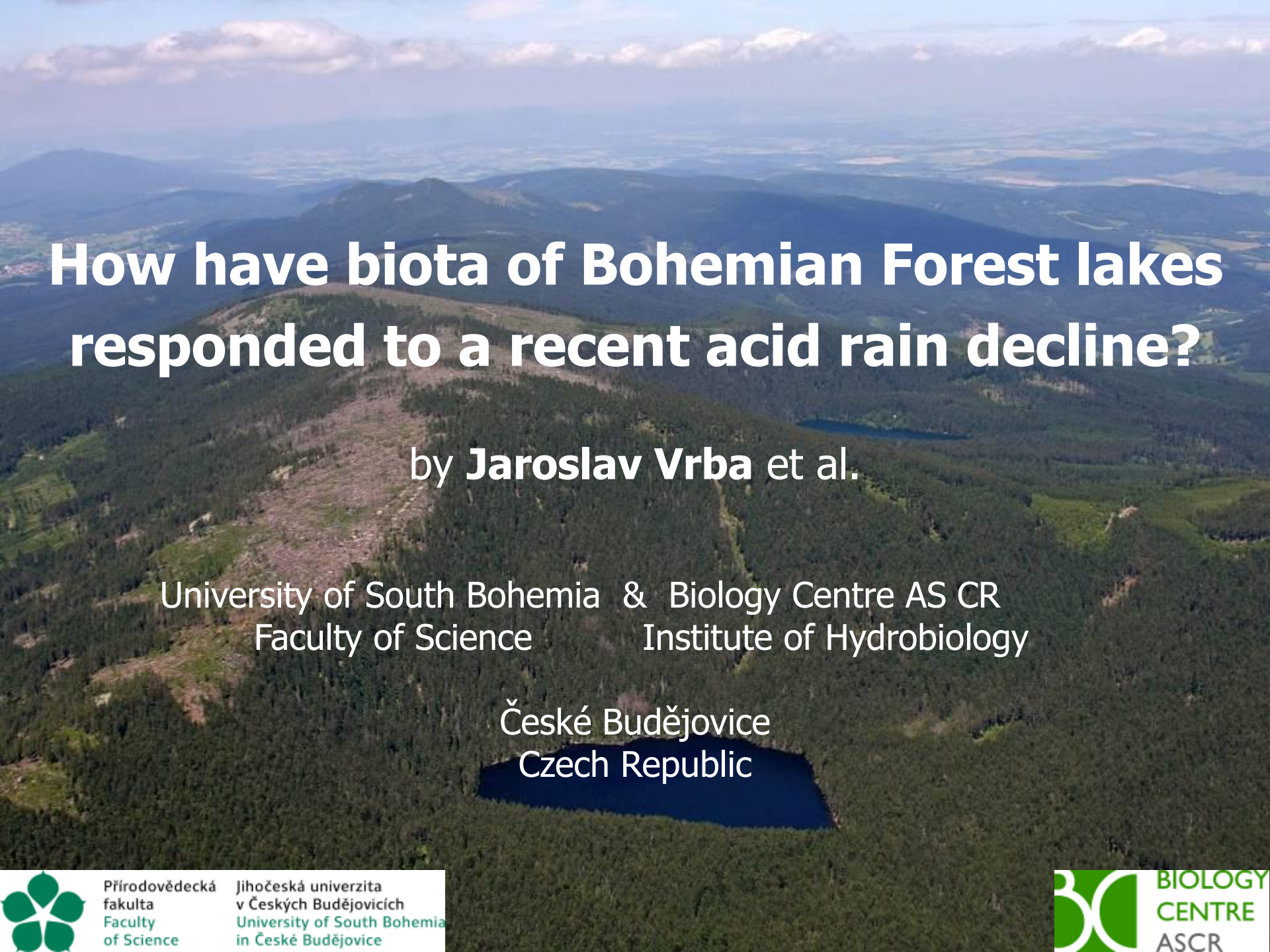

How have biota of Bohemian Forest lakes responded to a recent acid rain decline?

by **Jaroslav Vrba** et al.

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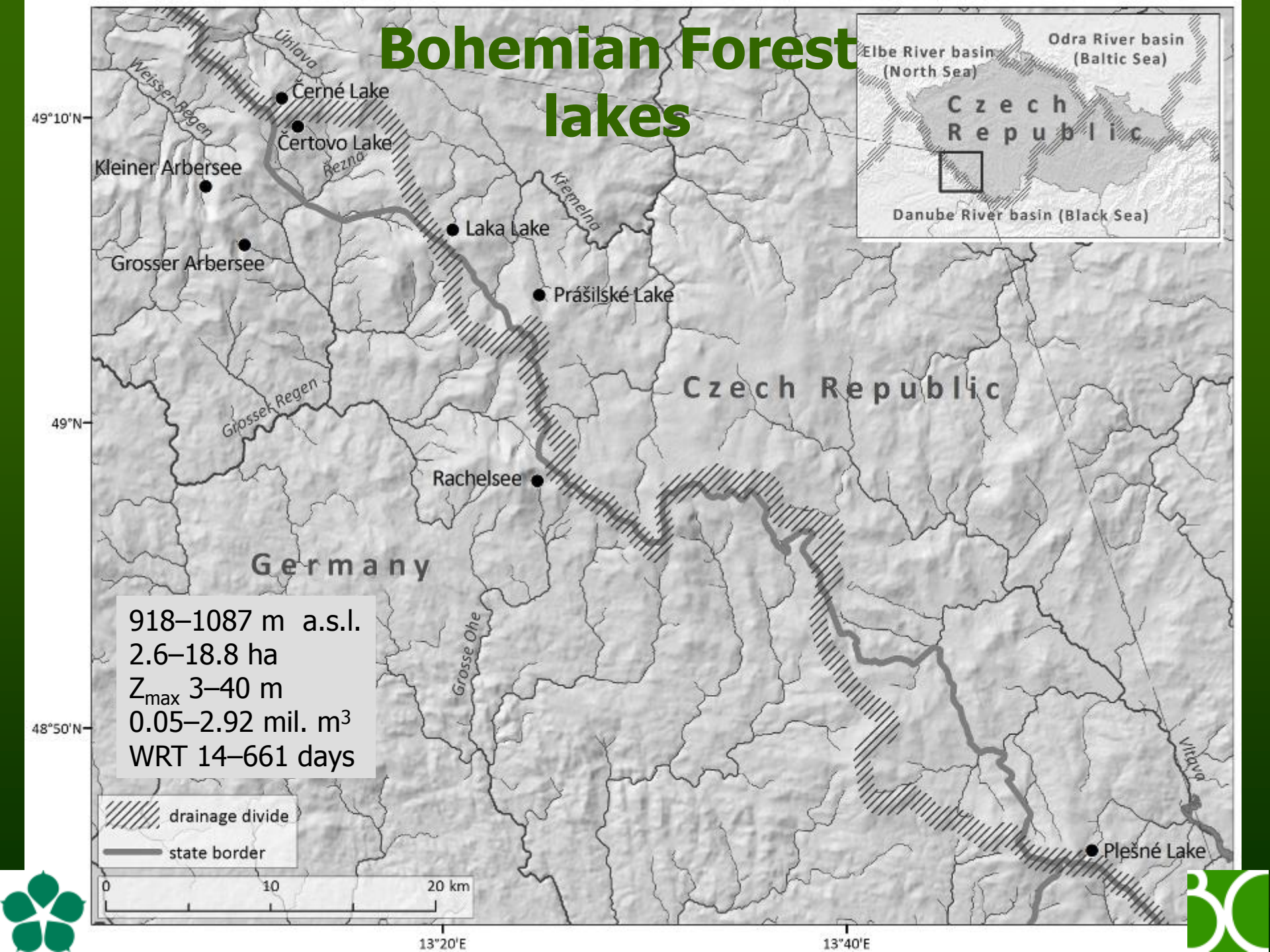
Jihočeská univerzita v Českých Budějovicích
University of South Bohemia in České Budějovice

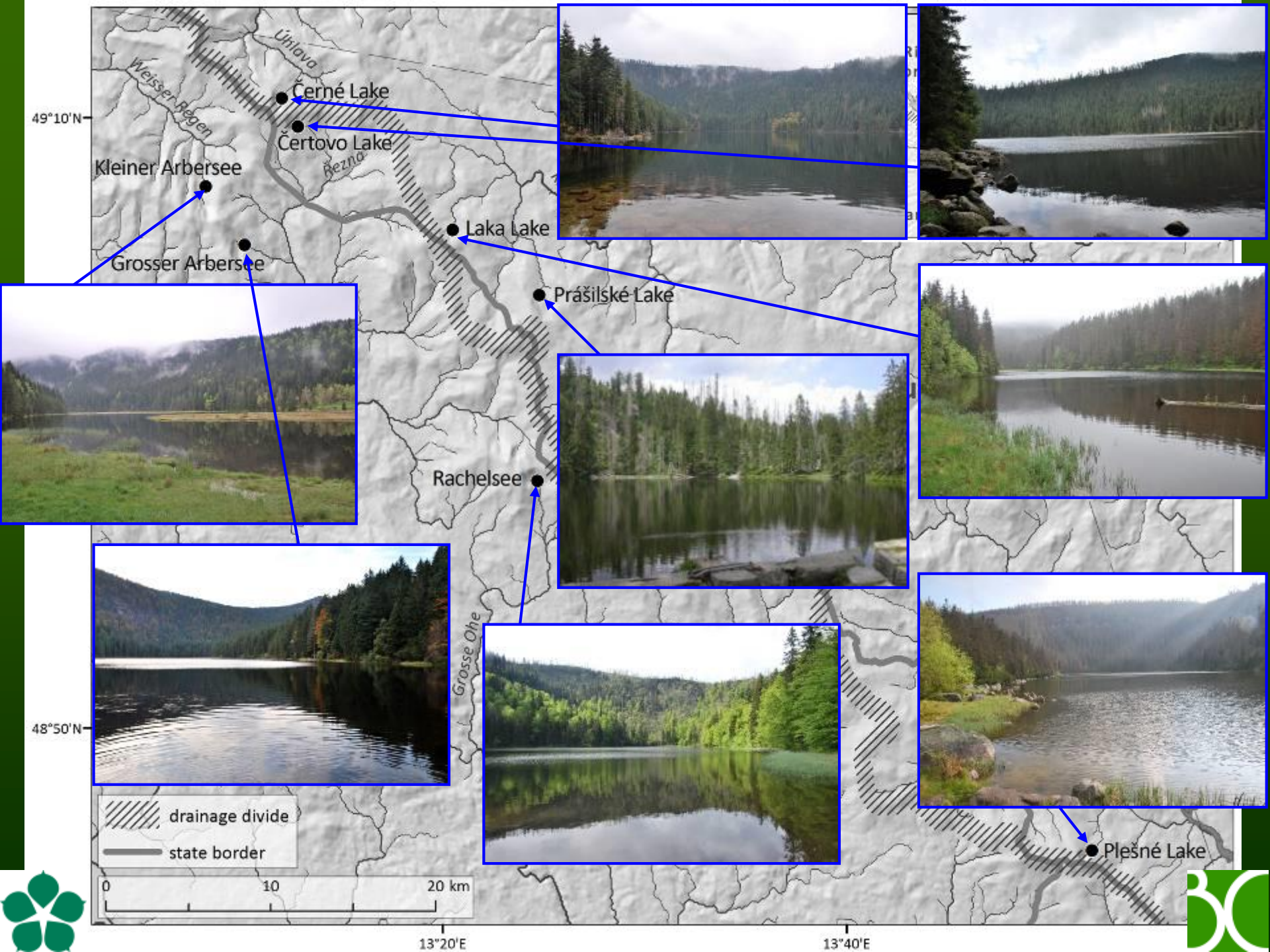
BIOLOGY CENTRE ASCR

Outlines

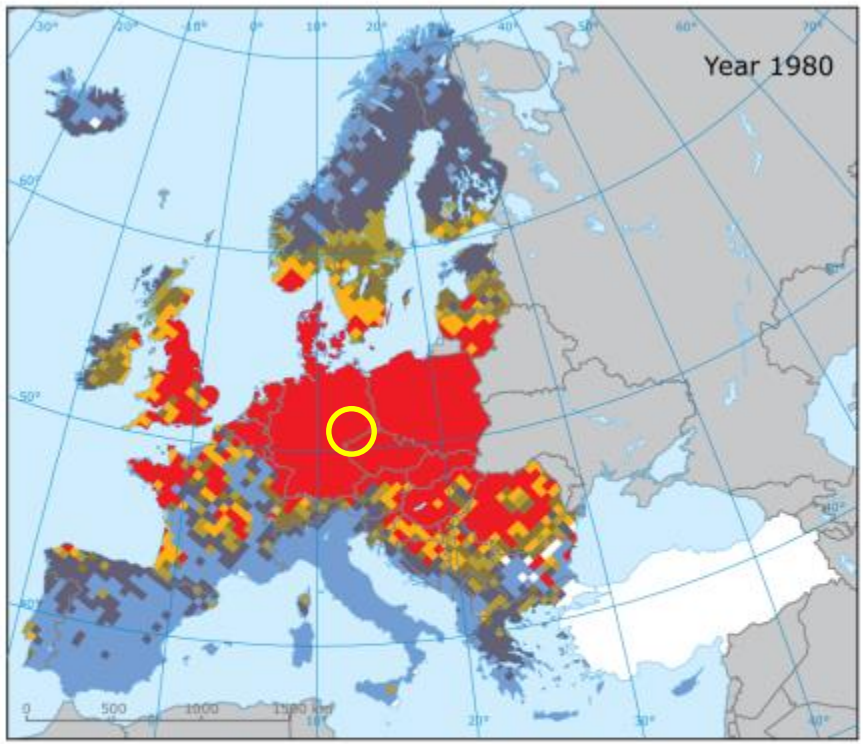
1. Bohemian Forest lakes
2. Atmospheric acidification and recovery
3. Biodiversity loss and potential for recovery
4. Aluminium bottleneck for reproduction & productivity
5. Distinct recovery of different taxonomic groups
6. What are the constraints of biological recovery?

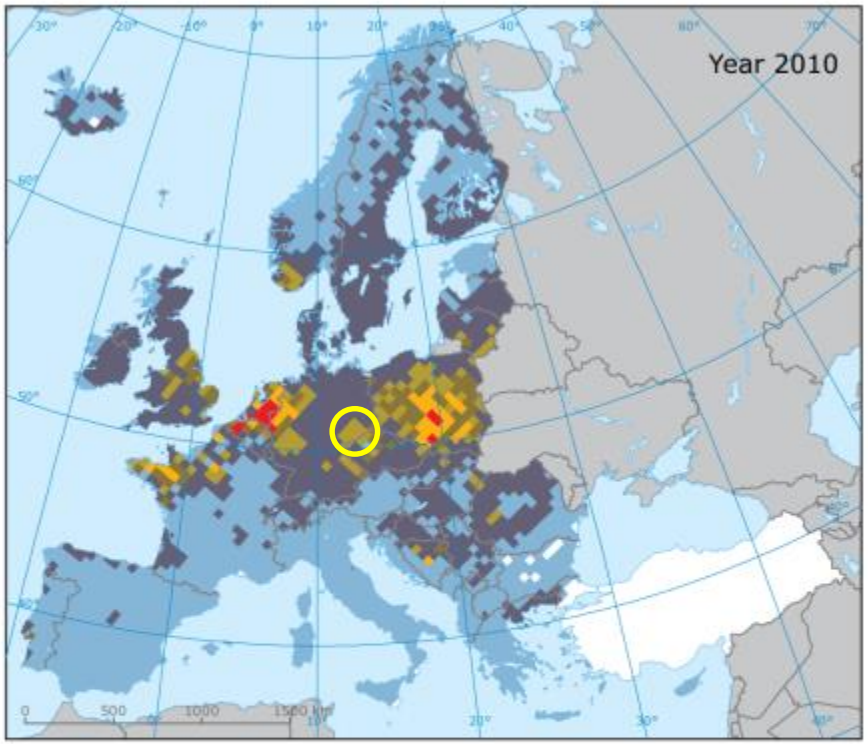
Co-authors: Jidřiška Bojková, Pavel Chvojka, Martina Čtvrtlíková, Jan Fott, Jiří Kopáček, Miroslav Macek, Linda Nedbalová, Miroslav Papáček, Veronika Sacherová, Tomáš Soldán & Michal Šorf


Bohemian Forest lakes
Černé Lake
Čertovo Lake
Kleiner Arbersee
Grosser Arbersee
Laka Lake
Prášilské Lake
Rachelsee
Plešné Lake
Czech Republic
Germany
Elbe River basin (North Sea)
Odra River basin (Baltic Sea)
Danube River basin (Black Sea)
Weisser Regen
Grosser Regen
Grosse Ohe
Vltava
Křemelná
Řezná
Úhlava
49°10'N
49°N
48°50'N
13°20'E
13°40'E
0
10
20 km
drainage divide
state border
918–1087 m a.s.l.
2.6–18.8 ha
Z_{max} 3–40 m
0.05–2.92 mil. m^3
WRT 14–661 days


Černé Lake
Čertovo Lake
Kleiner Arbersee
Grosser Arbersee
Laka Lake
Prášilské Lake
Rachelsee
Plešné Lake
Weisser Regen
Úhlava
Řezná
Grosse Ohe
49°10'N
48°50'N
13°20'E
13°40'E
drainage divide
state border
0
10
20 km

Atmospheric acidification and recovery





Exceedance of critical loads of acidity

eq $ha^{-1}a^{-1}$

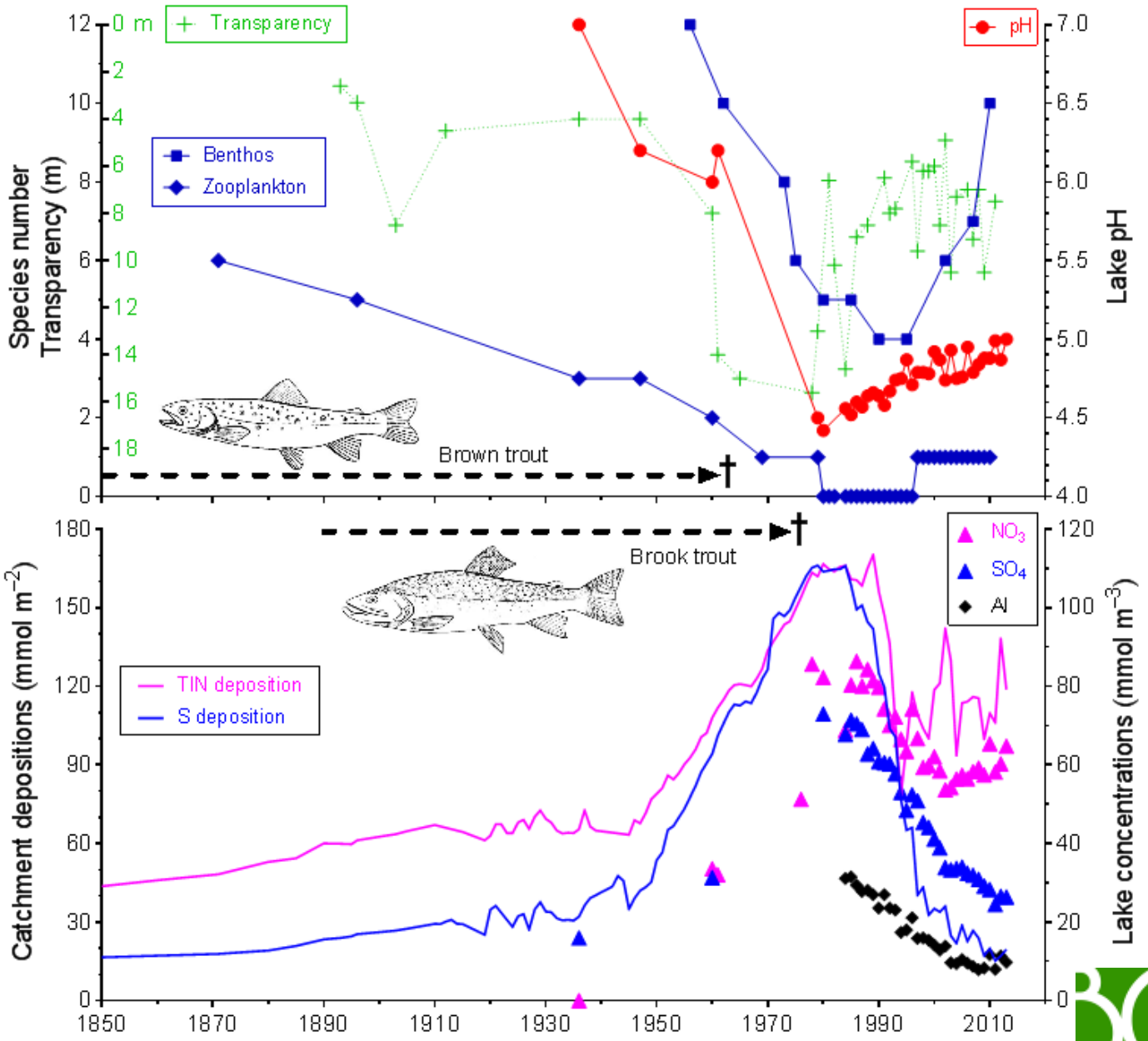
No exceedance	0–200	200–400	400–700	700–1 200	>1 200	No data	Outside coverage

(http://eusoils.jrc.ec.europa.eu/SOER2010/StateTrends.html)

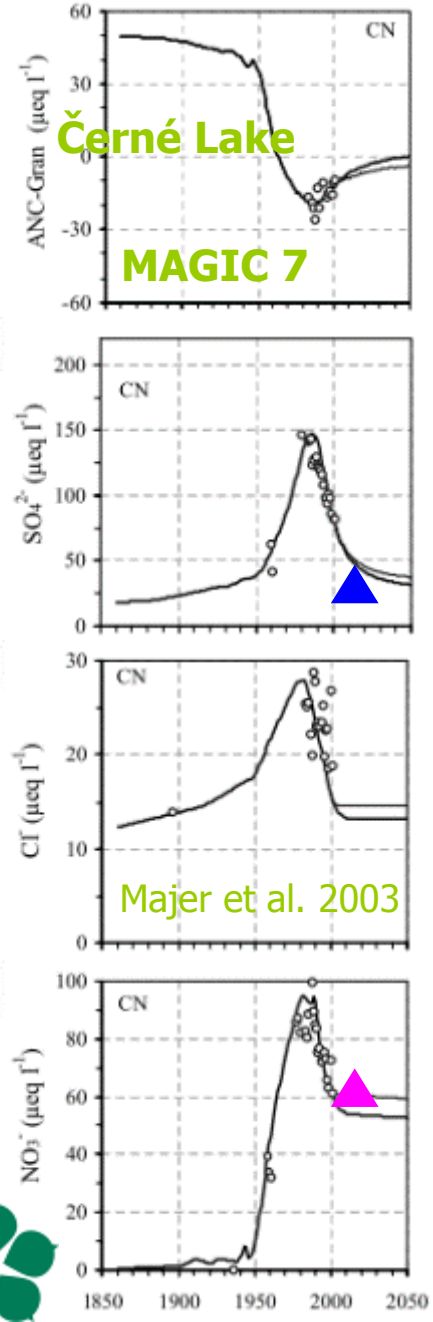
Atmospheric acidification and recovery

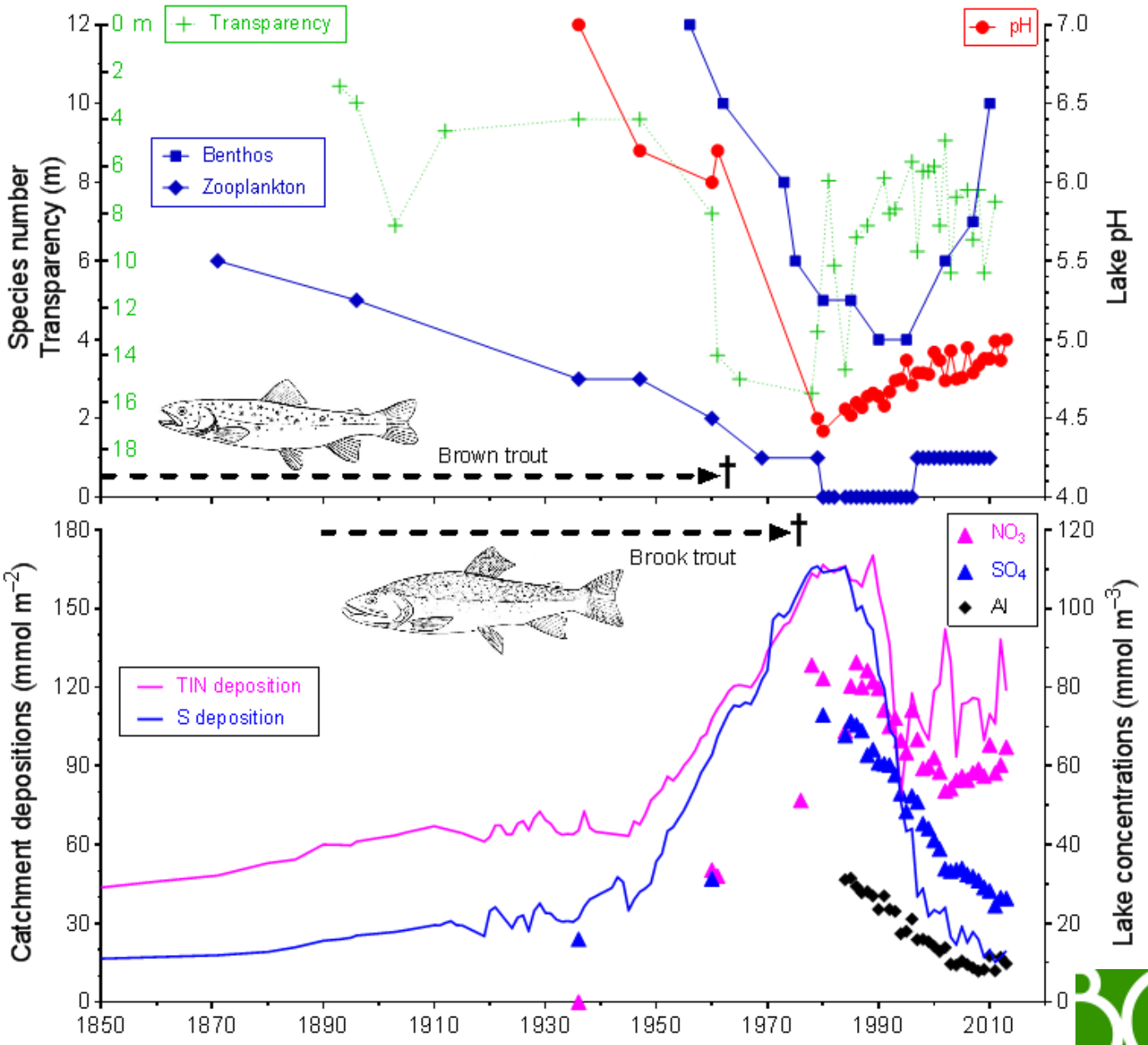
Černé Lake

Vrba et al. 2003

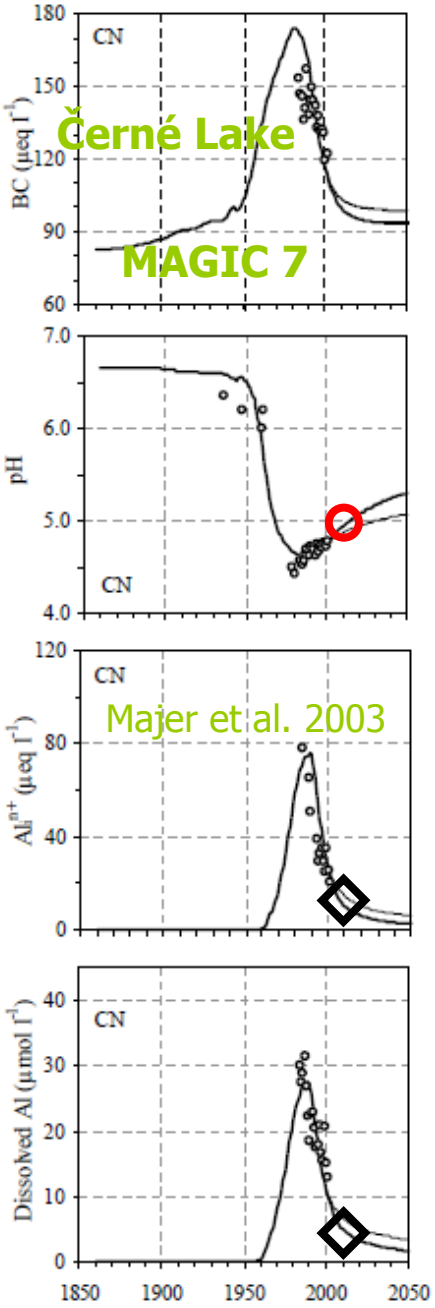


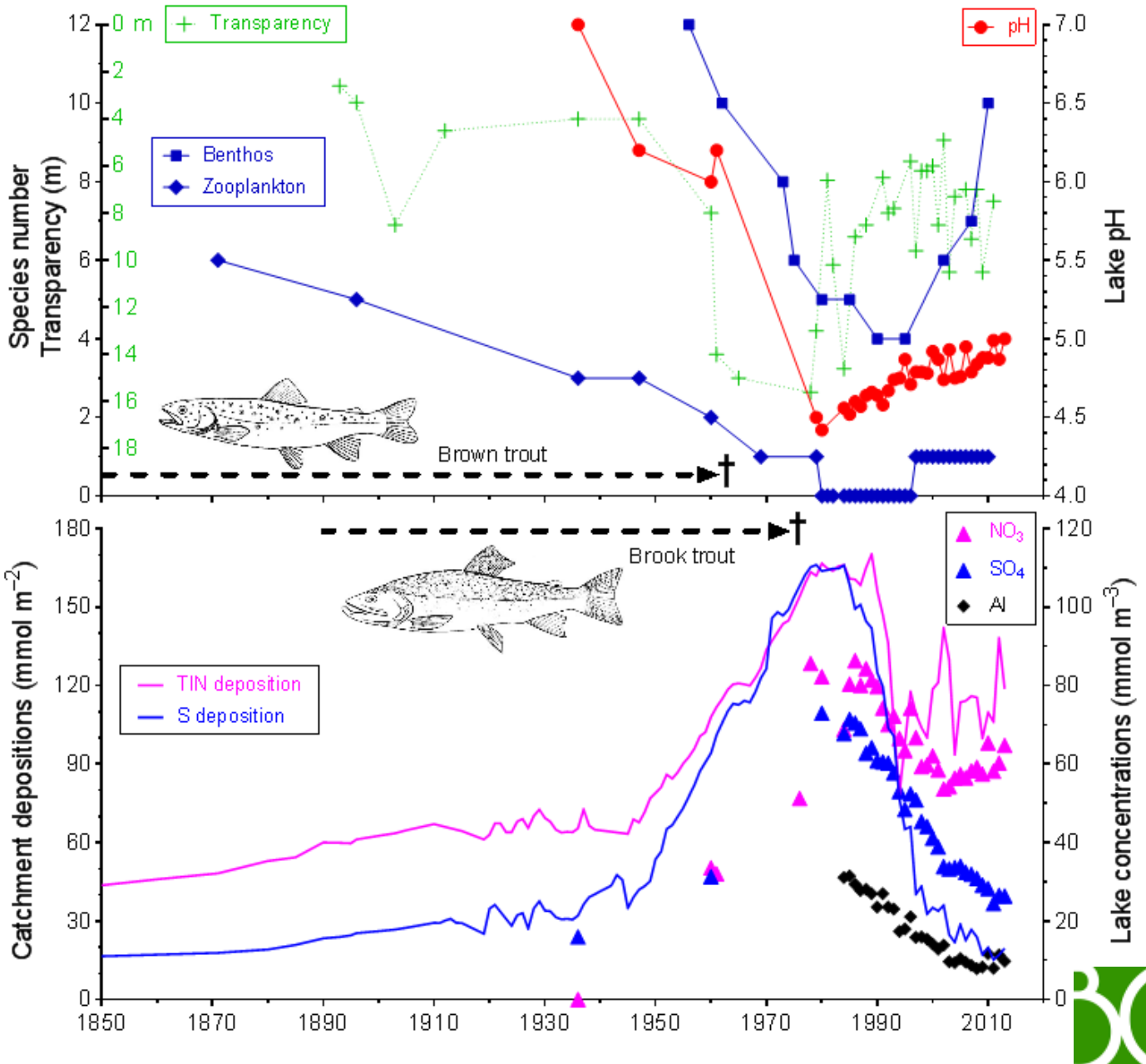
Atmospheric acidification and recovery



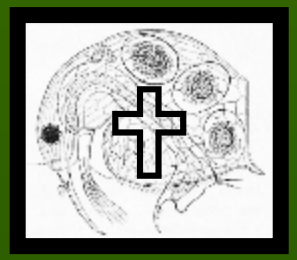


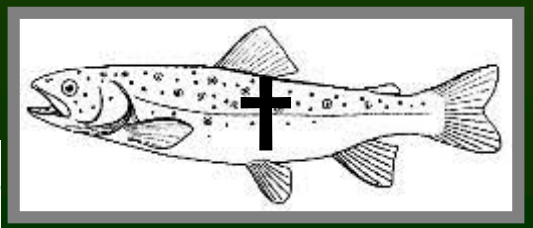
Atmospheric acidification and recovery

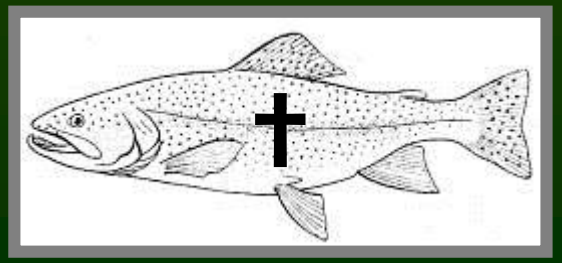


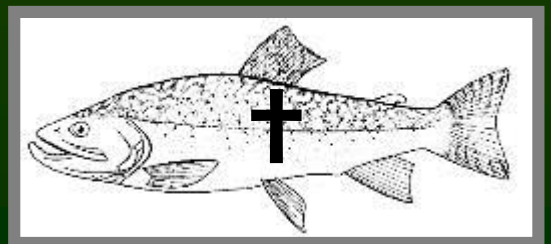


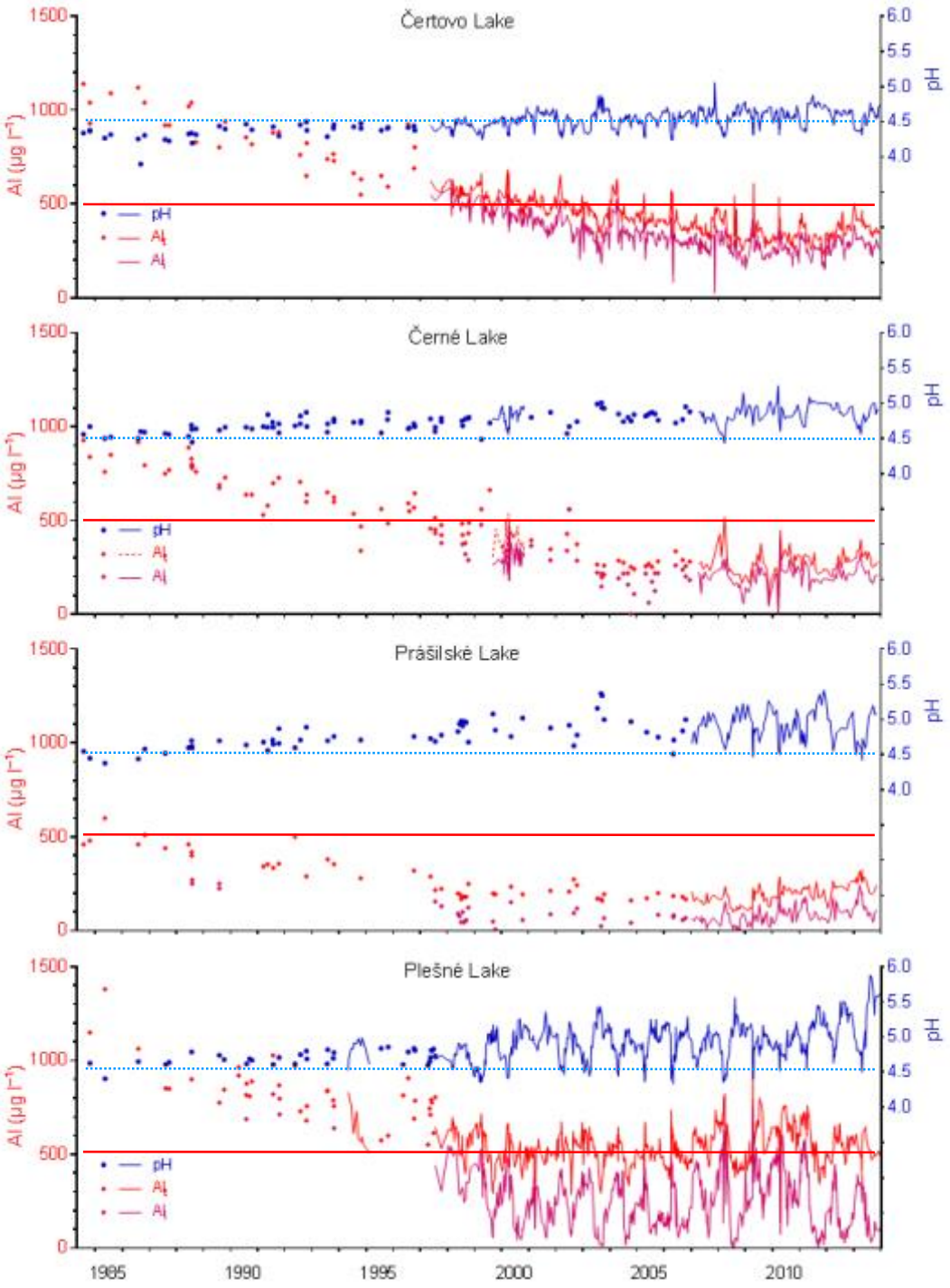
Biodiversity loss and potential for recovery

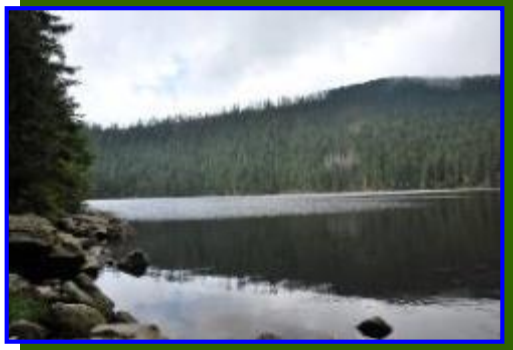


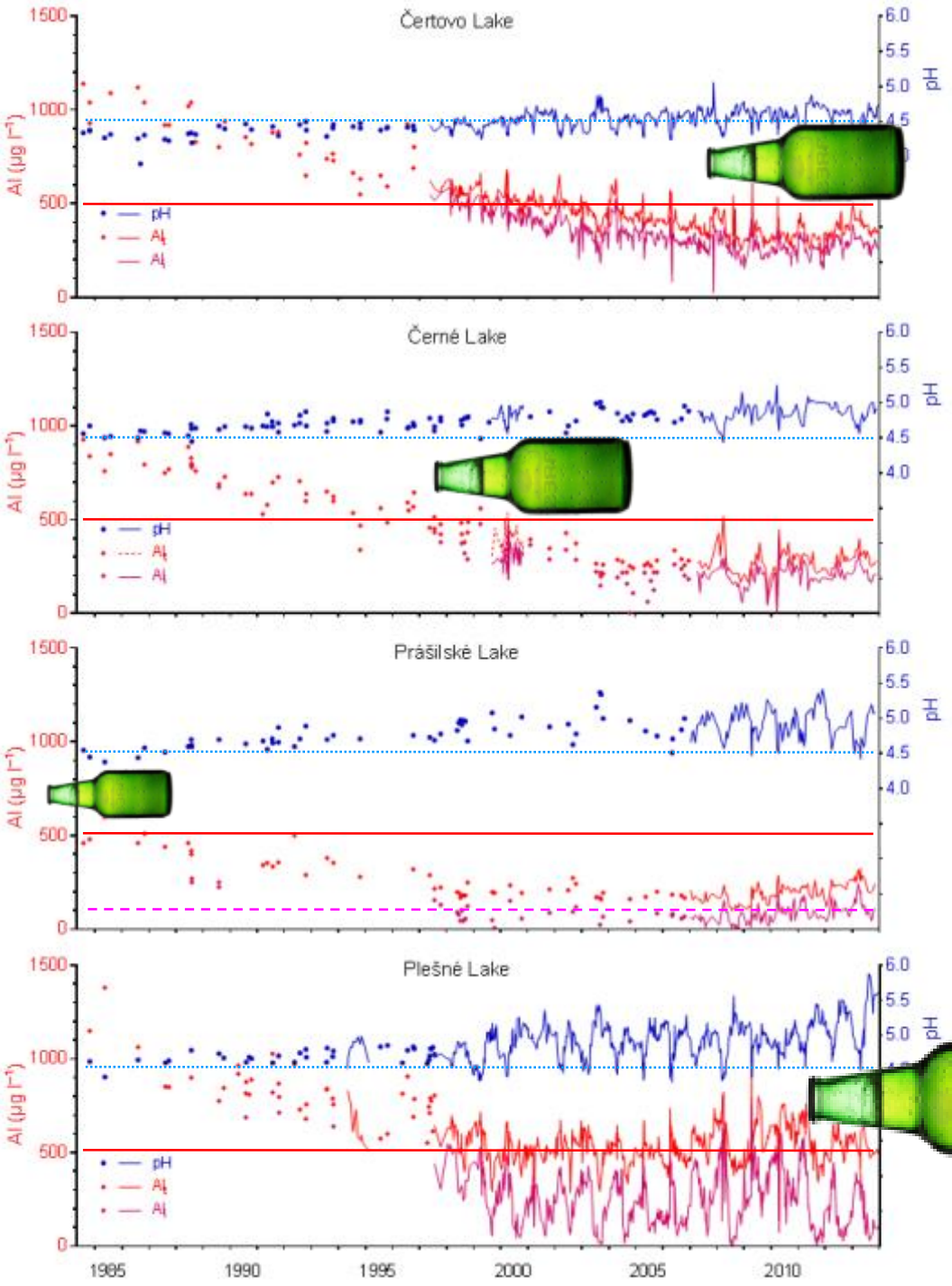




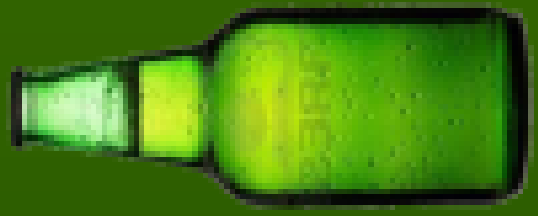



Čertovo Lake
Černé Lake
Prášilské Lake
Plešné Lake
Al (µg l⁻¹)
pH
1500
1000
500
0
6.0
5.5
5.0
4.5
4.0
pH
Al
Al
1985
1990
1995
2000
2005
2010

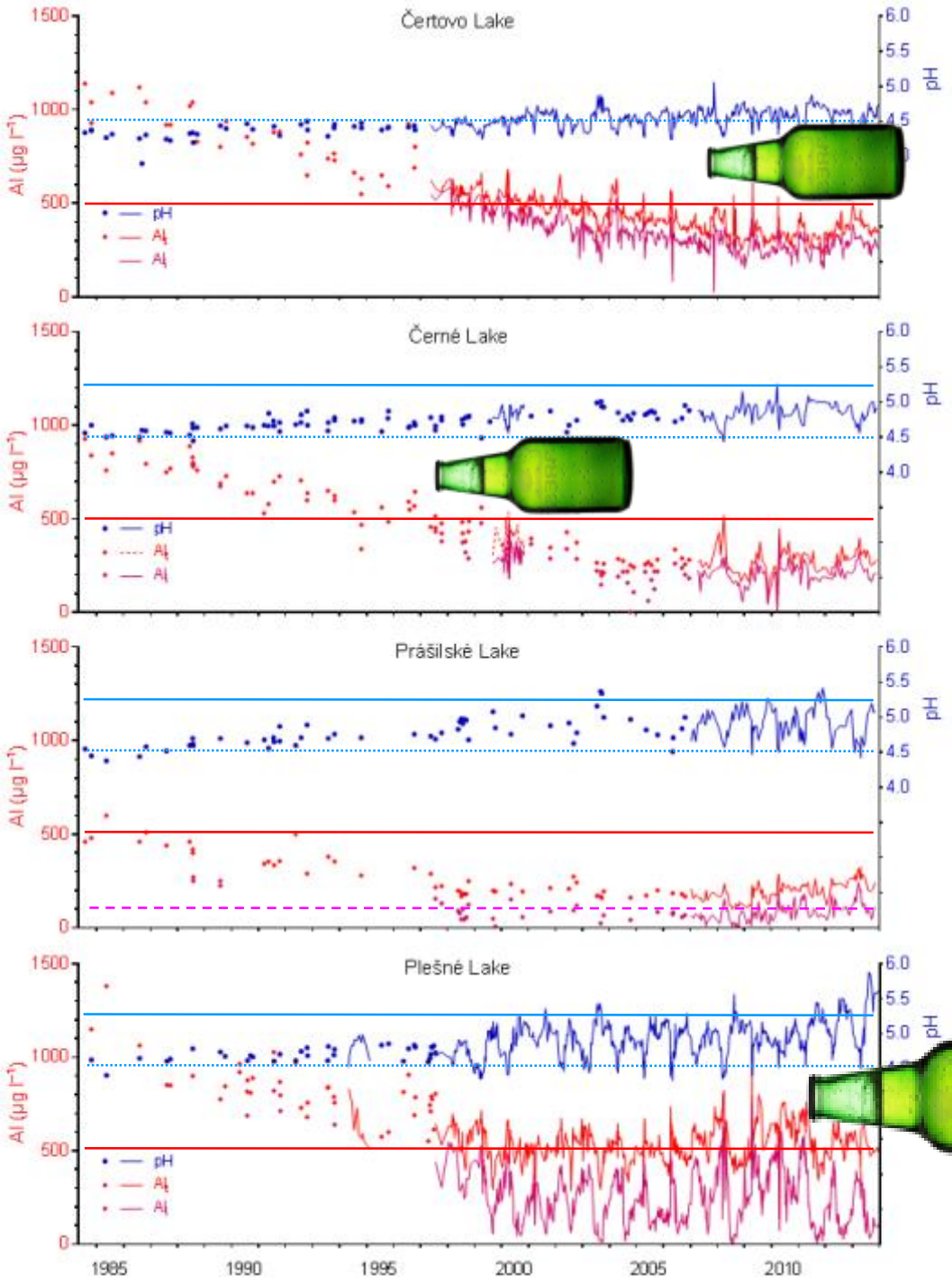




Aluminium has been a **bottleneck** for survival and biological recovery of the Bohemian Forest lakes.

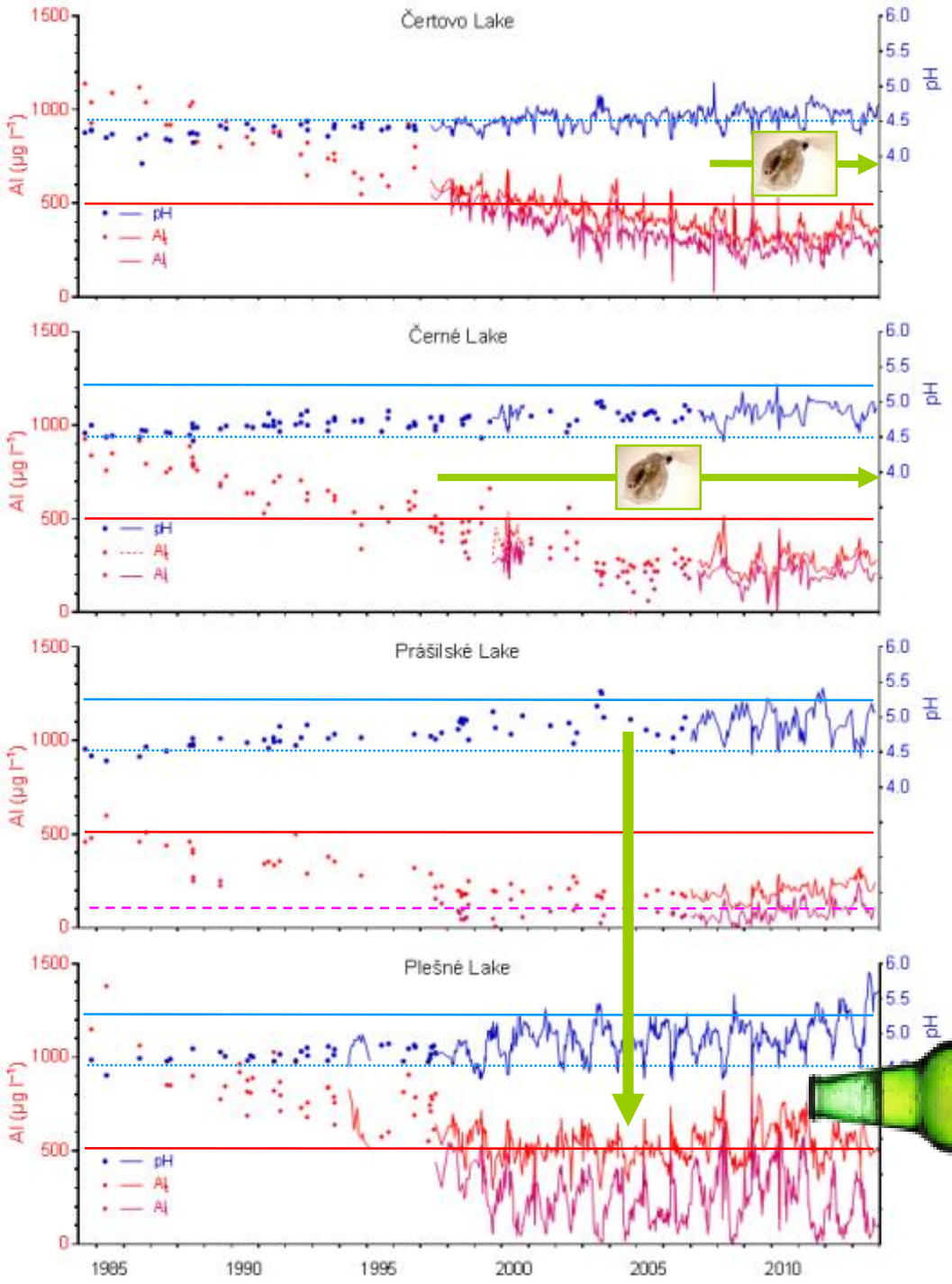


In the 1980s:
same pH
but **distinct Al levels**
and **speciation**!



Aluminium has been a **bottleneck** for survival and biological recovery of the Bohemian Forest lakes.

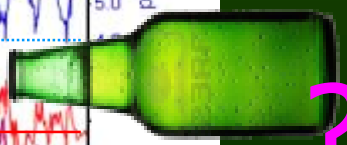
After two-decadal decline in S a N deposition:
increase in pH by ~0.5 unit with seasonal oscillations!
+ spring (snow-melt) maxima of ionic Al!



Aluminium has been a **bottleneck** for survival and biological recovery of the Bohemian Forest lakes.

Stepwise return of *Ceriodapnia qudrangula* !

A whole-lake experiment in September 2004: zooplankton reintroduction from Prášilské L. to Plešné L.



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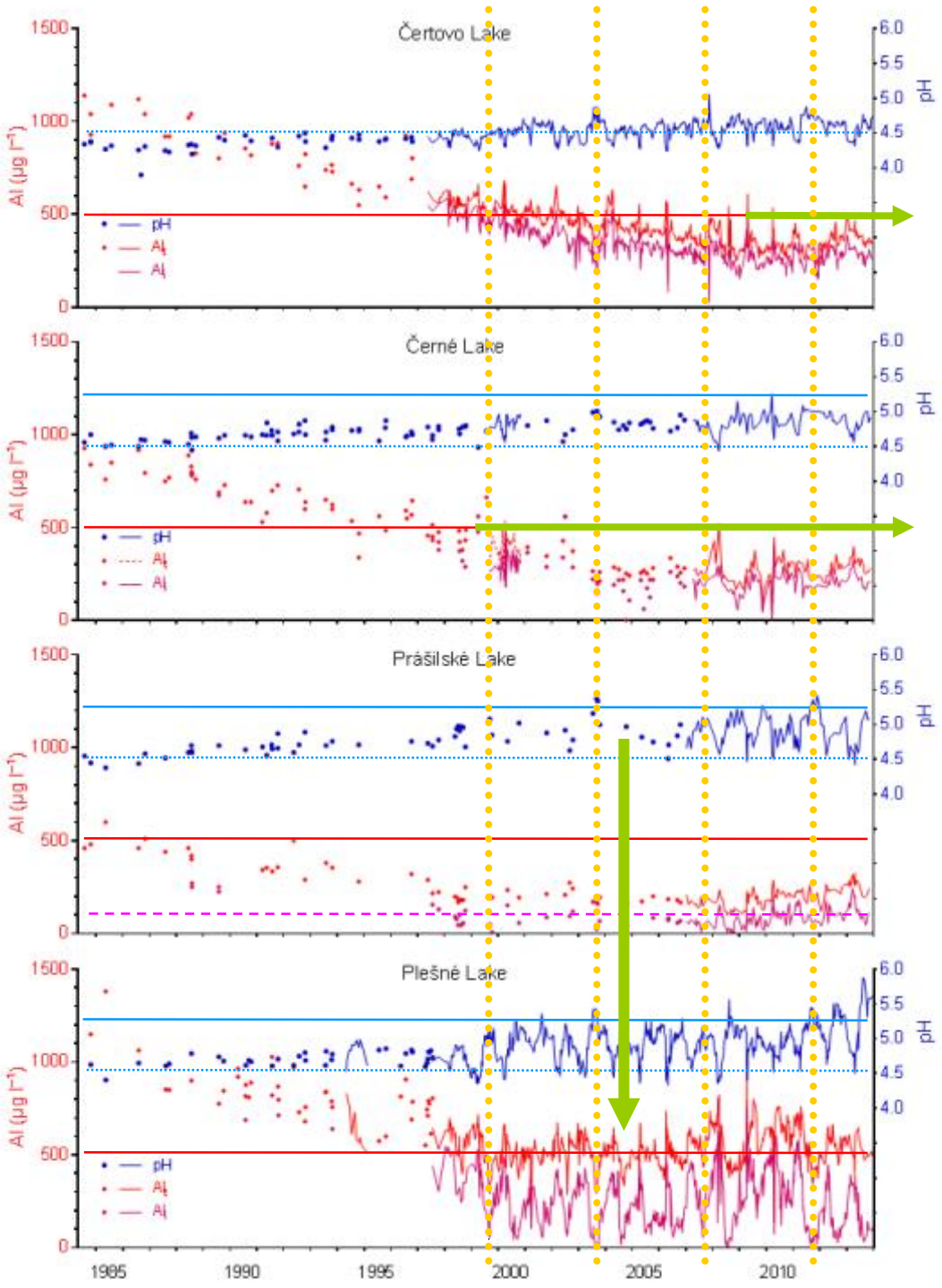
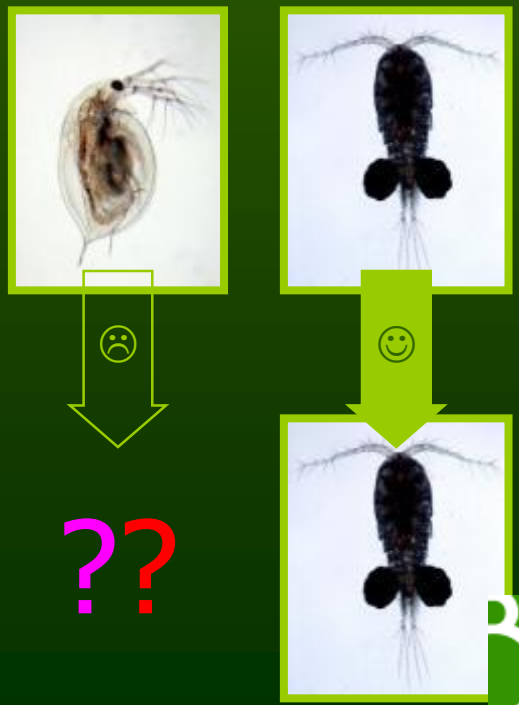
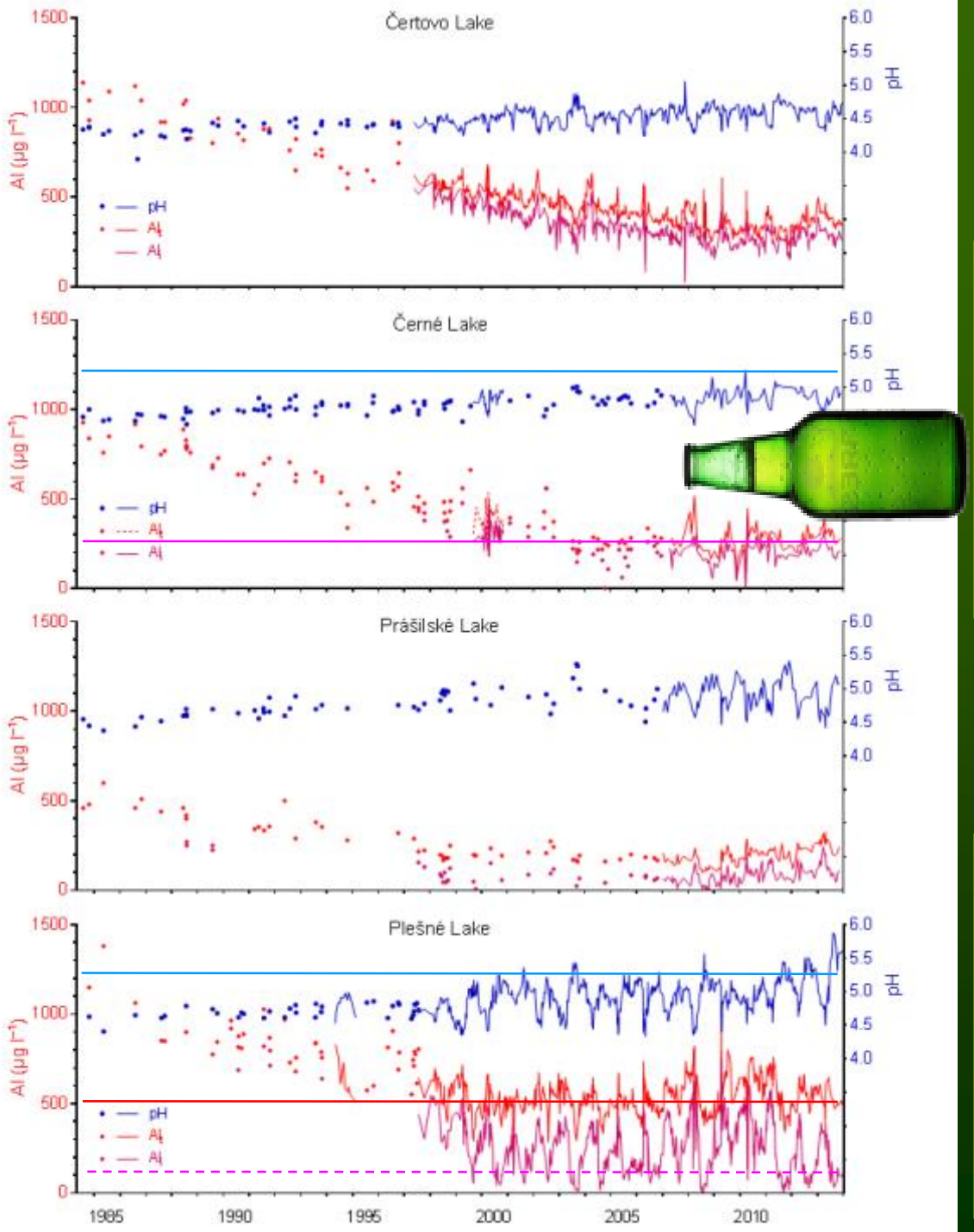


Aluminium has been a **bottleneck** for survival and biological recovery of the Bohemian Forest lakes.

Other constraints?

Four sampling campaigns of all Bohemian Forest lakes in September 1999, 2003, 2007 and 2011



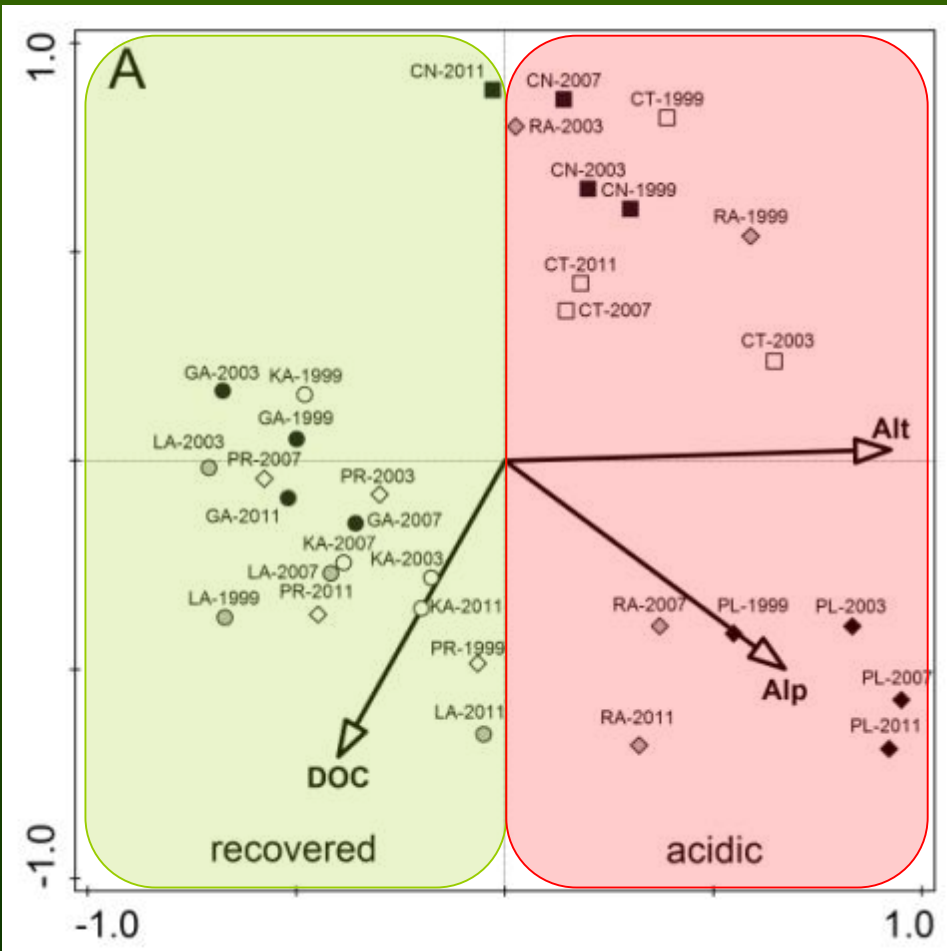


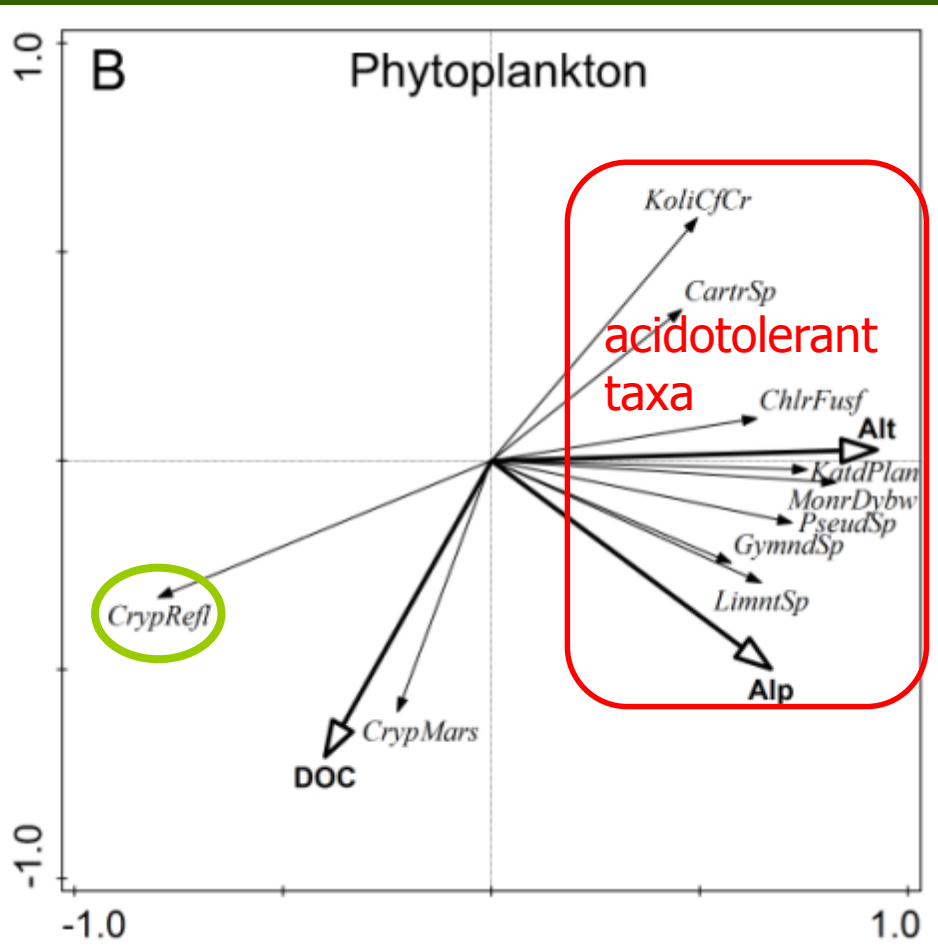
Aluminium has been a **bottleneck** for survival and biological recovery of the Bohemian Forest lakes.

Distinct phenology of quilworts' spore germination that is **sensitive to high Al_i concentrations.**

Phytoplankton recovery

Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Phytoplankton: 28 taxa (similar species in most lakes, but distinct dominance),
Al controls P availability; certain **increase in biomass**; low top-down control



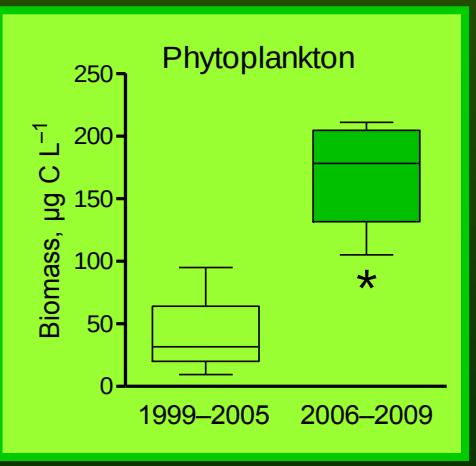


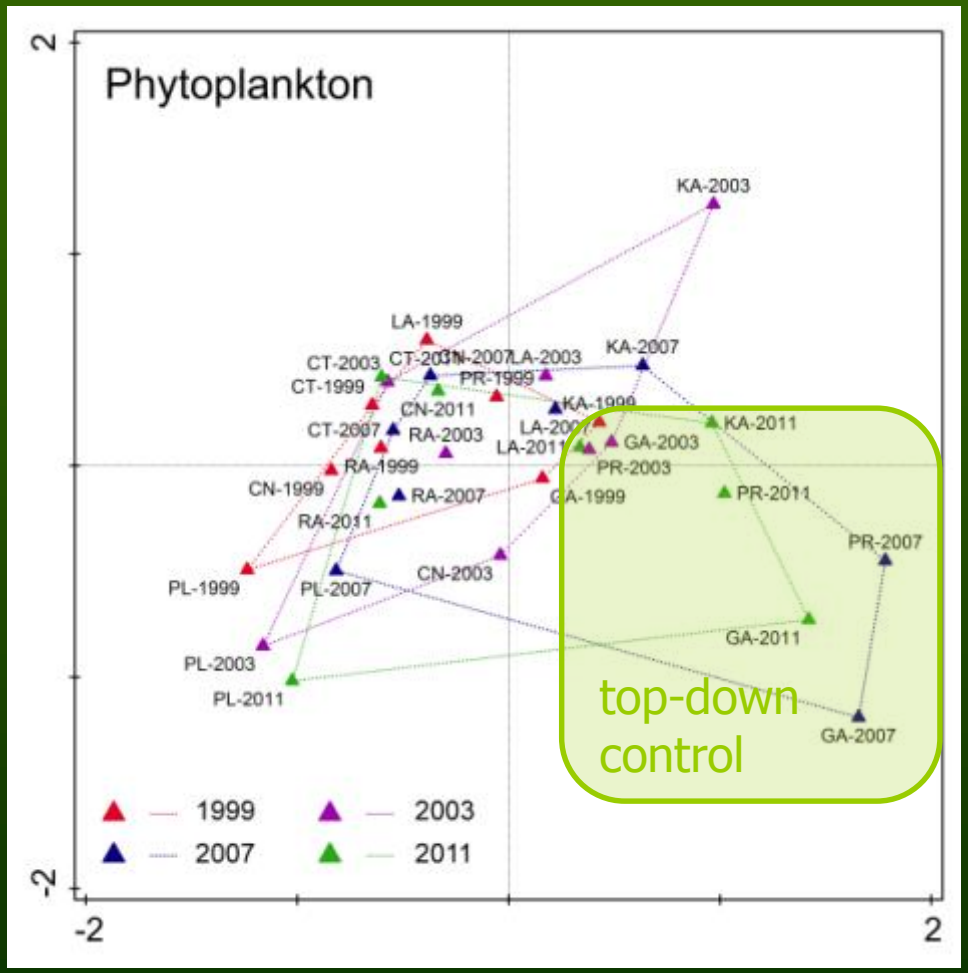
RDA model: 72.1%; axis 1: 32.8%, axis 2: 11.9%, P=0.019;
Forward selection: **24.9% by Alt**, P=0.002

Phytoplankton recovery

Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Phytoplankton: 28 taxa (similar species in most lakes, but distinct dominance),
Al controls P availability; certain **increase in biomass**; low top-down control

Lake Rachelsee

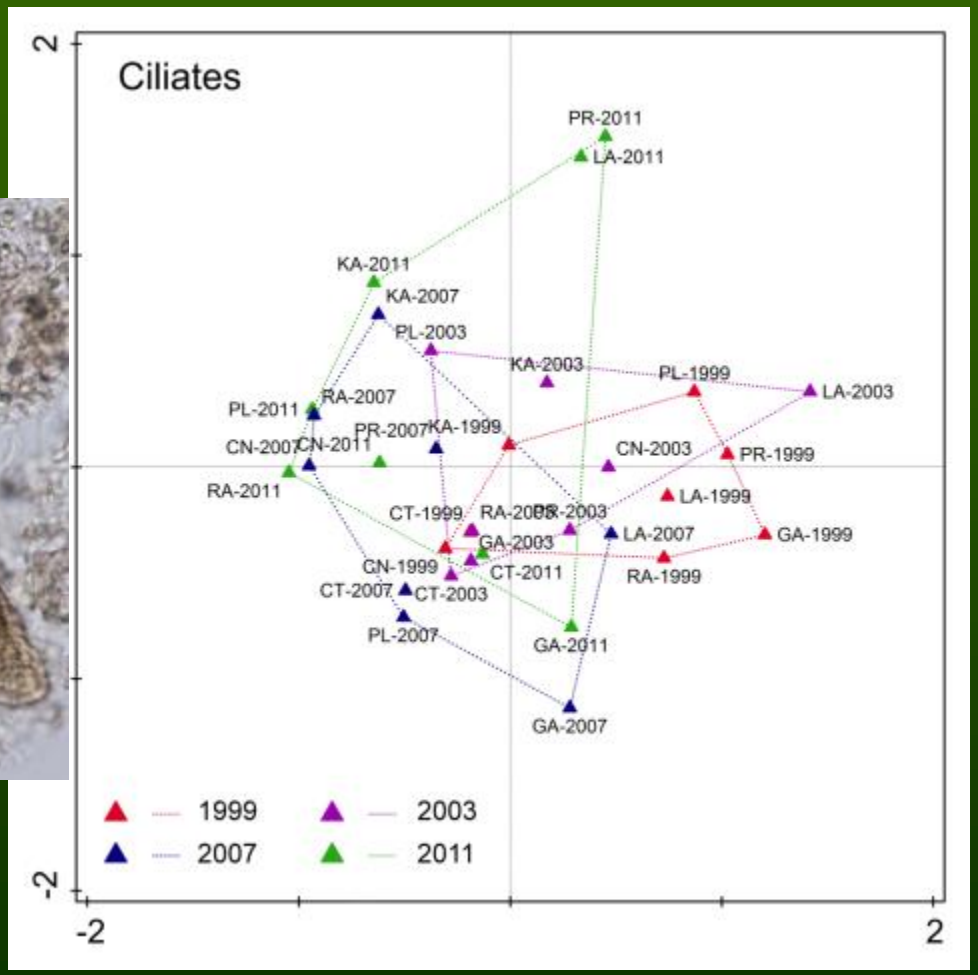




NMDS Bray-Curtis model; abundance of taxa; dissimilarity of lakes & sampling campaigns

Ciliates' recovery?

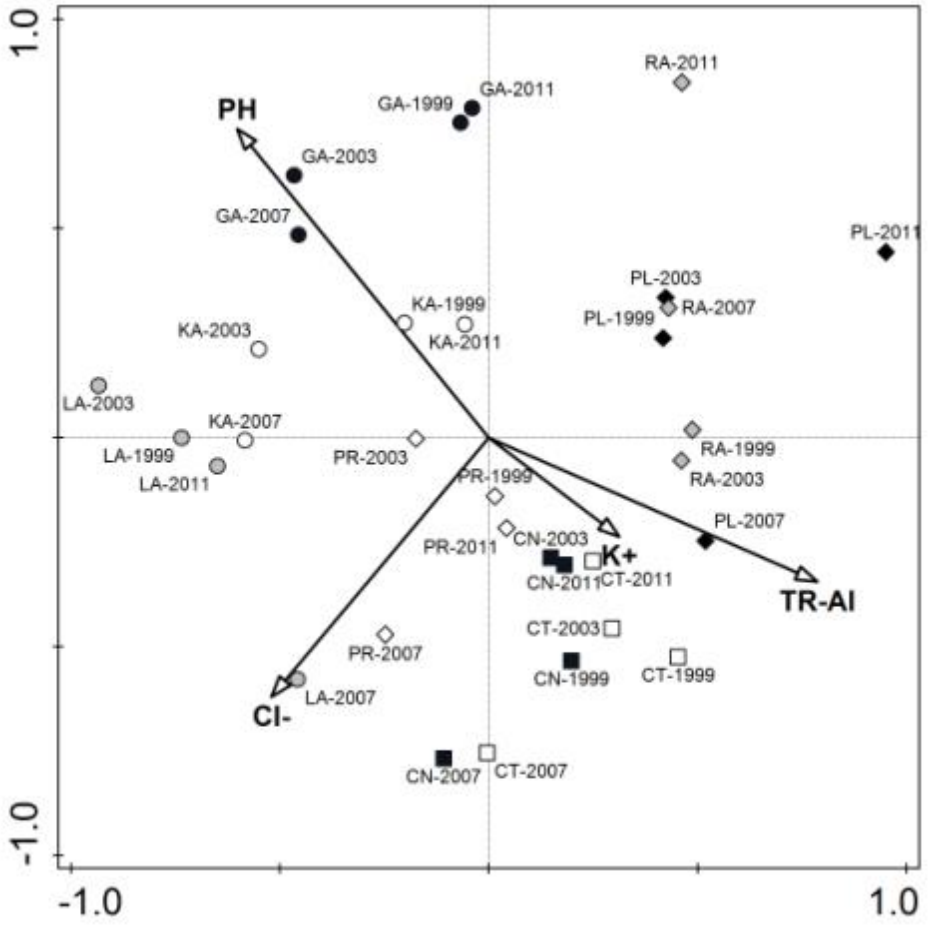
Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Ciliates: 42 taxa (9 anoxic not included), more diverse among the lakes, low abundance, increase in species number (omnivores, mixotrophs, algivores)

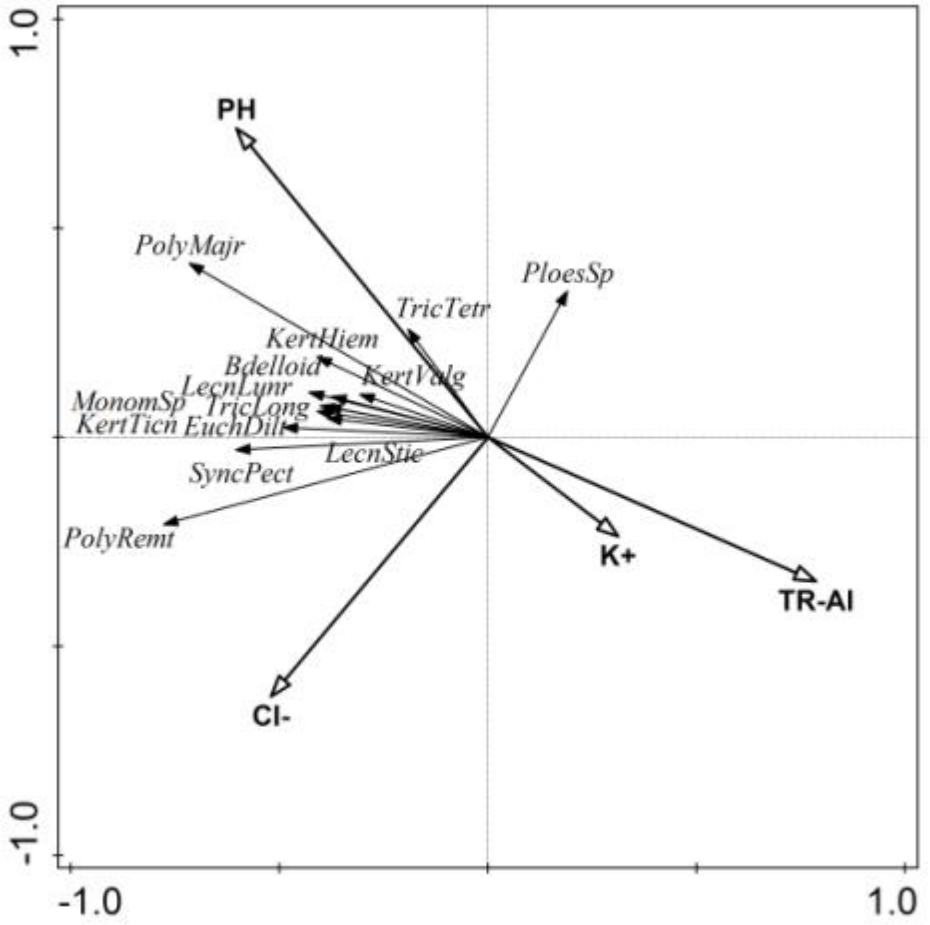


NMDS Bray-Curtis model; abundance of taxa; dissimilarity of lakes & sampling campaigns

Rotifers' recovery

Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Rotifers: 33 taxa (few common acidotolerant species, low abundance), increase in abundances; new circum-neutral species; top-down control



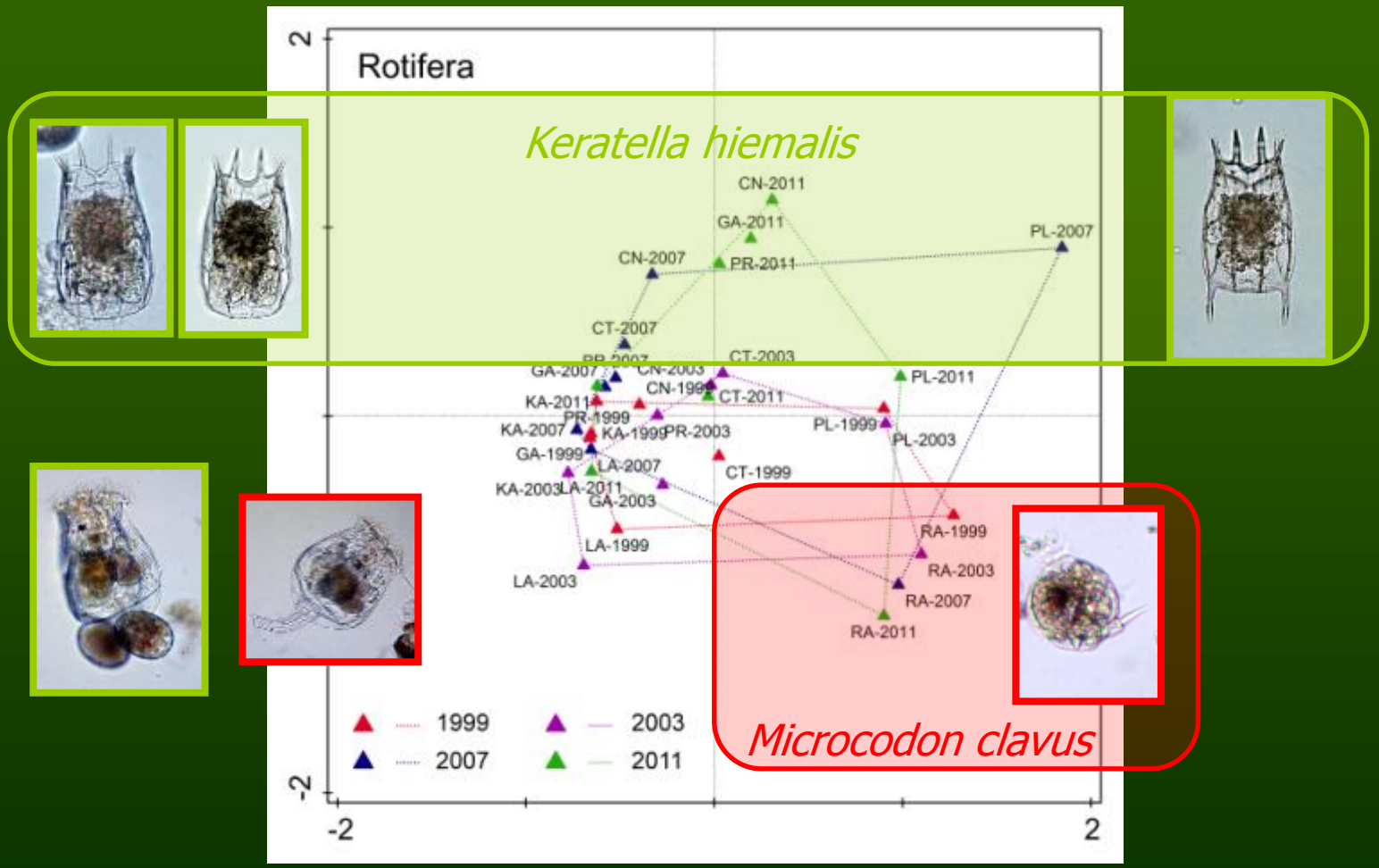


RDA model: 81.8%; axis 1: 53.1%, axis 2: 9.8%, P=0.006;
Forward selection: **27.4% by TR-Al**, P=0.016

Rotifers' recovery

Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011

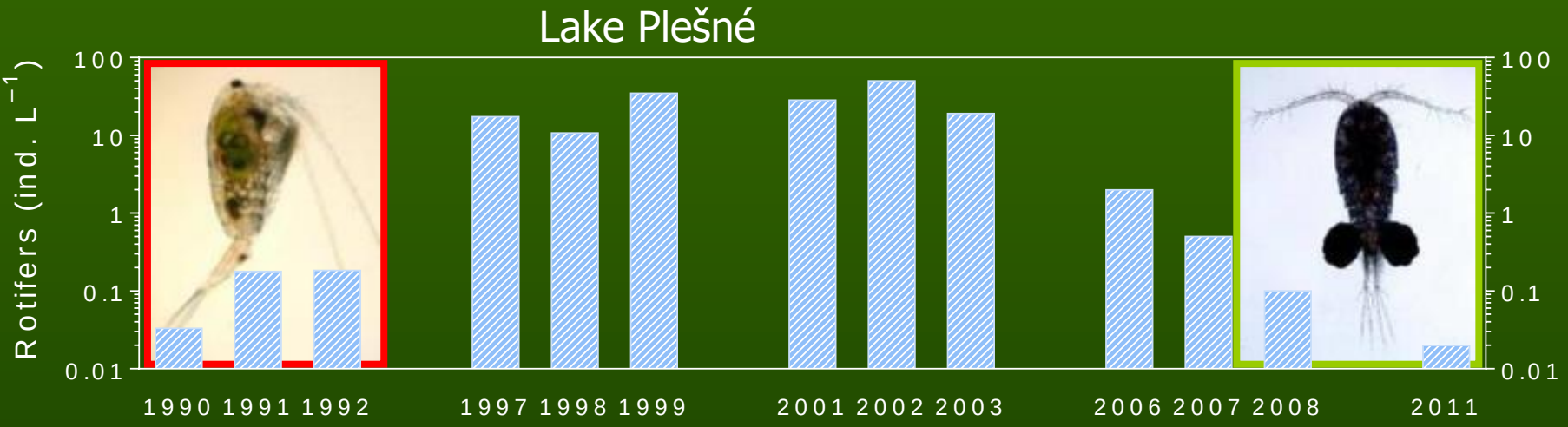
Rotifers: 33 taxa (few common acidotolerant species, low abundance), increase in abundances; new circum-neutral species; top-down control

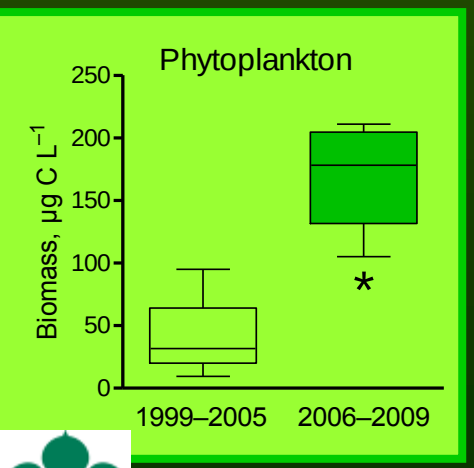


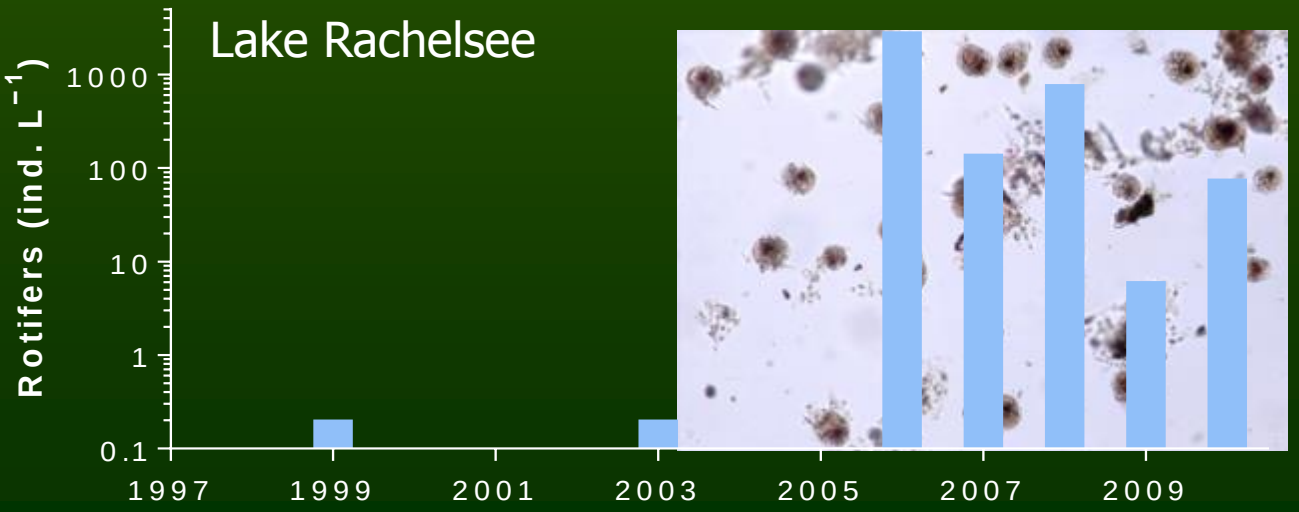
NMDS Bray-Curtis model; abundance of taxa; dissimilarity of lakes & sampling campaigns

Rotifers' recovery

Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Rotifers: 33 taxa (few common acidotolerant species, low abundance),
increase in food resources; food stoichiometry; **top-down control**

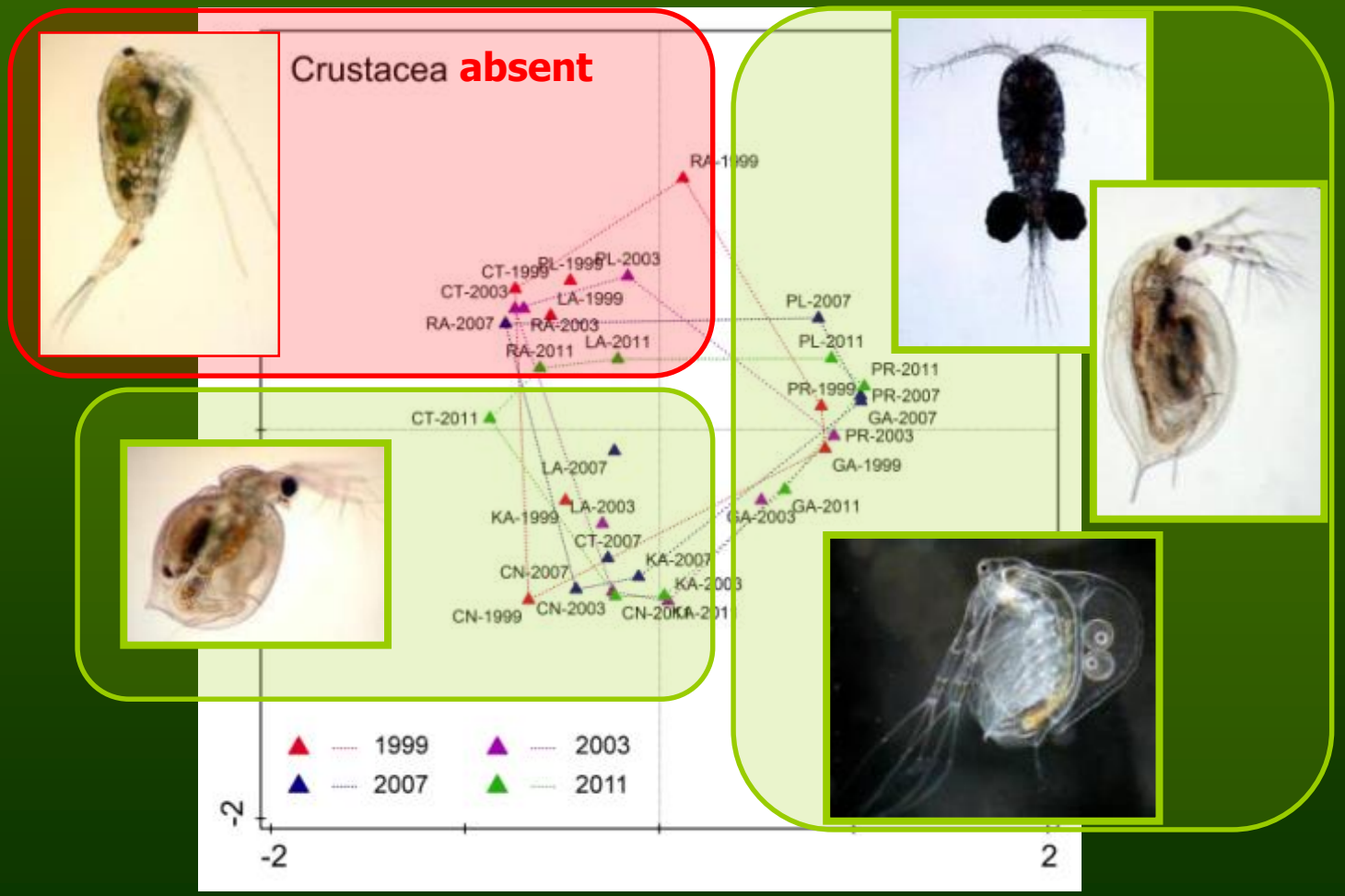






Cladoceran recovery

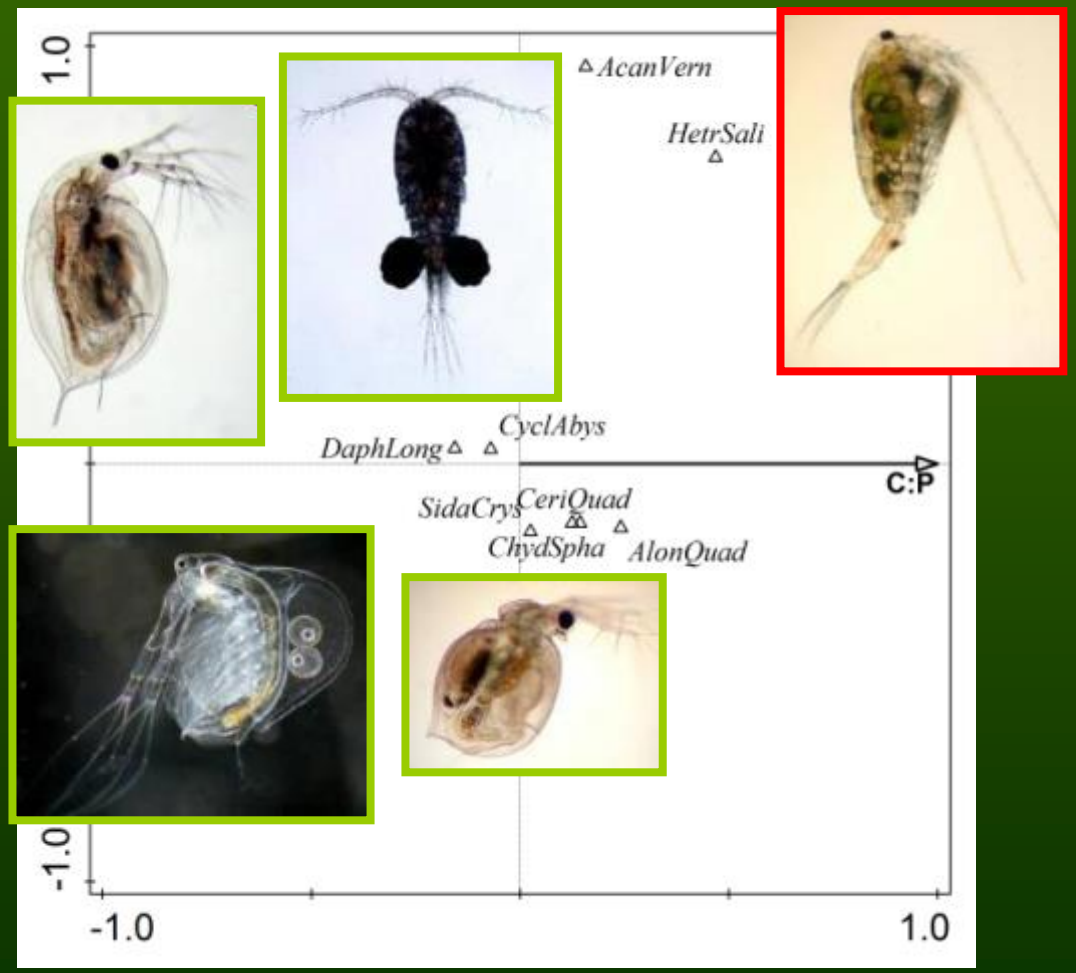
Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Crustacea: 27 taxa (21 Cladocera & 6 Copepoda), missing or different species, dispersal (regional absence), food stoichiometry (seston C:P), fish predation?



NMDS Bray-Curtis model; abundance of taxa; dissimilarity of lakes & sampling campaigns

Cladoceran recovery

Four sampling campaigns of all 8 lakes: September 1999, 2003, 2007 and 2011
Crustacea: 27 taxa (21 Cladocera & 6 Copepoda), missing or different species, dispersal (regional absence), **food stoichiometry** (seston **C:P**), fish predation?

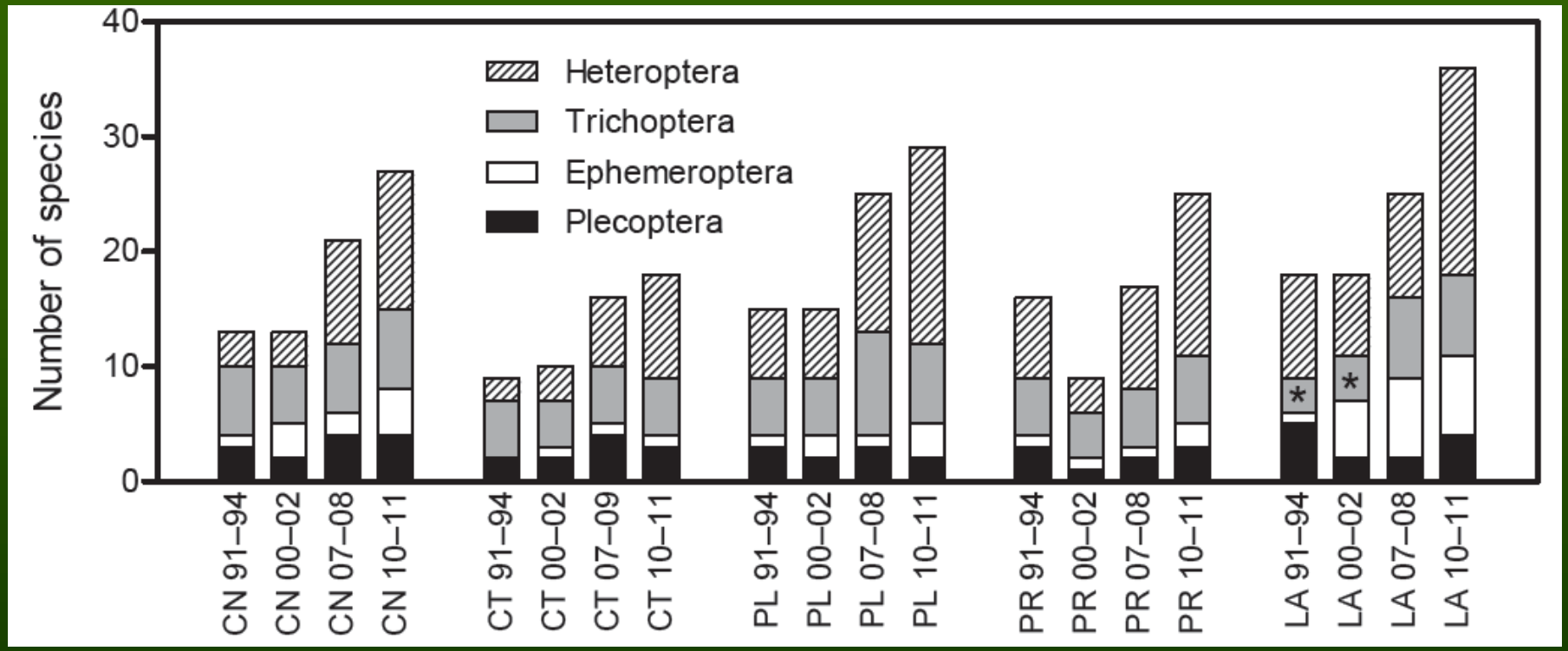


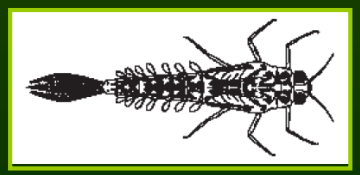
CCA model: 74.1%; axis 1: 18.3%, P=0.02;
Forward selection: **10.1% by C:P**, P=0.012

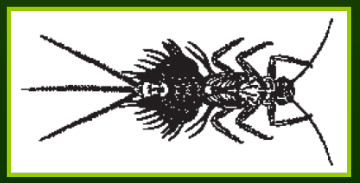
Aquatic insects' recovery?

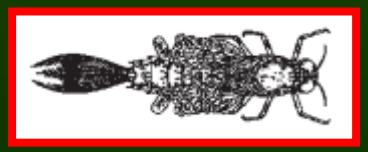
Only five Czech lakes

Aquatic insects: acidity, food resources, littoral habitats, dispersal rates





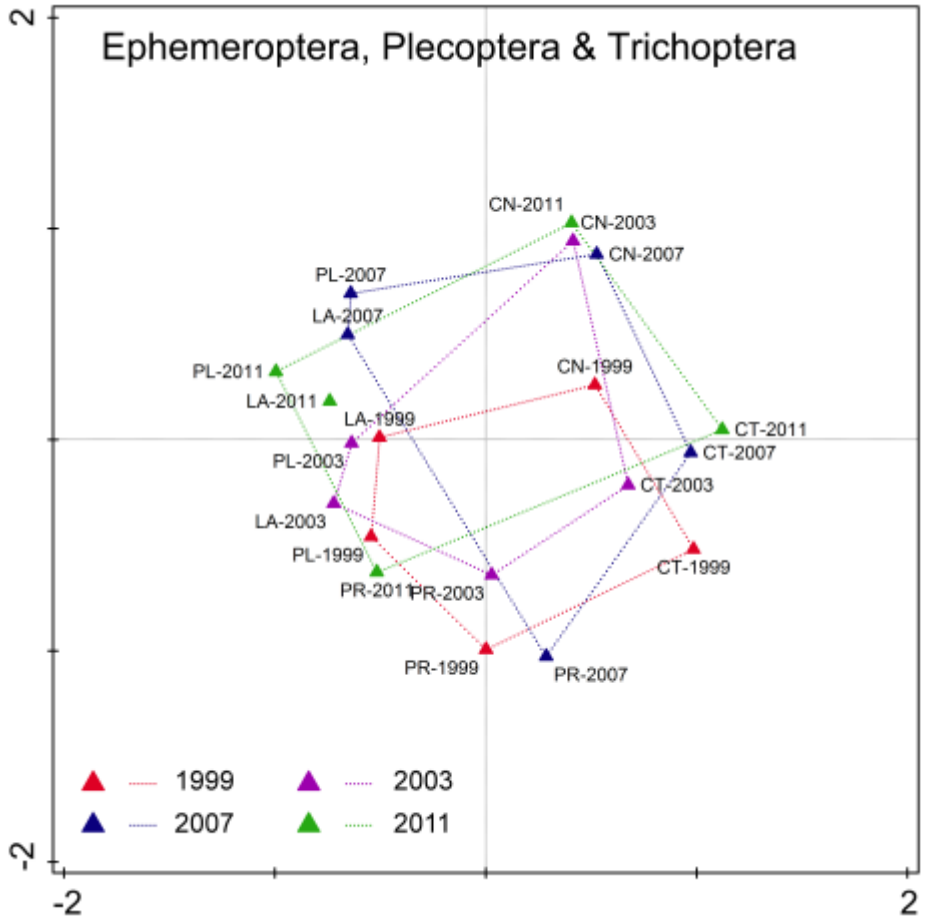


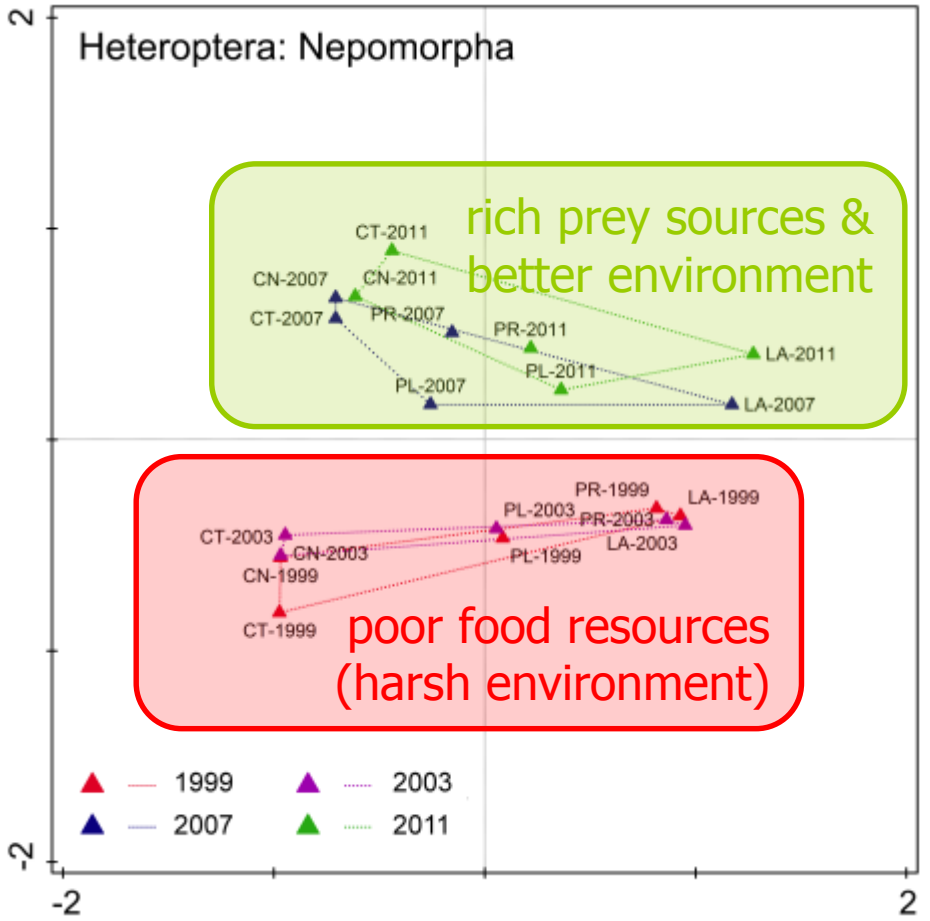


Soldán et al., 2012: Aquatic insects of the Bohemian Forest glacial lakes: Diversity, long-term changes, and influence of acidification. **Silva Gabreta 18: 123–283**.

Aquatic insects' recovery?

Four sampling campaigns of 5 Czech lakes: September 1999, 2003, 2007 and 2011
EPT: 30 taxa (7 Ephemeroptera, 8 Plecoptera, 15 Trichoptera), **Nepomorpha**: 21 taxa, acidity, littoral habitats, food/**prey availability**, **dispersal rates**

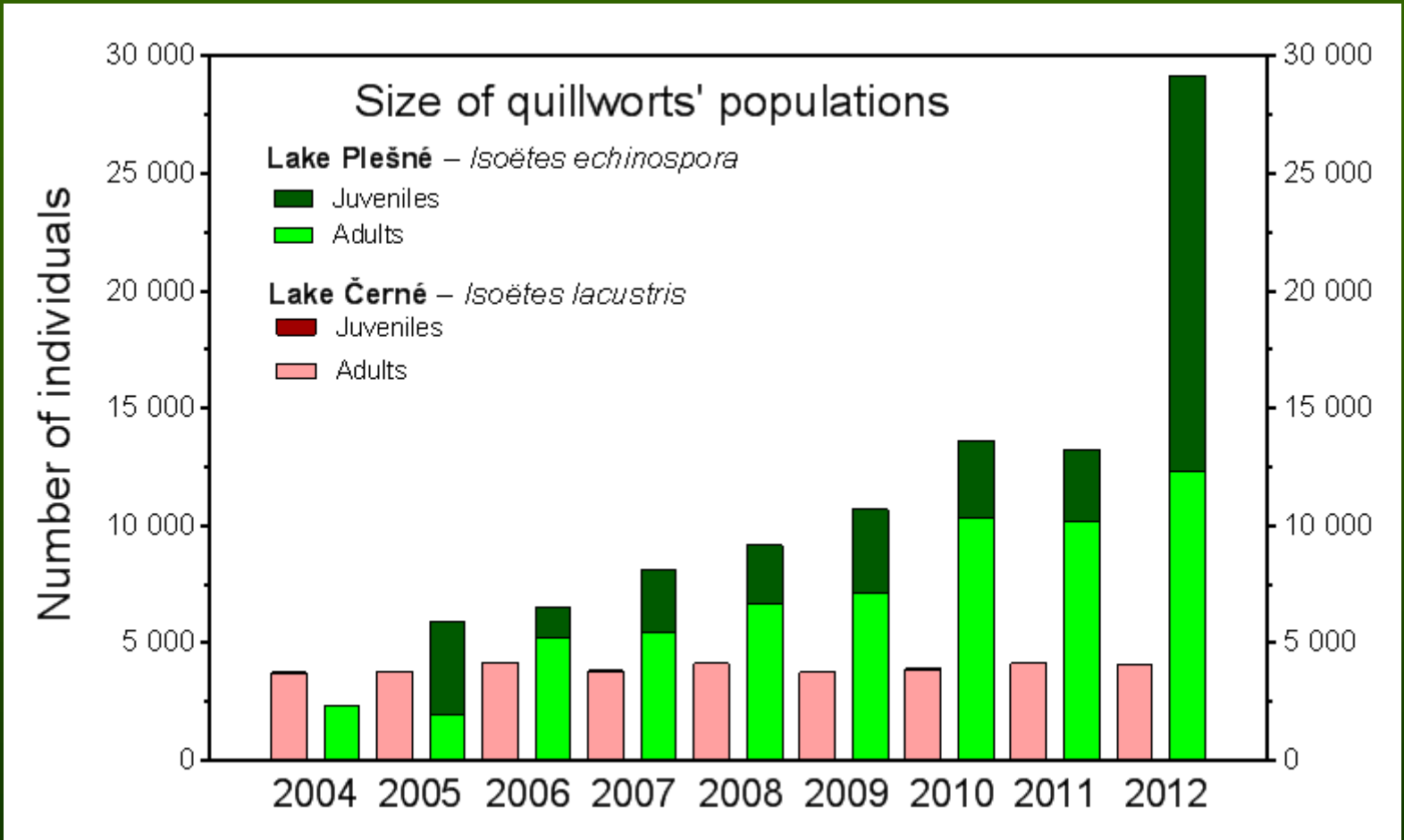




NMDS Bray-Curtis model; abundance of taxa; dissimilarity of lakes & sampling campaigns

Quilworts' recovery

Glacial relict populations of two *Isoëtes* species in two Czech lakes
Different recovery due to **distinct reproduction phenology**

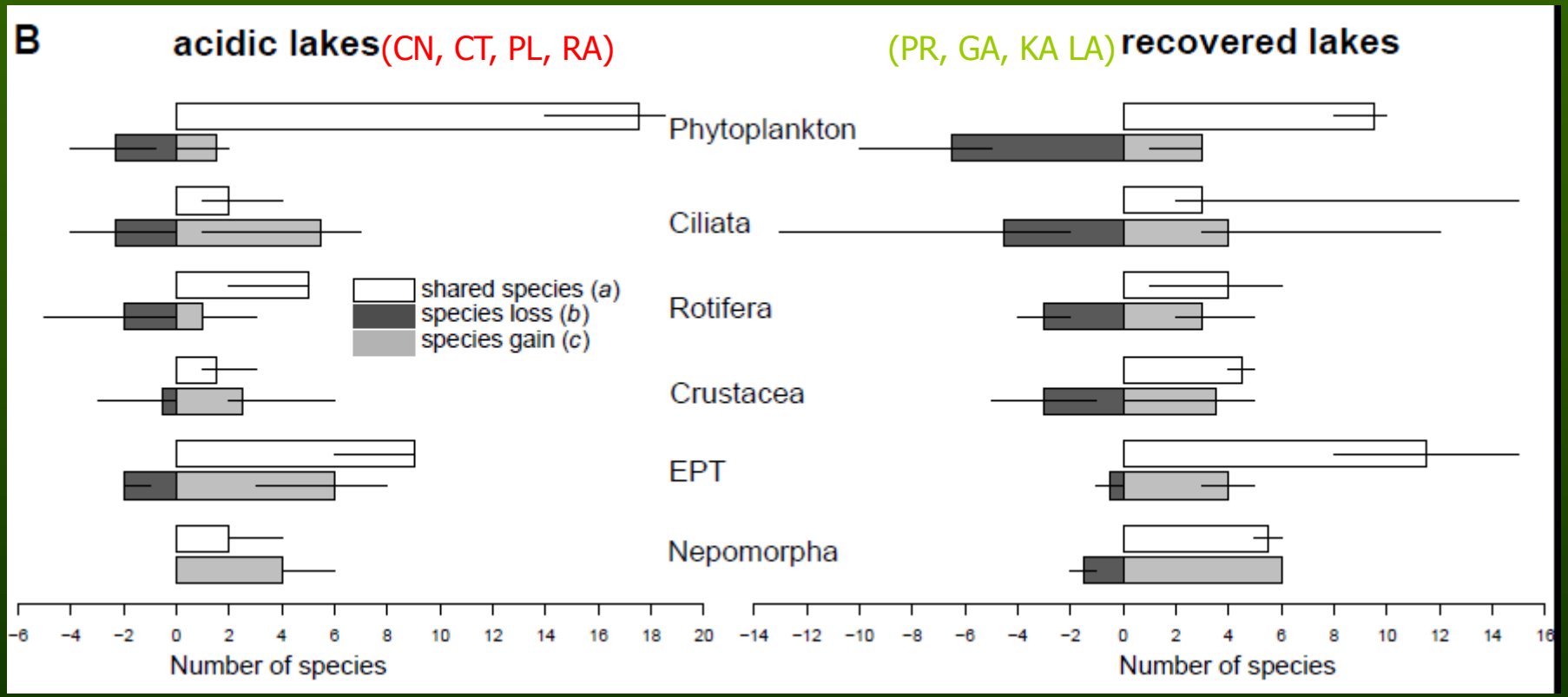


Čtvrtlíková et al., 2012: Effect of temperature on germination phenology of *Isoëtes echinospora*. **Preslia 84: 141–153.**

Čtvrtlíková et al., 2014: Effects of temperature on germination phenology of *Isoëtes lacustris*. **Preslia 86: 279–292.**

Summary of biological recovery 1999 vs. 2011

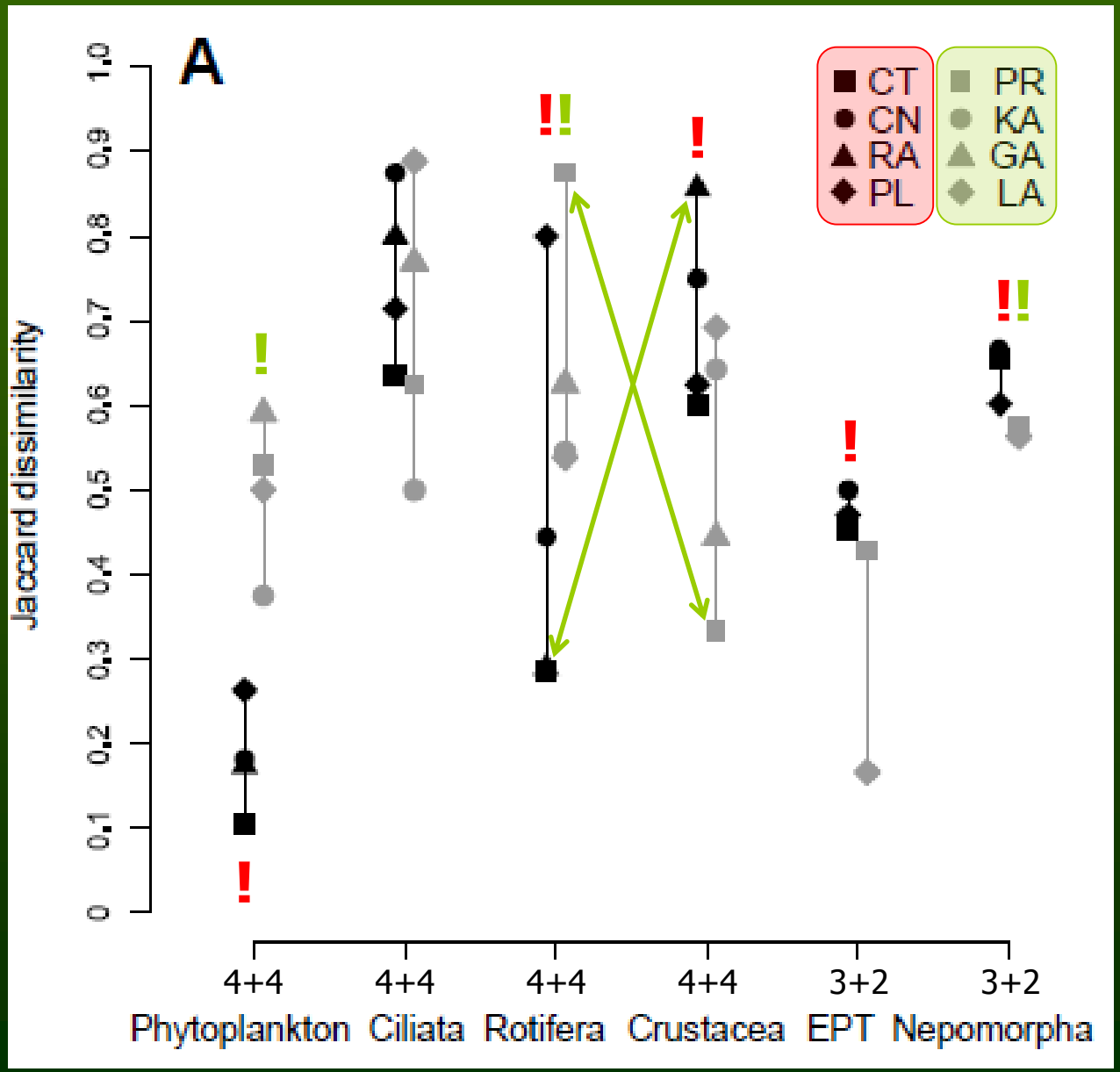
Distinct responses in different taxonomic groups
Overall **high species turnover**



661–87 days water residence time 14–157 days

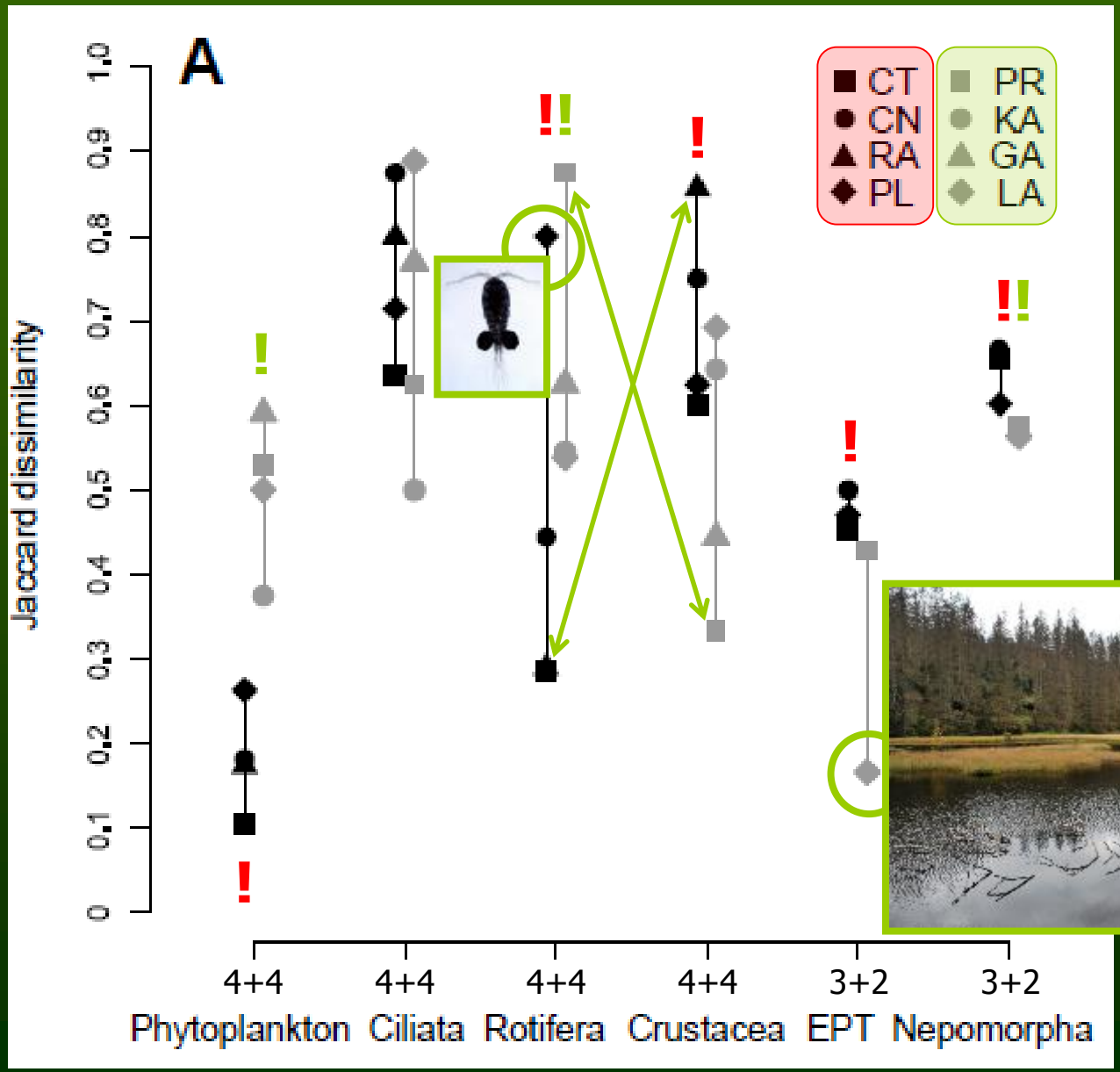
Summary of biological recovery 1999 vs. 2011

Distinct responses in different taxonomic groups



Summary of biological recovery 1999 vs. 2011

Distinct responses in different taxonomic groups



What are the constraints of biological recovery? Summary

1. **Aluminium bottleneck** (in-lake pH gradients!):
- Direct **Al toxicity** (spring Al^{3+} peaks)
- Reduces **P availability** (phytoplankton production & stoichiometry)
- Impairs respiration (unless frequent moulting – mayflies & stoneflies)
2. **Food quantity & quality** – low **C:P ratio** for rotifers or cladocerans (r-strategists)
3. **Water residence time** and morphology (stratification)
4. **Littoral conditions** (suitable habitats) for macrozoobenthos
5. **Mobility** and **prey availability** for top predators (aquatic bugs)
6. Low **dispersal rates** of plankton species (to remote lakes)
7. Malaise traps indicate great **colonisation potential** of aquatic insects

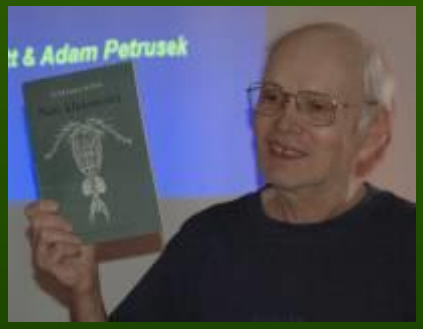
Acknowledgements

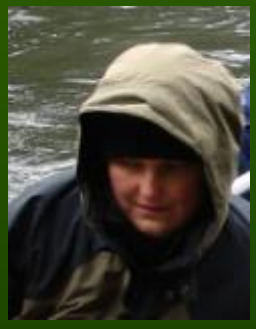
J. Bojková, P. Chvojka, M. Čtvrtlíková, J. Fott, J. Kopáček, M. Macek, L. Nedbalová, M. Papáček, V. Sacherová, T. Soldán, M. Šorf;

P. Bitušík, J. Kaňa, L. Kohout, J. Nedoma, P. Porcal, V. Straškrábová, E. Stuchlík, J. Sychra, J. Tátosová, J. Turek, † Josef Veselý, E. Zelenková;

C. Bässler, B. Beudert, L. Butz, W. Dörfer, W. Müller, H. Rall, J. Schaumburg;

and many others…





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