4.5 Ecology of biological soil crusts in relation to mechanical disturbance

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INTRODUCTION

In this chapter, we discuss the effects of disturbance treatments (conducted on localities at Ralsko and Chvaletice) on both biotic and abiotic data of biological soil crusts. We report patterns of response to disturbance in individual organismal groups and, finally, we discuss results of this experiment as a whole.

MATERIAL AND METHODS

The localities, design of an experiment and sampling details are included in the previous chapters. The lichen quantities were counted as a percentage of surface cover that was subsequently divided into four semiquantitative categories. Methods of measuring the abiotic data and ecophysiological characteristics can be found in Chapter 3.2. Statistical analyses of species data involved the significance testing of differences in species composition following the disturbance using Manhattan distances by non-parametric two-group ANOSIM permutation tests with 10 000 permutations (Clarke 1993; Hammer et al. 2001). The differences in species diversity between disturbed and non-disturbed samples in 2006 were evaluated using permutation tests (with 10 000 permutations) on Menhinick diversity index of data sets using a script written in R 2.3.1 (R Core Development Team, 2006). Two-matrices Mantel tests of matrix correlations were used to test for higher similarity in species composition on identical squares between seasons (Mantel 1967). Matrices of Manhattan distances were used to indicate dissimilarity in species composition and they were correlated with matrices of identity (0)/difference (1) in squares assignment. Significance was assessed by 10 000 permutations of original matrices. Ordination plots and graphs were created using SigmaPlot, ver. 9.01, and PAST, ver. 1.74.

The pattern of abiotic and ecophysiological data was illustrated using PCA. The significance of changes in abiotic and ecophysiological data following disturbance was evaluated using pairwise t-tests of 2005/2006 difference in individual factors.

RESULTS

Species composition of algae and cyanobacteria did not differ significantly between 2005 and 2006 samples in both Chvaletice (ANOSIM p-value = 0.584) and Ralsko localities (ANOSIM p-value = 0.549). At the same time, the 2006 samples did not differ significantly in its algal and cyanobacterial species composition with regard to disturbance effect both in Chvaletice (ANOSIM p-value = 0.656) and Ralsko samples (ANOSIM p-value = 0.399). When looking at diversity indices, we see that average diversity in disturbed plots in 2006 was slightly higher in comparison to undisturbed sites in the Chvaletice locality (Menhinick index for disturbed sites was 3.65, for undisturbed sites 3.16). However, this difference was not significantly different in permutation test on Menhinick index (difference between Menhinick indices of disturbed and undisturbed 2006 sites was 0.486, permutation p-value 0.55). In Ralsko, disturbed plots had lower average biodiversity (Menhinick index for disturbed sites 3.54, for undisturbed sites 5.13). A permutation test demonstrated weak statistical significance of this difference (difference between Menhinick indices of disturbed and undisturbed 2006 sites was 1.587, permutation p-value 0.0347). Species composition in both Chvaletice and Ralsko was highly dependent on square identity (Mantel tests permutation p-values: 0.0003 and 0.0018 respectively), which indicates relative stability of algal and cyanobacterial species composition between seasons – with no regard to disturbance treatment.

When looking at lichen diversity dynamics, we encountered stable species composition in comparison of 2005 and 2006 samples in both Chvaletice (ANOSIM p-value = 0.0707) and Ralsko localities (ANOSIM p-value = 0.072) when using Manhattan distances that took into account quantitative differences in total cover of individual species. However, Dice index that does not take into account the quantitative changes and counts only presences or absences of individual species revealed a significant change between 2005 and 2006 (Chvaletice: ANOSIM p-value = 0.0044, Ralsko: ANOSIM p-value = 0.0191). The 2006 lichen samples did not differ significantly in species composition with regard to disturbance both in Chvaletice (ANOSIM p-value = 0.63) and Ralsko samples (ANOSIM p-value = 0.698). Average lichen diversity in disturbed plots in 2006 was not significantly different from undisturbed sites in both localities (Chvale-

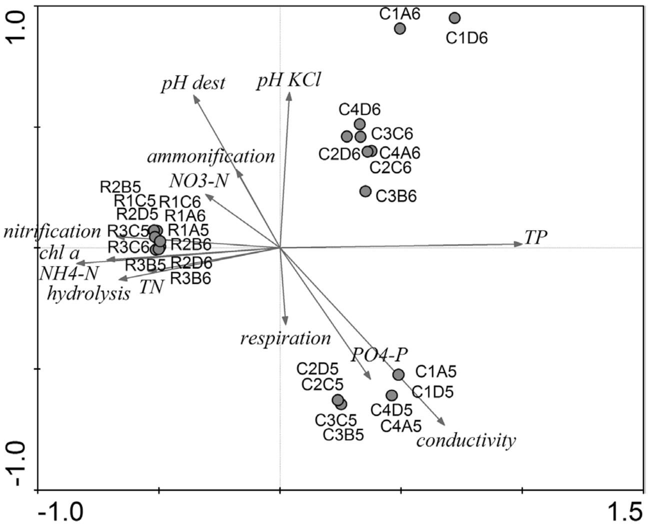

Fig. 4.5.1 The PCA ordination diagram of abiotic data.

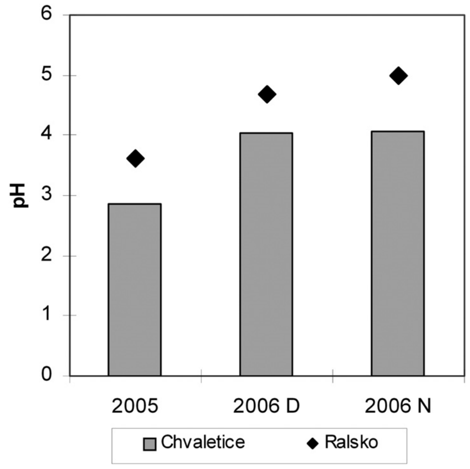

Fig. 4.5.2 The pH values at the Chvaletice and Ralsko localities in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

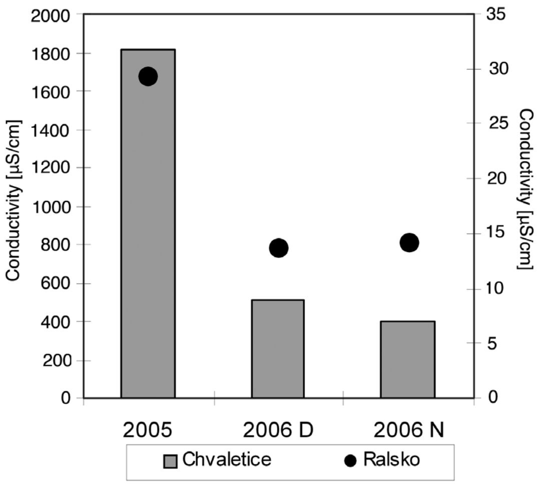

Fig. 4.5.3 The values of conductivity in Chvaletice and Ralsko in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

tice: permutation p-value on Menhinick index = 0.8485, Ralsko: permutation p-value on Menhinick index = 0.6712).

The microscopic fungi species composition changed highly significantly between 2005 and 2006 samples in Chvaletice (ANOSIM p-value = 0.003) and in Ralsko (ANOSIM p-value = 0.009). The 2006 samples did not differ in their species composition with regard to disturbance effect in Chvaletice (ANOSIM p-value = 0.83) and in Ralsko (ANOSIM p-value = 0.189). Fungi diversity in disturbed plots in 2006 was not significantly different from undisturbed sites in both localities (Chvaletice: permutation p-value on Menhinick index = 0.565, Ralsko: permutation p-value on Menhinick index = 0.421).

The principal component analysis of abiotic data demonstrated profound change in parameters of the Chvaletice locality between 2005 and 2006 samples (Fig. 4.5.1). On the other hand, Ralsko samples were much more homogenous across seasons (Figs. 4.5.2–4.5.7). The Chvaletice samples consistently had more total phosporus concentrations, whereas in Ralsko, most quantitative parameters of biotic activity had higher values, which were reflected by the position of individual localities along the first PC axis. The pairwise t-tests of individual parameters revealed significant difference in change of chlorophyll *a* concentrations at the Ralsko locality, where disturbance lowered increase in this parameter (p-value = 0.011). In addition, hydrolysis activity decreased more distinctly on disturbed sites at Ralsko (p-value = 0.038). The differences in changes of other parameters were not significant.

DISCUSSION

We have detected profound differences in seasonal stability of species composition between individual major organismal groups. Algae and cyanobacteria largely had a very stable composition at both localities and lichens were relatively stable, too. However, species of microscopic fungi changed profoundly in 2006, when compared with the year 2005. This pattern nicely corresponds with the assumption that cyanobacteria, algae and lichens are the major constituents of biological soil crusts (Evans & Johansen 1999; Belnap & Lange 2001), whereas microscopic fungi form a more or less random and very fluctuating part of crust ecosystems with a significant proportion of allochthonous species.

In their review, Evans and Johansen (1999) illustrated importance of algae and cyanobacteria for biological soil crusts in semiarid ecosystems. They noted the effect of algal mucilaginous sheath for stabilization of a crust and the role of nitrogen-fixing cyanobacteria in increasing trophic level of the substrate. Negative effect of mechanic disturbance on productivity and taxonomic structure of natural desert crusts was several times demonstrated (Hodgins & Rogers 1997; Johnston 1997; Eldridge & Koen 1998; Belnap 2002; 2003). However, in our study one year after disturbance we did not encounter any significant effects of mechanical destruction of the crust cover on diversity. The profound disturbance effect on desert crusts has mainly been related to wind and water erosion that increased in generally arid

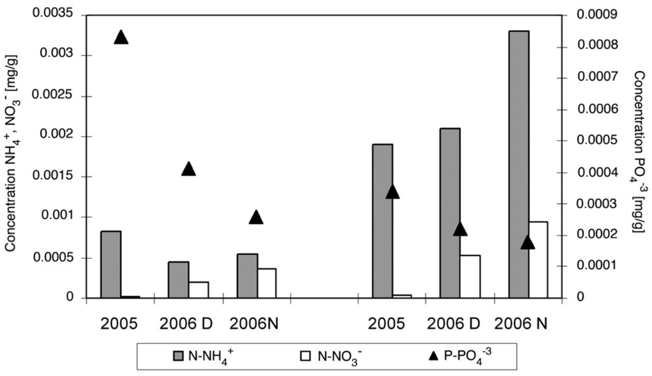

Fig. 4.5.4 Concentrations of N-NH_4^+, N-NO_3^-, P-PO_4^{-3} ions in Ralsko and Chvaletice in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

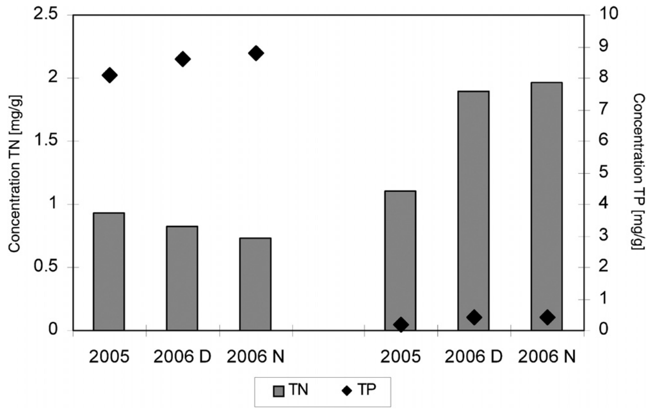

Fig. 4.5.5 TN and TP values measured in Ralsko and Chvaletice in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

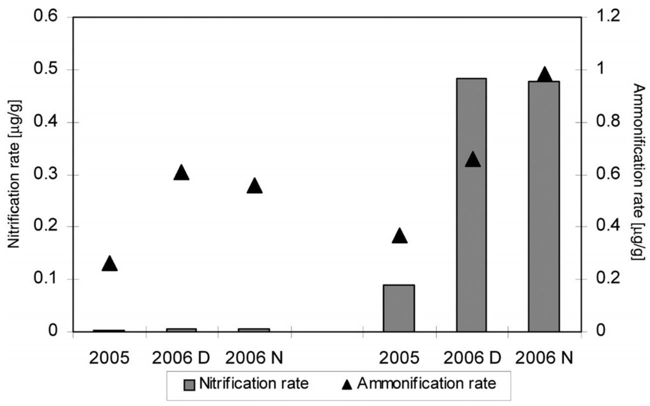

Fig. 4.5.6 The ammonification and nitrification rates detected after incubation of soil samples from investigated Ralsko and Chvaletice localities in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

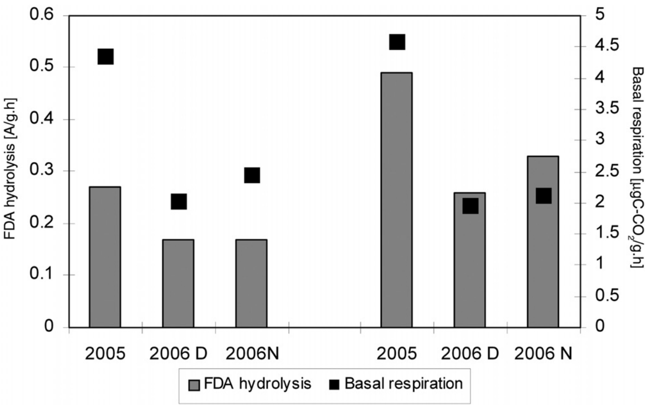

Fig. 4.5.7 Basal respiration and FDA hydrolysis of microbial communities measured in Ralsko and Chvaletice in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

environment after the compact crust cover was destructed (Eldridge & Leys 2003; Belnap et al. 2007). In addition, drought stress hampers development of vascular plant cover at such localities. On the other hand, the crusts of industrial sedimentation basins are determined rather by toxicity of the substrate which limits vascular plant vegetation. Most of the investigated localities exceeded the permissible toxicity levels for non-agricultural soils in many toxic elements (Czech Ministry of Environment 1994). The cadmium levels were generally higher than 0.001 $mg \cdot g^{-1}$ of a substrate, delimited as the maximum permissible level for non-agricultural soils in Czech Republic. The cadmium concentrations were considerably higher than the comparable levels of natural European soils (Chlopecka et al. 1996; Abollino et al. 2002; Gil et al. 2004; Papadopoulos et al. 2007). In addition, the low organic matter and high clay content (Rauch 2004) of sedimentation basin substrates facilitate cadmium bioavailability (Prokop et al. 2003). Concentrations of copper exceeded the 0.1 $mg \cdot g^{-1}$ maximum level for non-agricultural soils in the Czech Republic in both the ash sedimentation localities and in the Radvanice ore sedimentation basin site, where, in addition, the Pb-levels reached the maximum permissible level. The manganese levels were rather low in comparison with Mn-loaded sites (Paschke et al. 2005; Li et al. 2007) with the exception of Radvanice locality which contained levels comparable with those of waste soils of Mn-ore mines (Li et al. 2007). Thus, we believe that toxicity of industrial substrates is crucial in development of biological soil crust instead of vascular plant communities. In such conditions, one-time mechanical disturbance does probably not necessarily lead to change of the algal and lichen community as competition of vascular plants is low. However, our disturbance experiments were conducted on a limited set of plots and on a single locality (Chvaletice ore sedimentation basin) so that we cannot preclude significant disturbance effects in differently composed crusts of other sedimentation basin localities.

Biological soil crusts of industrial sedimentation basins consist of relatively stable algal, cyanobacterial, fungal and, in some cases, lichen assemblages that experience little variation of species composition between seasons. In addition, they resisted one-time mechanical destruction of the crust cover which does not lead to change in their taxonomic composition or eco-physiological parameters. The biological soil crusts dominate large areas of the abandoned sedimentation basins even more than 20 years after industrial activity ceased and, in many cases, there is no indication that vascular plants could successfully colonise these habitats. On the other hand, we believe that – even in temperate conditions of Central Europe – biological soil crusts, similar to those of semiarid ecosystems, possibly represent the stable stage of ecosystem development at these man-made localities.

The semiarid biological soil crusts are usually quite susceptible to even unrepeated mechanical disturbance with long-term effects on diversity, productivity and physiognomy of the micro-ecosystem (Belnap 2002; Belnap 2003). Most importantly, the intense wind and water-overflow effects quickly erode exposed surfaces with disturbed crust cover. However, these factors are obviously not so intense in the investigated temperate crust localities. In this respect, we propose that unfavourable abiotic factors (i.e., extremely low pH values, substrate toxicity or high salinity) effectively hamper vascular plant succession leading to their rather low competition with crust microorganisms. In addition, wind erosion is of less effect in more humid temperate conditions, compared with to semiarid ecosystems. Crust microorganisms with relatively short life cycles are thus able to sustain unrepeated disturbance events and quickly restore the crust cover. This stability of species composition and ecological parameters of investigated crusts we consider as a rather remarkable result of our investigation.

On the other hand, looking at the physiognomy of exposed vegetation-less parts of sedimentation basins with high level of disturbance by off-road vehicles (e.g., at the Radvanice and Měděnec localities), we are convinced that repeated disturbance leads to effective destruction of crusts and results in an decrease of diversity, primary production and increase of erosion. However, we detected that these negative changes cannot be ascribed to single, unrepeated destructive disturbing events. However, this presumption should be specifically investigated in future research.