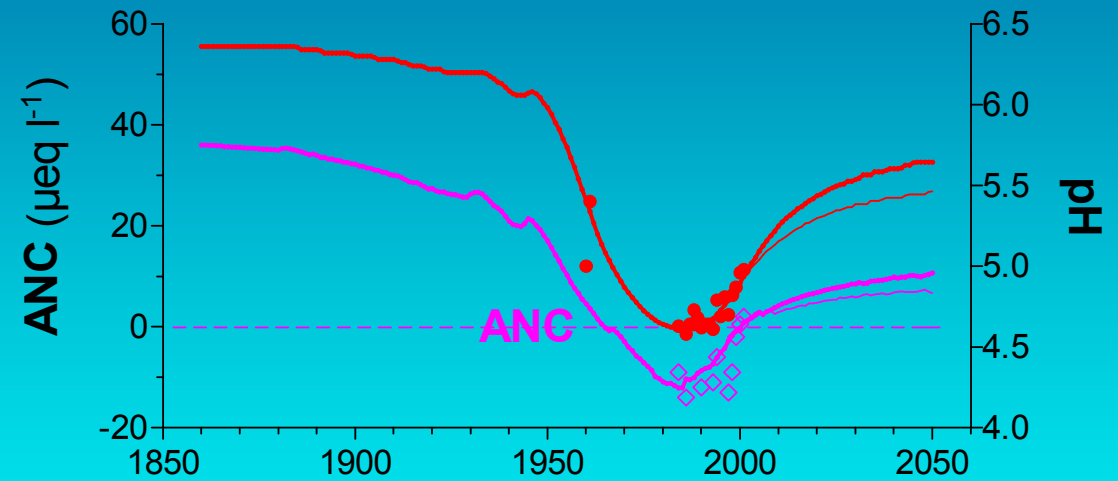
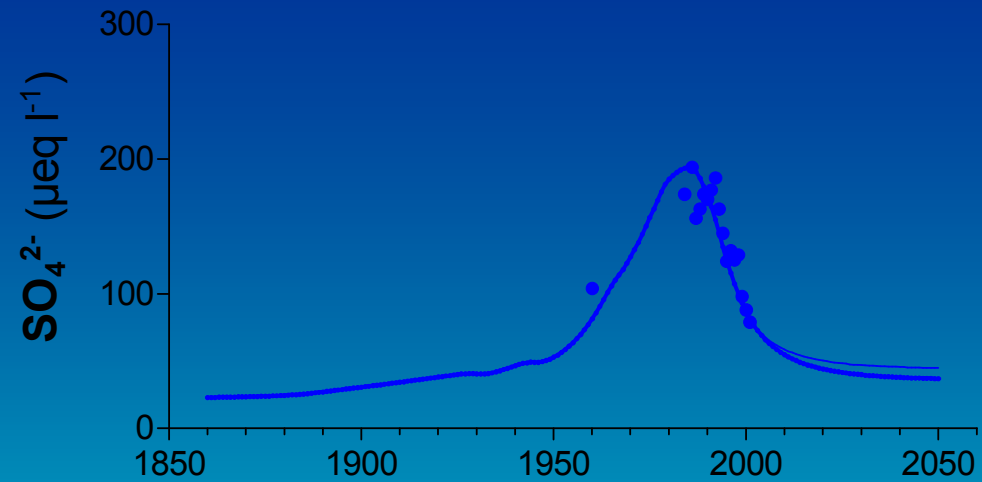
Plešné jezero: model acidifikace (MAGIC: 1850 – 2050)

Majer et al. 2003



Plešné jezero: model acidifikace (MAGIC: 1850 – 2050)

Majer et al. 2003

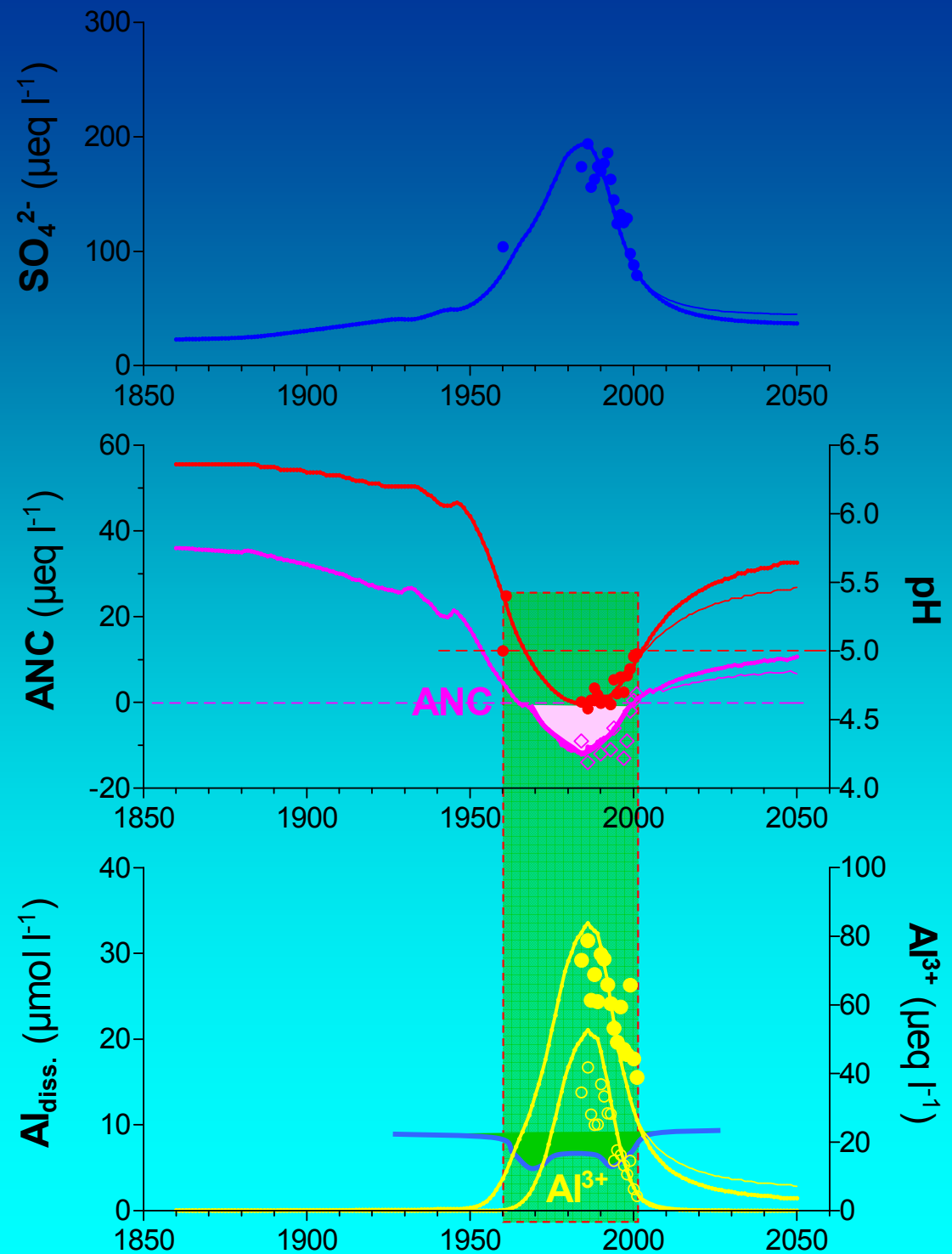


Plešné jezero: model acidifikace (MAGIC: 1850 – 2050)

Majer et al. 2003

• současná limitace CO₂?

• snížená dostupnost P

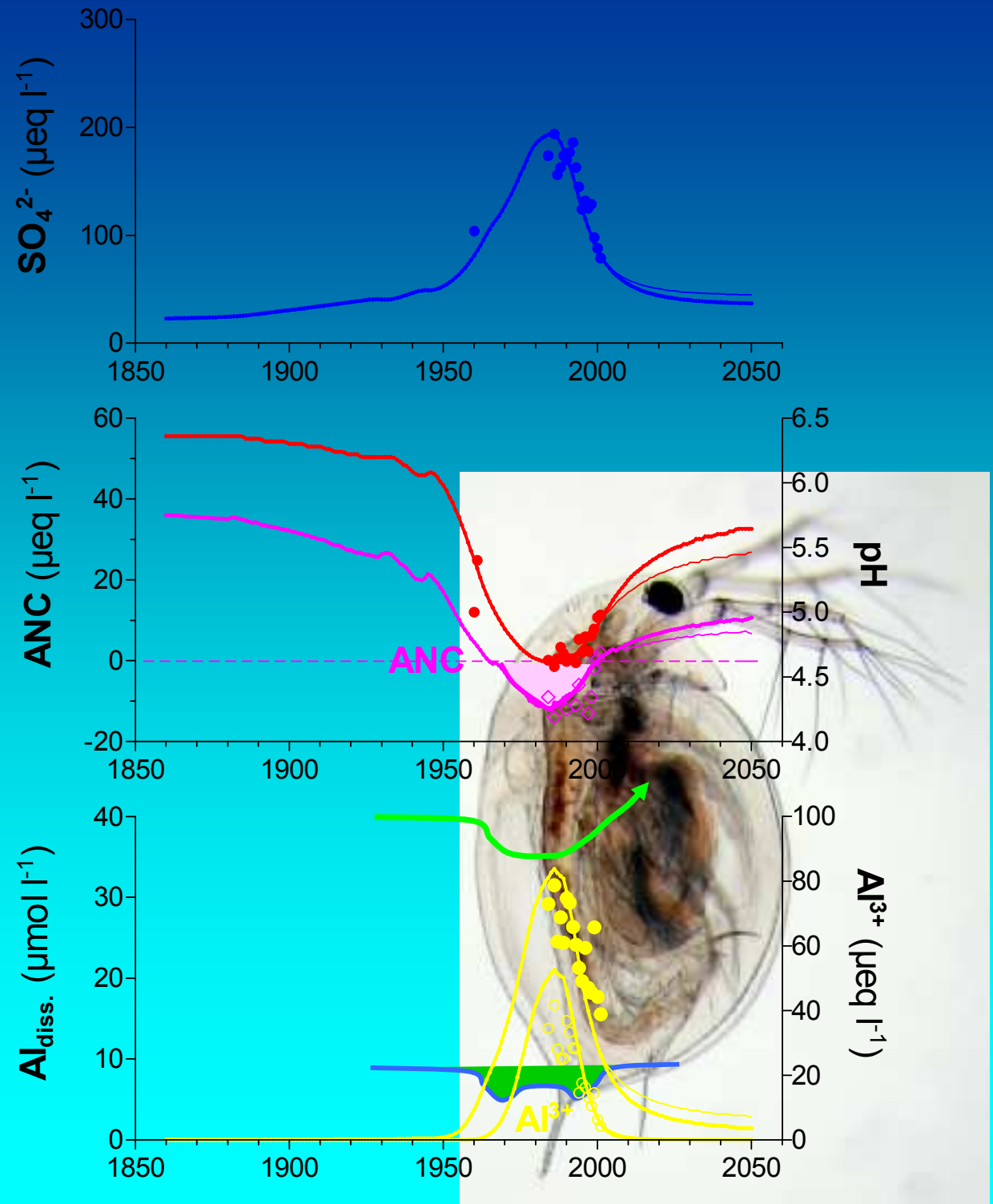


Plešné jezero: model acidifikace (MAGIC: 1850 – 2050)

a zotavení planktonu

- "oligotrofizace" během acidifikace
- "eutrofizace" při zotavení

• snížená dostupnost P



Plešné jezero 23. září 2004:
repatriace zooplanktonu z Prášilského jezera
(*Daphnia longispina* & *Cyclops abyssorum*)



Zotavování ekosystému Plešného jezera

- **Fytoplankton** — nárůst biomasy
- **Zooplankton** — nárůst počtu vířníků
- **Zotavování planktonu** je zjevně funkcí koncentrace **Al**,
- jež závisí (i) na **poklesu atm. depozice S a N** (hystereze),
(ii) inverzně na **atm. teplotě** (Veselý et al. 2003),
a (iii) na **rozvoji kůrovcové kalamity** !
- **Kůrovcová kalamita může zpomalit/zastavit zotavování planktonu** (jarní tání/míchání)



Vápnit acidifikovaná povodí?

Povodí Audna,
Norsko

Raddum & Fjellheim
2003

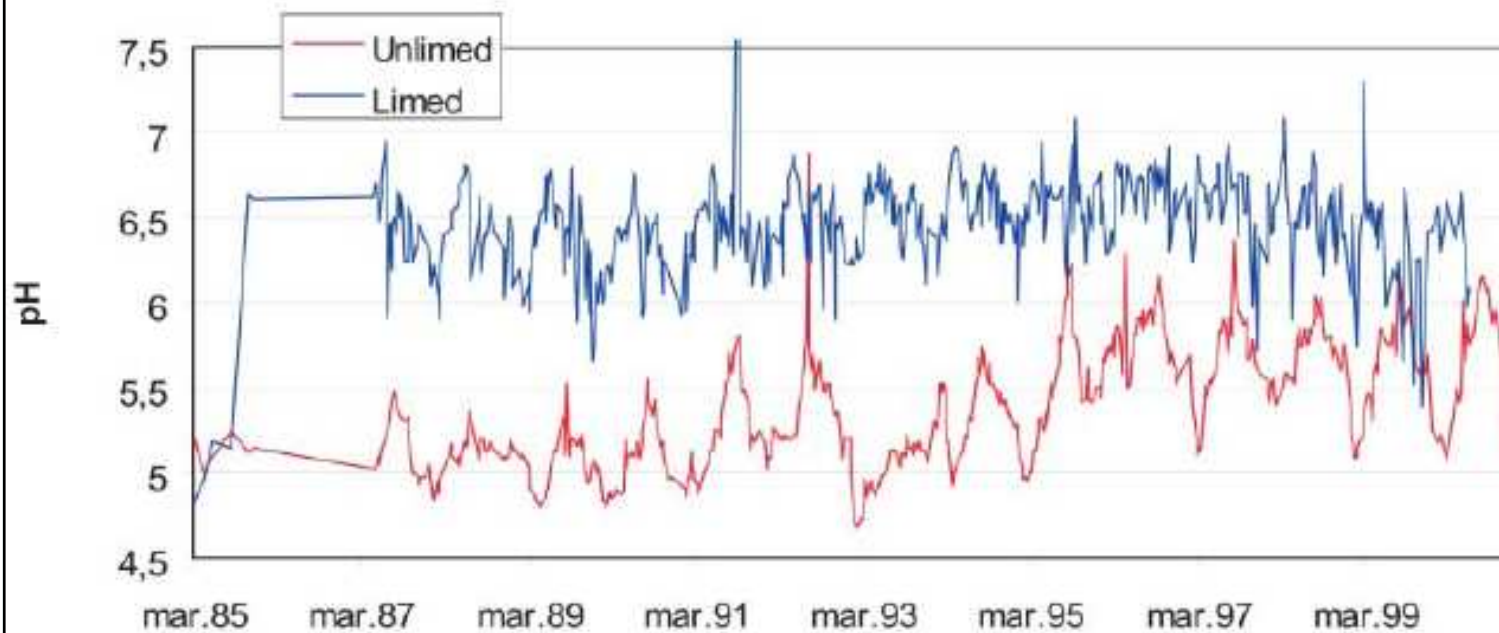
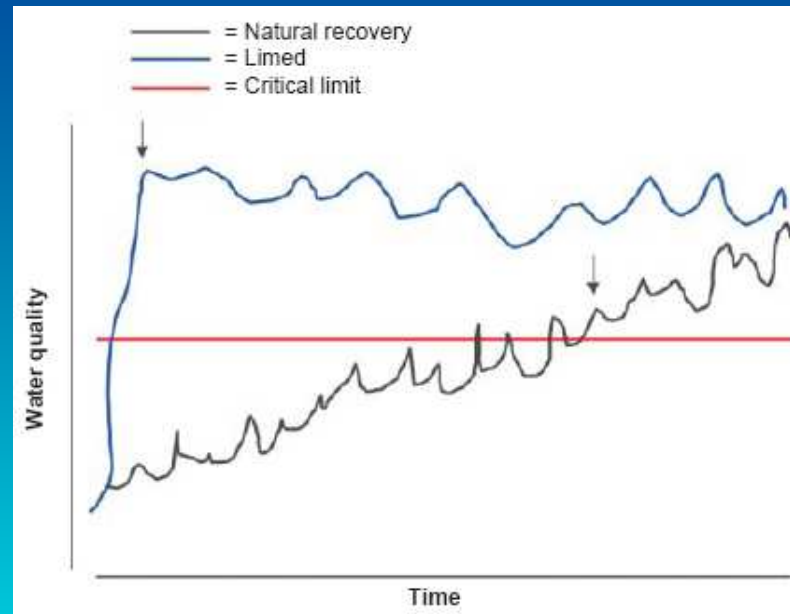
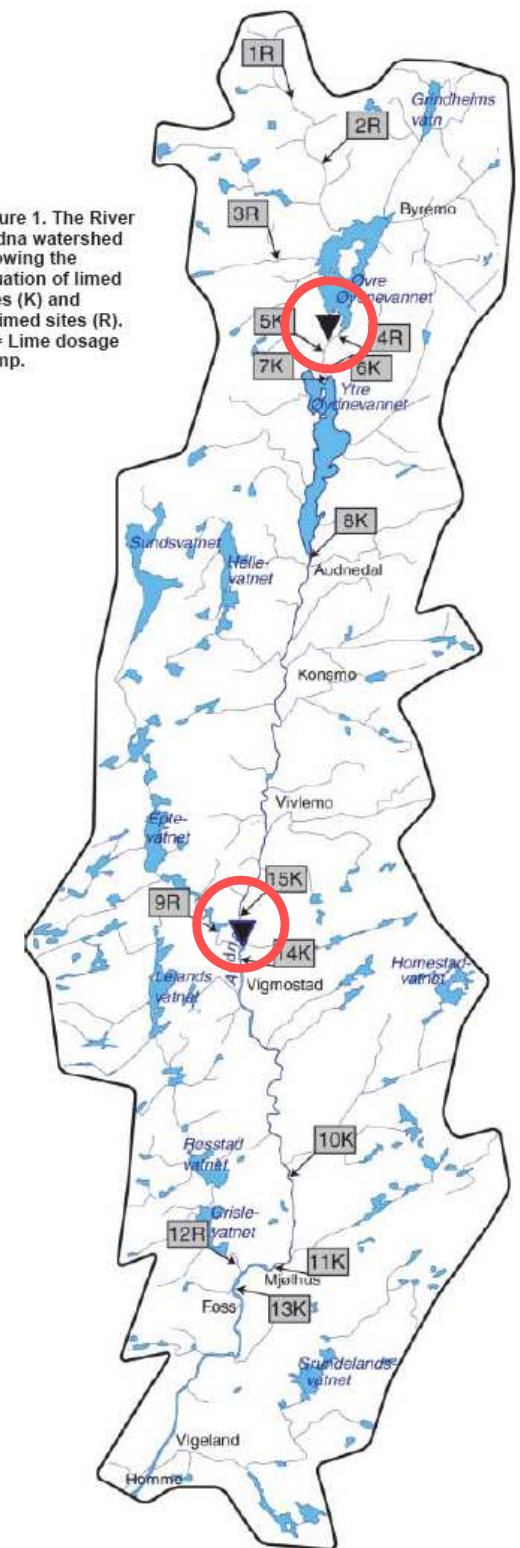


Figure 1. The River Audna watershed showing the situation of limed sites (K) and unlimed sites (R). ▼ = Lime dosage pump.



Vápnit acidifikovaná povodí?

Povodí Audna,
Norsko

Raddum &
2003

Figure 4. Accumulated number of sensitive taxa recorded in limed and unlimed sites in River Audna.

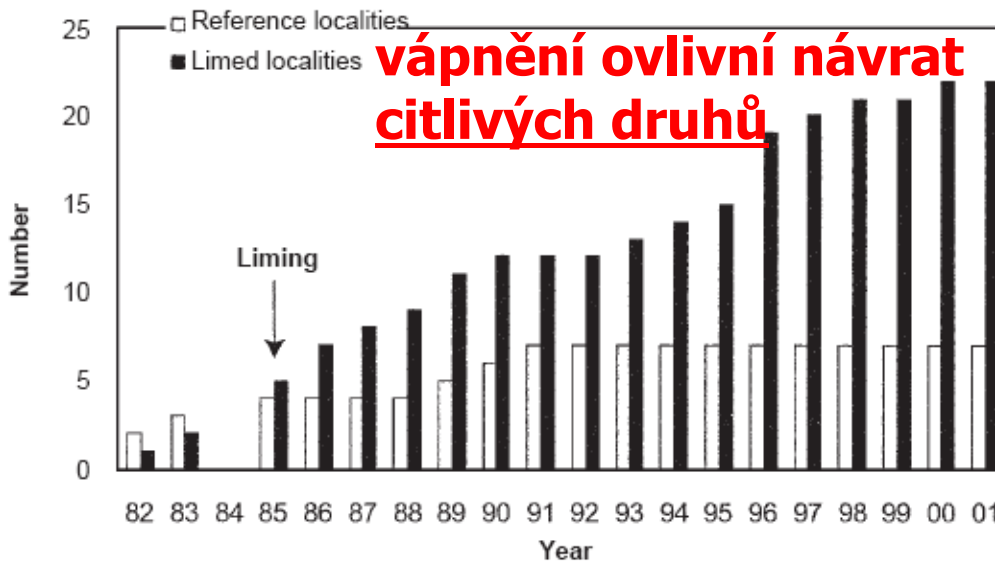


Figure 5. Accumulated number of tolerant taxa recorded in limed and unlimed sites in River Audna.

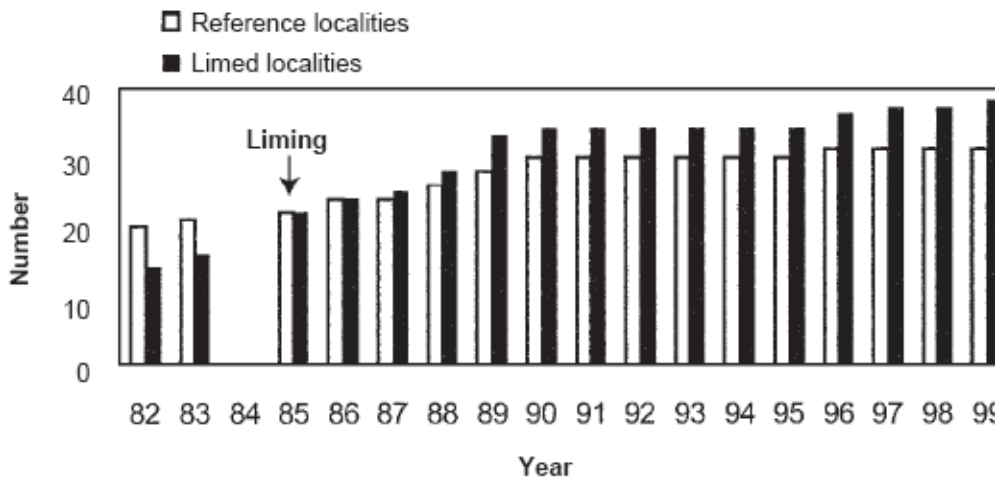
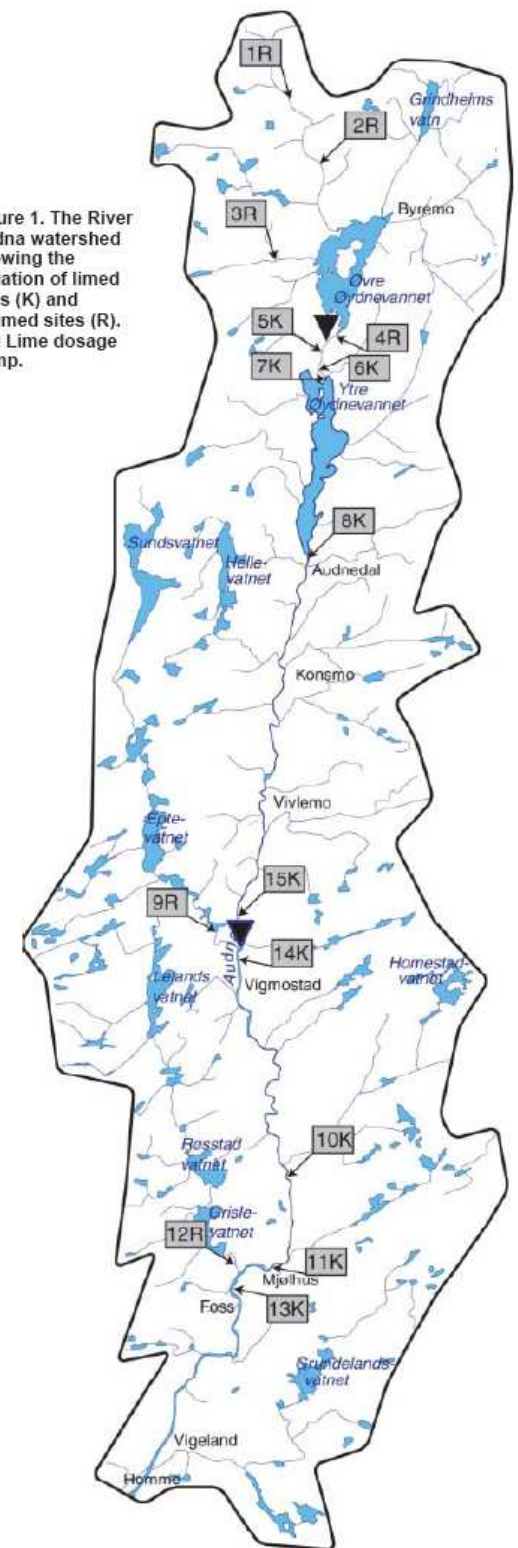


Figure 1. The River Audna watershed showing the situation of limed sites (K) and unlimed sites (R). ▼ = Lime dosage pump.

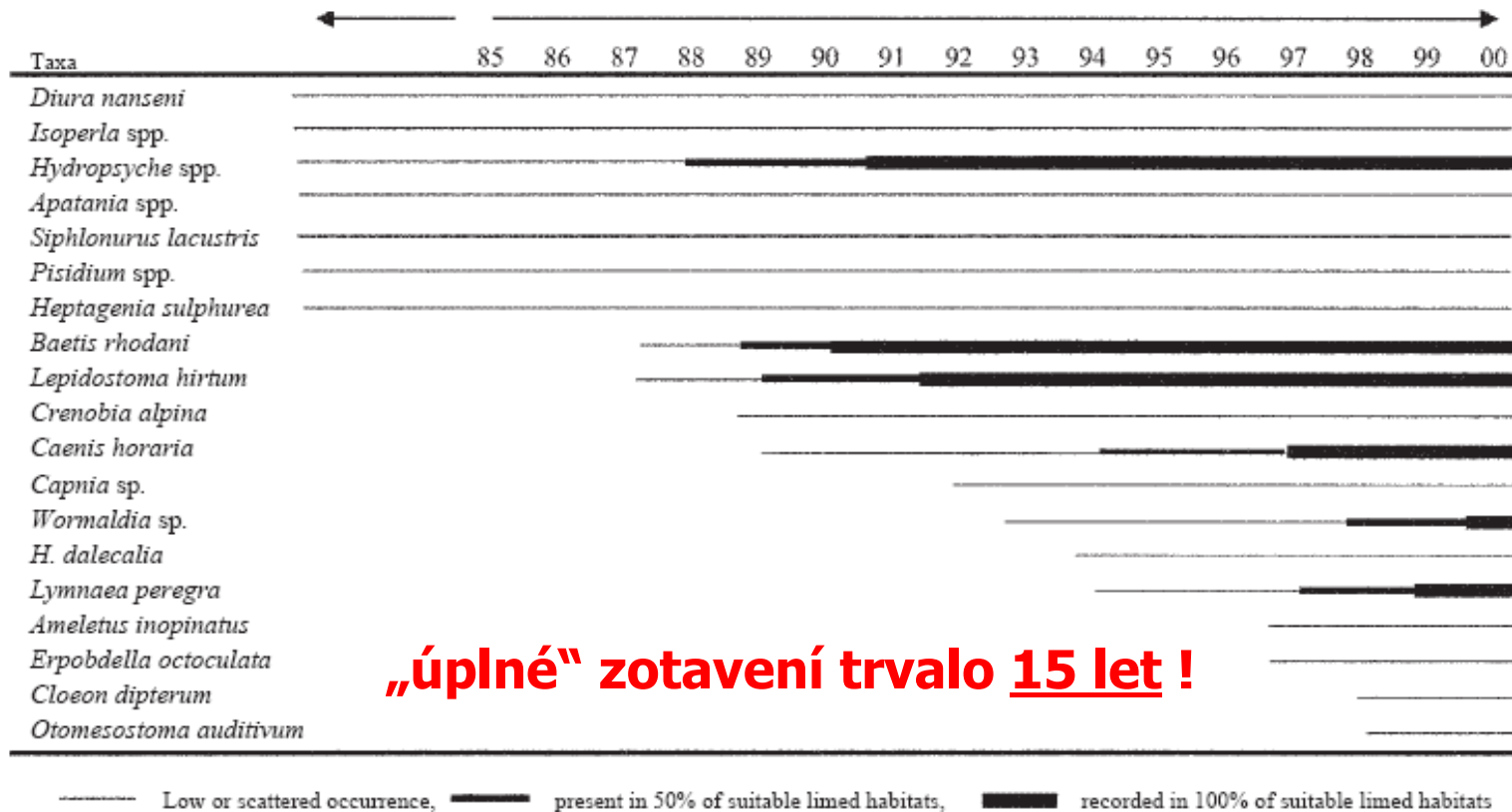


Vápnit acidifikovaná povodí?

Povodí Audna,
Norsko

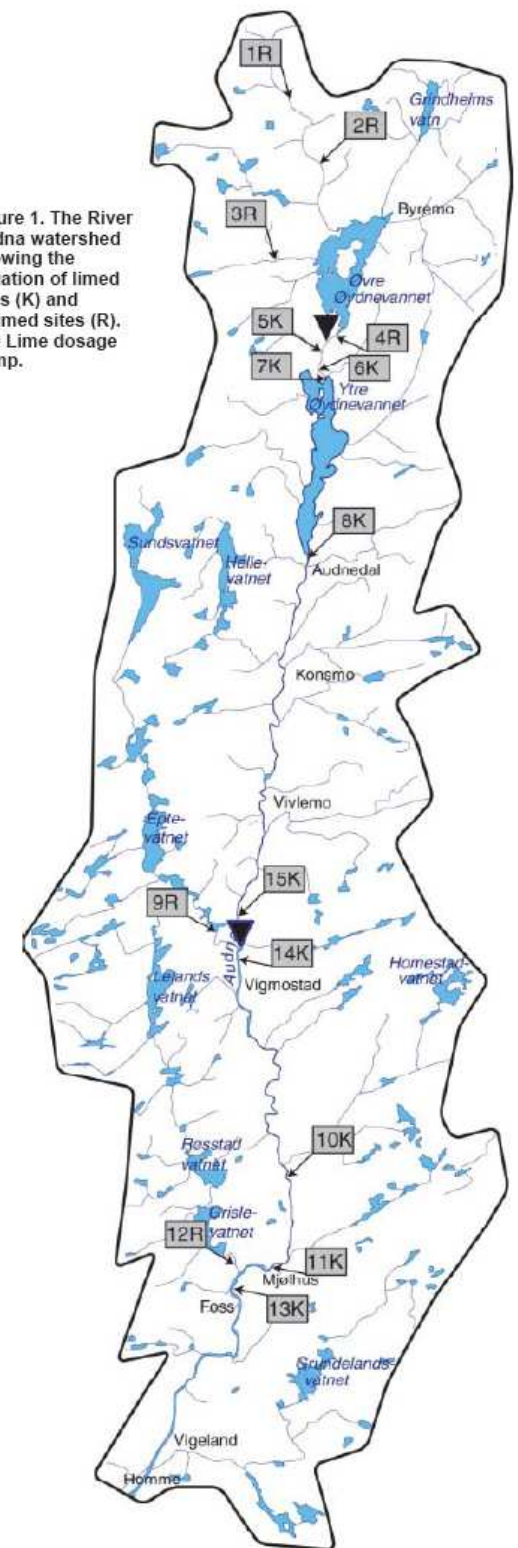
Raddum & Fjellheim
2003

**vápnění ovlivní návrat
citlivých druhů**



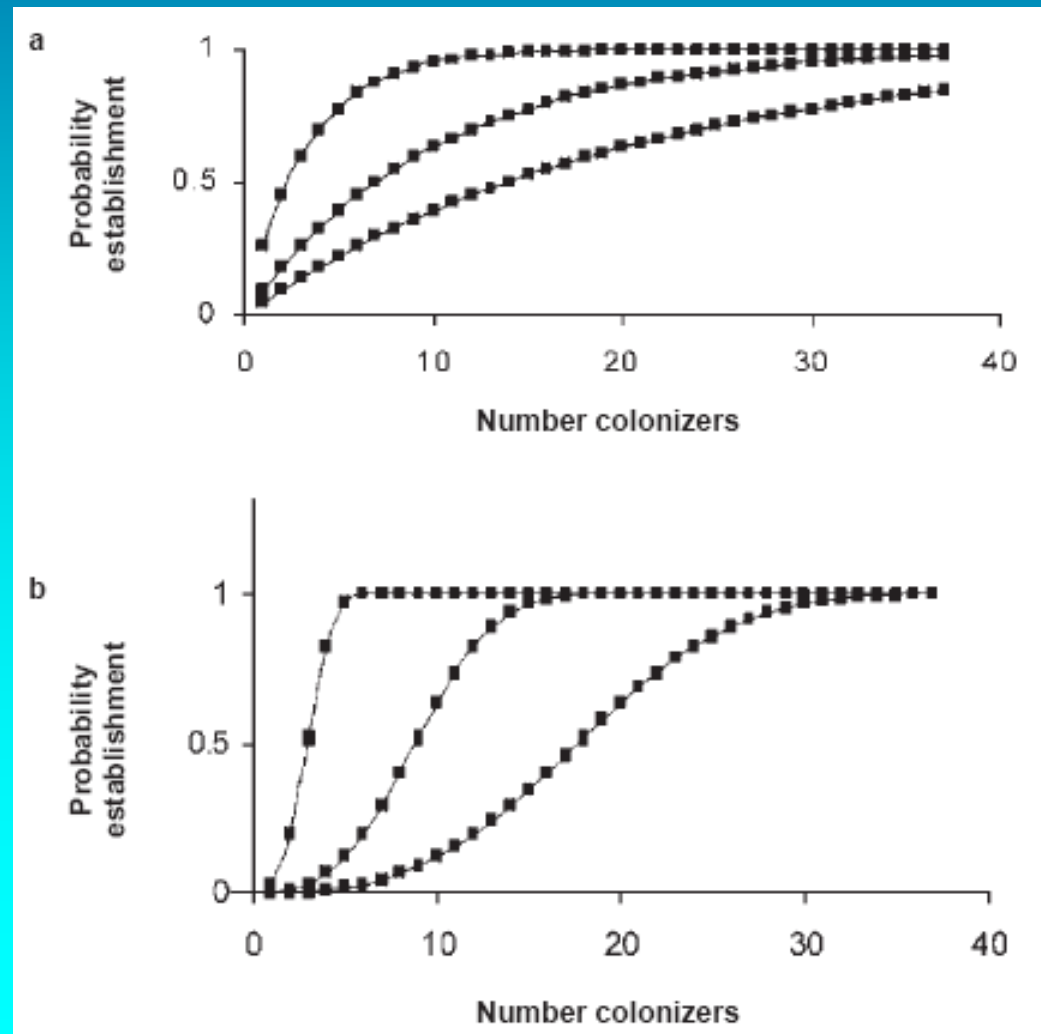
„úplné“ zotavení trvalo 15 let !

Figure 1. The River Audna watershed showing the situation of limed sites (K) and unlimed sites (R). ▼ = Lime dosage pump.



Překážky návratu/zotavení planktonu

- ekologická stechiometrie – nepříznivý C:P
- ekologický odpor (resistance) – bezobratlí predátoři
- schopnost šíření
- Alleeho efekt

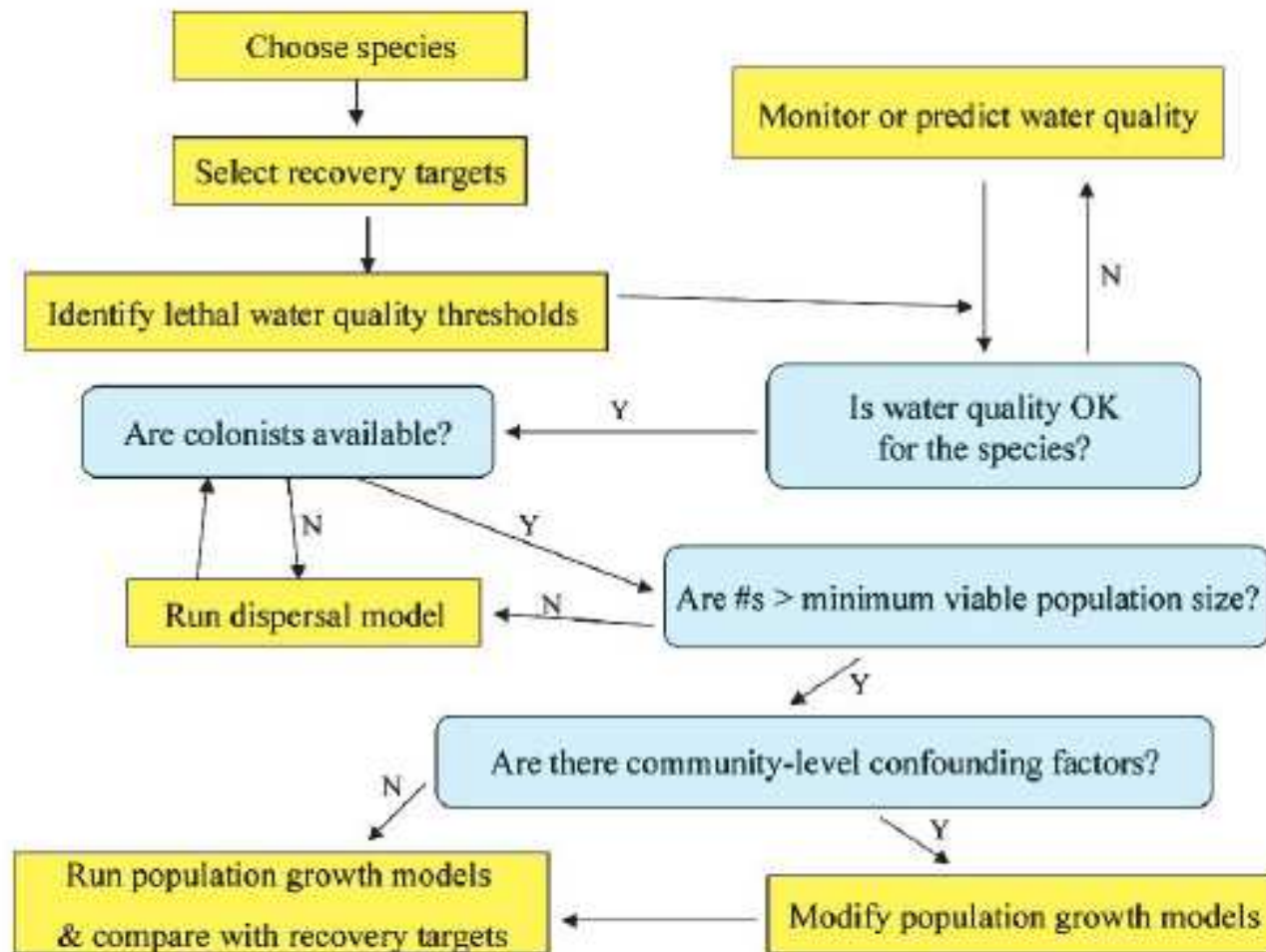


Překážky návratu/zotavení planktonu

- **ekologická stechiometrie** – nepříznivý C:P
- **ekologický odpor** (resistance) – bezobratlí predátoři
- **schopnost šíření**
- **Alleeho efekt** – „čím menší inokulum, tím menší šance“

Predikční modely biologického zotavení

Figure 1. First conceptual framework of the processes in the ecological recovery of a species from historical acidification. Yellow boxes indicate actions of management agencies. Blue boxes reflect questions managers must answer about key ecological processes which influence recovery. Negative answers highlight bottlenecks to recovery, which may require management interventions to speed recovery (see Fig. 2). The framework begins with an assumption of a particular S deposition rate producing a particular water quality. This assumption is relaxed in Figure 2.



Predikční modely vs. realita

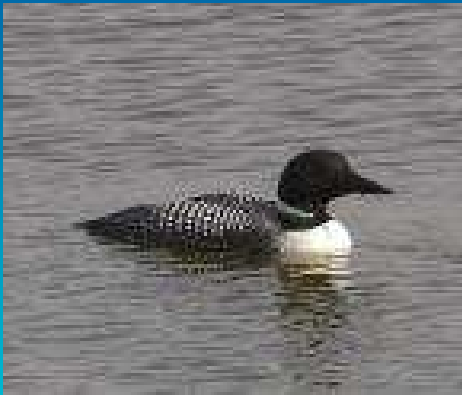


Figure 4. Mean (± 2 standard errors) proportion of 'successful' breeding of Common Loon pairs observed on 292 Ontario lakes, 1987 through 1999. The red line represents a significant downward slope of modeled success. The observed and modeled patterns differ slightly because modeled values take into account the variation in average lake area and pH resulting from annual differences in the set of lakes actually surveyed (e.g. low pH lakes predominated in the 1996 sample set).

