4. SUMMARY AND CONCLUSIONS

This thesis deals chiefly with various aspects of plankton ecology in mountain lakes recovering from anthropogenic acidification. A brief summary of attached publications and general conclusions with an emphasis on phytoplankton assemblages follow.

Biological recovery of the Bohemian Forest lakes from acidification (NEDBALOVÁ & al. 2006a)

Based on data collected in autumn 2003, this study of eight Bohemian Forest lakes focused in detail on an evaluation of the current progress in their chemical and biological recovery from acidification. In comparison with a 1999 survey, four lakes (Kleiner Arbersee, Prášilské Lake, Grosser Arbersee and Laka) have recovered their carbonate buffering system. However, the other four lakes (Černé Lake, Čertovo Lake, Rachelsee and Plešné Lake) still remain chronically acidified. The composition and amount of volume-weighted plankton biomass reflected differences in the acidification status and nutrient loading to particular lakes. While bacterioplankton was the main component in acidified lakes except for Plešné Lake, phytoplankton and zooplankton co-dominated the plankton biomass in the recovering lakes. A dominance of phytoplankton was characteristic for mesotrophic Plešné Lake, because of higher phosphorus input to this lake. Overall, the species composition and amount of phytoplankton biomass reflected differences in acidification status, nutrient availability and zooplankton status among the lakes. For example, grazing pressure of filtering zooplankton seems to be the cause for the high proportion of the large dinoflagellate *Gymnodinium uberrimum* in the phytoplankton biomass of some lakes. Concerning newly observed signs of biological recovery, we documented an increase in zooplankton biomass in the recovering lakes and a two-order-of-magnitude increase in rotifer abundance in acidified Plešné Lake. Moreover, this survey is the first evidence of the return of some macrozoobenthos species that were extinct during acidification (in particular from the Ephemeroptera and Plecoptera).

Phytoplankton of a high mountain lake (Ľadové pleso, the Tatra Mountains, Slovakia): seasonal development and first indications of a response to decreased acid deposition (NEDBALOVÁ & al. 2006b)

In this one-year study, we examined the seasonal and vertical distribution of phytoplankton in a non-acidified high mountain lake (Ľadové Lake, High Tatra Mts) with an emphasis on the effect of the currently less-pronounced episodic acidification of surface layers during melting periods. Unicellular flagellates, namely from the Cryptophyceae and Chrysophyceae dominated the phytoplankton, and different seasonal and depth distributions of important species (*Plagioselmis lacustris*, *Crypptomonas* cf. *erosa*, *Ochromonas* spp. and *Mallomonas akrokomos*) indicated differences in their ecological requirements. Total phytoplankton biomass did not exceed values typical for oligotrophic lakes, and showed a marked seasonal development with two high peaks in the deeper layers: one in December under thin clear ice and one just after the improvement of growth conditions due to melting of the winter cover. The specific content of chlorophyll-*a* showed clear patterns in both seasonal and vertical distribution. Concerning long-term trends in the lake water chemistry from 1980–2004, a significant increase in surface pH and acid neutralising capacity was observed, and the extent of episodic acidification has diminished both in time and space. We suppose that the shift in species composition, as well as the increase in phytoplankton abundances in comparison with a 1990–1991 study can be considered as the first sign of a biological response to decreased acid deposition.

Long term studies (1871–2000) on acidification and recovery of lakes in the Bohemian Forest (Central Europe) (VRBA & al. 2003a)

In this paper, we documented long-term changes in acid deposition, lake water chemistry and biodiversity of eight Bohemian Forest lakes. Due to a 130-year research tradition, we were able to cover the pre-acidification period, the period of strong acidification as well as the period of reversal from acidity, especially in the case of the most extensively studied Černé Lake. During the 1960s and 1970s, heavy acid deposition caused a drop of 2 pH units in this lake. The shift in lake water chemistry was accompanied by a drastic reduction in biodiversity, which included the extinction of most species of crustacean zooplankton, littoral macrozoobenthos (Ephemeroptera, Plecoptera) and fish. Acidification resulted in reduced biodiversity in all lakes, and pelagic food webs became dominated by microorganisms. Concerning phytoplankton, the 1999 survey documented the presence of 20–23 species in the seven dimictic lakes. Due to scarce historical records, we could not evaluate acidification-driven changes in phytoplankton species composition and biomass in detail. However, a comparison of the 1999 survey with older data suggested that many phytoplankton species were able to survive when the lakes became acidic. As regards signs of potential biological recovery from acidification, we observed an almost 50 % increase in chlorophyll-*a* concentrations in Plešné Lake between 1994 and 1998, which was likely a consequence of reduced phosphorus immobilisation by aluminium. Moreover, the population of *Ceriodaphnia* *quadrangula* returned to the pelagial of Černé Lake and the number of rotifers started to increase in Plešné Lake.

A key role of aluminium in phosphorus availability, food web structure, and plankton dynamics in strongly acidified lakes (Vrba & al. 2006)

This study focused on the evaluation of aluminium as a key factor driving plankton structure in four acidified lakes in the Bohemian Forest. The highest proportion of ionic aluminium was found in the most acid Čertovo Lake; on the other hand, the highest phosphorus input was characteristic for Plešné Lake. Phytoplankton in all lakes was apparently phosphorus limited, which was demonstrated both by elevated carbon to phosphorus ratios and the extremely high activity of acid extracellular phosphatases. The changes in lake water chemistry (pH and aluminium speciation) between 1998 and 2003 resulted in a significant increase in phytoplankton biomass. We suggested that both ionic and particulate aluminium may govern phosphorus availability namely through direct toxicity, inhibition of extracellular phosphatase activity and phosphorus inactivation. In lakes with lower concentrations of phosphorus, flagellates probably dominate the phytoplankton biomass due to their capacity for active migration. Moreover, mixotrophic species (e.g. frequent *Dinobryon* spp.) can partially satisfy their phosphorus demand by grazing on unicellular bacteria. Non-motile species (e.g. *Monoraphidium dybowskii*) likely take advantage of the higher phosphorus input to Plešné Lake. The dominance of this species in Plešné Lake can be further supported by its tolerance to high levels of toxic aluminium species. Hence, a unique set of specific food webs dominated by microorganisms have developed in the pelagic zone of particular lakes as the result of differences in aluminium and phosphorus input and acidification status.

Massive occurrence of heterotrophic filaments in acidified lakes: seasonal dynamics and composition (Vrba & al. 2003b)

We documented the massive presence of extremely long (> 100 μm) heterotrophic filaments in the plankton of acidified lakes in the Bohemian Forest. Our aim was to evaluate possible reasons for their seasonal development patterns and their high proportion in the plankton biomass in particular lakes. The main factors influencing filament dynamics were identified as both grazing of mixotrophic flagellates from the genus *Dinobryon* (Chrysophyceae) on unicellular bacteria and filtration of *Daphnia longispina*, which occassionally reduced protistan grazers as well as the filaments. In both oligotrophic lakes (Čertovo and Prášilské), *Dinobryon pediforme* was often the most abundant phytoplankton species, taking advantage of mixotrophic growth in conditions of severe phosphorus limitation. On the other hand, *Dinobryon sociale* var. *americana* occurred in mesotrophic Plešné Lake usually in low abundace, and autotrophic phytoplankton species dominated in this lake due to the elevated nutrient supply. The plankton composition and dynamics in the lakes clearly showed the influence of both protistan grazing and the top-down control of cladoceran grazing on shaping the structure of pelagic assemblages.

Overall, we tried to determine key factors and mechanisms influencing actual species composition and structure of plankton biomass in acidified lakes under study. Through the effects of direct toxicity, phosphorus immobilisation and inhibition of extracellular phosphatases, aluminium was shown to shape the specific structure of pelagic food webs in particular Bohemian Forest lakes. The amount of total plankton biomass was apparently the result of a complex interplay between pH and phosphorus and aluminium concentrations in tributaries and lake water. In addition, protistan grazing by *Dinobryon* spp. was identified as the reason for an unusually high proportion of heterotrophic filaments in the plankton biomass. Concerning phytoplankton, higher nutrient input seems to favour the occurrence of non-motile forms. On the other hand, flagellates often with the ability of mixotrophic nutrition dominate in the lakes with lower nutrient input, as it is typical for oligotrophic mountain lakes elsewhere.

Furthermore, the results of an extensive limnological survey have demonstrated in detail that the beginning of biological recovery of the lakes from acidification has been significantly delayed after the chemical reversal. However, a significant progress was recorded in comparison with previous studies. Due to the harsh growth conditions in the lakes already during the pre-acidification period, the response of phytoplankton communities was manifested chiefly through increases in biomass as a result of reduced phosphorus immobilisation by aluminium in conditions of higher pH. However, we have documented a shift in phytoplankton species composition in a lake characterised by diminishing extent of episodic acidification. Most likely, further reversal in lake water chemistry in both lake districts will be reflected in changes in biomass and relative proportion of species due to the varying importance of bottom-up and top-down control. In general, we suppose that namely the ecosystem resistance may prevent full biological recovery of the lakes.