ROLE OF GRASSLAND ECOSYSTEMS IN PROTECTION OF FORESTED WETLANDS

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The *Protected Headwater Area of the Jizera Mountains* was proclaimed in 1978 to support the important role of local headwater catchments in water and soil conservation. However, an ecologically oriented watershed management had not been realised until 1990s. In the 1970-1980s, watersheds of the Jizera Mts. declined as a consequence of the acid atmospheric deposition (namely sulphate originate by lignite combustion), and commercial forestry practices (spruce plantations of a low stability, extensive clear-cut, heavy forest mechanisation, non-effective control of insect epidemics, and unsuccessful reforestation). Both run-off genesis and water quality in streams and reservoirs deteriorated. Particularly, the erosion of soil increased from 0.01 to 1,34 mm/year, and sediment run-off up to 30% of the soil volume eroded. In the surface waters, low pH values (4-5), high content of toxic metals (namely aluminium, 1-2 mg/l), extinction of fish and drastically reduced zooplankton, phytoplankton and benthic fauna were observed. A recent recovery of surface waters in the Jizera Mts. (an increase in mean annual pH values to 5-6, a drop in aluminium concentrations to 0.2-0.5 mg/l, successful reintroduction of brook char, *Salvelinus fontinalis*) results namely from the decreased air pollution (in the 1990s, the deposition of sulphate decreased to cca 40% in comparison with the year 1987), and from the stabilisation of forested wetlands by grass cover (at clear-cut areas, the leaf area index dropped from 18 to 3.5). After the clear-cut of spruce plantations, Junco effusi-Calamagrostis villosae became a new dominant community in headwater catchments of the Jizera Mts. During the period of 13 years, at the clear-cut slope of the Jizerka catchment, the composition of herb layer changed following increased moisture conditions. The Ellenberg's soil mosture index increased in each point of the investigated slope. Headwater pet-lands play an important role in fixing the free Al^{3+} in organic complexes not toxic for fish.

J. Krecek and M. Haigh (eds.),
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1. Introduction

Mountain forested wetlands are valuable and fragile components of a watershed [8]. Mountain bogs and fens provide watersheds with a large scale of downstream benefits. Traditionally, it is widely considered that they serve important ecological functions in supporting biodiversity and preventing downstream flooding by absorbing precipitation. Recently, bogs have been recognized for their role in regulating the global climate by storing large amounts of carbon in peat deposits [12].

In the Jizera Mountains (350 km^2, altitude of 50°40' - 50°52', longitude of 15°08' - 15°24', humid temperate zone, Northern Bohemia, Czech Republic), peat soils and peat bogs are important parts of forested headwater catchments. In the 1980s, headwaters of the Jizera Mts. have been declined as a consequence of the acid atmospheric deposition, die-back of spruce plantations, and commercial forest practices (an extensive clear-cut and use of heavy mechanisation). Strategies of nature protection and conservation (Landscape Protected Areas, Nature Reserves or Protected Headwater Regions) were not effective because of a very limited focus [6]. Reforestation of large cleared areas was complicated and the upper plain of the mountains has been overgrown by invasive grasses (particularly *Calamagrostis villosa*).

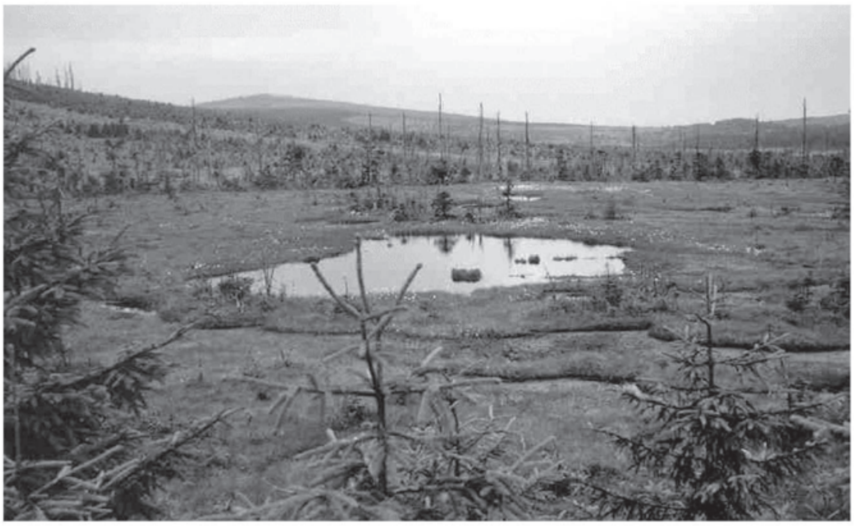

Figure 1. Headwater bog fed from upslope sources in the Jizera Mts.

The aim of this research was to evaluate the role of grassland ecosystems on hydrological processes feeding headwater wetlands, as well as on their downstream benefits.

2. Methods

In 1982, the small headwater basin Jizerka (area of 100 ha, elevation: 860-980 m) was instrumented. The long-term hydrological investigation has been conducted to study effects of clear-cut of mature spruce stands and succession of herbaceous communities on water phenomena.

Gross precipitation was measured in the open field, through-fall was observed on two plots (30x30 m, 900 m^2) installed under the canopy of a mature spruce stand and under the herbaceous vegetation. Both plots were instrumented with 10 rain-gauges.

Since the time of clear-cut, botanical data were collected in vegetation seasons. Phytosociological relevés (4 x 4 m, Braun-Blanquet scale) were taken at each 100 m of the main slope of the basin. To include the impact of all species abundance, the data were transformed from the Braun-Blanquet scale to a nine-point scale according to [7]. For each relevés, the indication value of soil moisture was evaluated as a weighted average of particular indication value of all species present [2].

3. Results

3.1. ACID ATMOSPHERIC DEPOSITION

At Jizerka, the acid atmospheric load measured in the open field culminated in the late 1980s. Sulphate was 45% and nitrate 16% of the total atmospheric deposition. In the early 1990s, the acid atmospheric load of the open field already dropped to 40% of the 1987 level. This corresponds with the decreased SO_2 concentration in the air (Figure 2), resulting from the reduced productivity of coal power stations in central Europe, namely in former East Germany.

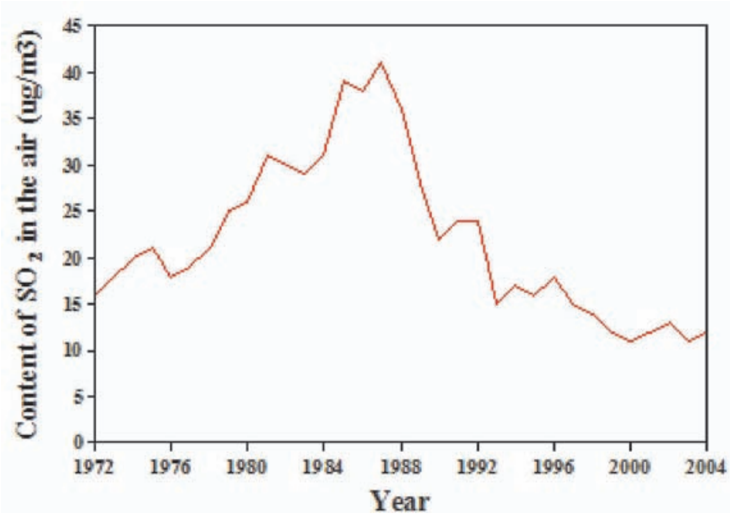

Figure 2. Mean annual content of SO_2 in the air: the Jizerka station (860 m a.s.l.), 1972-2004.

However, the atmospheric load of sulphur observed under the vegetation is still much higher than in the open, especially in spruce stands where the deposition decreases with defoliation. Much lower deposition of sulphur was measured under the herbaceous vegetation in cleared stands (Table 1).

	Spruce stand	**Spruce stand**	**Grass**
Defoliation (%)	35	75	-
Gross precipitation (mm)	1254	1254	1254
Throughfall (mm)	878	994	1056
Interception (mm)	376	260	198
Precipitation pH	4.4	4.4	4.4
Throughfall pH	3.8	4.1	4.5
Open field sulphur deposition (kg/ha)	11.8	11.8	11.8
Canopy sulphur deposition (kg/ha)	34.5	28.7	12.4

Table 1. Annual deposition of sulphur in mature spruce stands and herbaceous vegetation: Jizerka (980 m a.s.l.), 2000-2004.

3.2. SUCCESSION OF THE HERBACEOUS VEGETATION

After the clear-cut of spruce plantations, Junco effusi - Calamagrostis villosae became a new dominant community in headwater catchments of the Jizera Mts. However, during the period of 13 years, at the clear-cut slope of the Jizerka catchment, the composition of herb layer changed following increased moisture conditions. The Ellenberg's soil mosture index [2] increased in each point of the slope investigated (Figure 3).

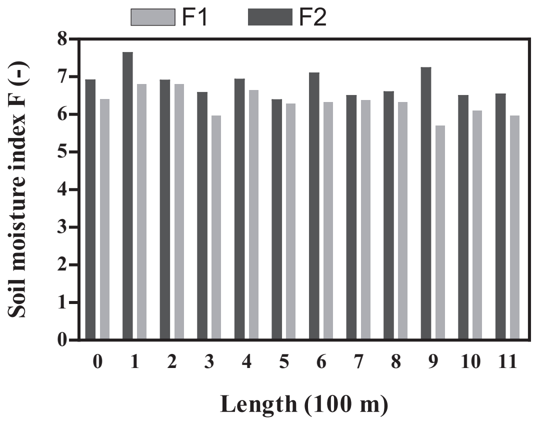

Figure 3. The soil moisture index at the investigated slope (1,100 m) of the Jizerka catchment (860 - 980 m a.s.l.): 1991-92 (F1) and 2002-03 (F2).

With higher moisture status, the effect of slope gradient on soil moisture is less evident (Figure 4).

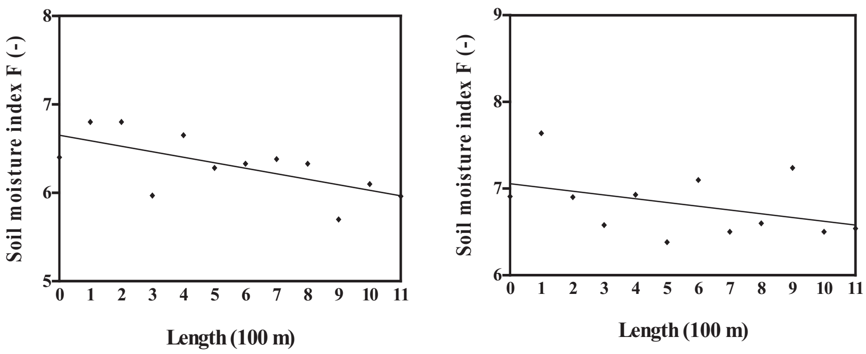

Figure 4. The soil moisture index decreasing with the slope length from the basin outlet of Jizerka (860 m): 1991-92 (left) and 2002-03 (right).

After the clear-cut, depleting the moisture storage of the catchment is not so intensive in comparison with the mature spruce stands. This corresponds to lower evapotranspiration and higher water yield (+108 mm) measured at the outlet of the catchment.

The herb vegetation plays a very important role in the protection of exposed cleared slopes to surface run-off and soil erosion. Although the infiltration capacity of the soil at investigated plots decreased dramatically from 150 to 40 mm/h, the measured sheet erosion there was still negligible. The significant soil erosion was measured only in the rills originated by skidding of timber. Thus after the clear-cut, the erosion of soil in the Jizerka catchment increased from 0.01 to 1,34 mm/year, and sediment run-off up to 30% of the soil volume eroded.

3.3. DECLINE AND REGENERATION OF STREAM-WATER CHEMISTRY

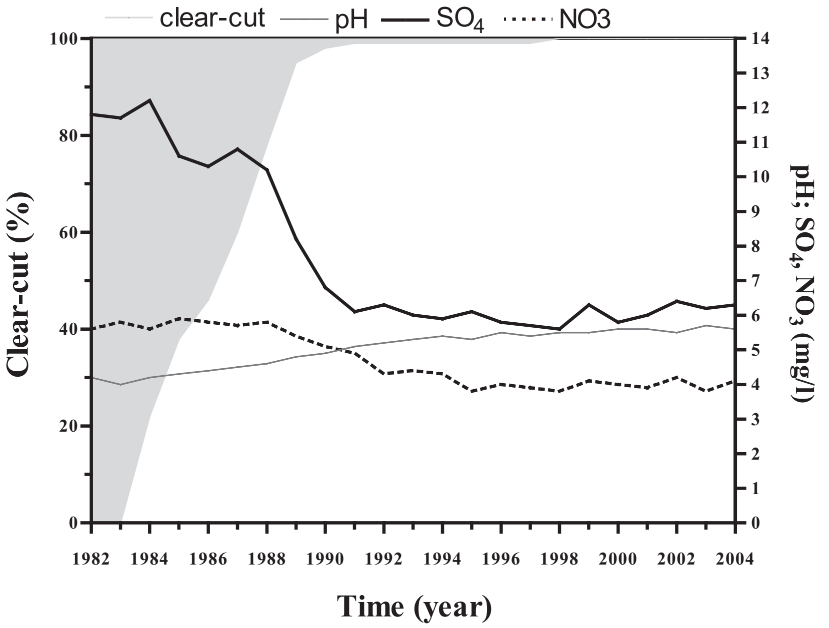

Figure 5. Stream-water chemistry and clear-cut of mature spruce stands: the Jizerka experimental basin, 1982-2004.

In the 1970-1980s, the water quality in water courses and reservoirs of the Jizera Mts. declined significantly: pH values dropped to 4-5, the content of aluminium increased to 1-2 mg/l (with a high level of toxic forms of aluminium - free Al^{3+} as well as inorganic complexes of Al), benthic fauna was reduced. In three headwater reservoirs (Bedrichov, Sous and Josefuv Dul), the extinction of fish was documented, and both zooplankton and phytoplankton were drastically reduced [10]. Seasonal changes in the water chemistry (episodical acidification after snowmelt or rain-storm) are relatively high.

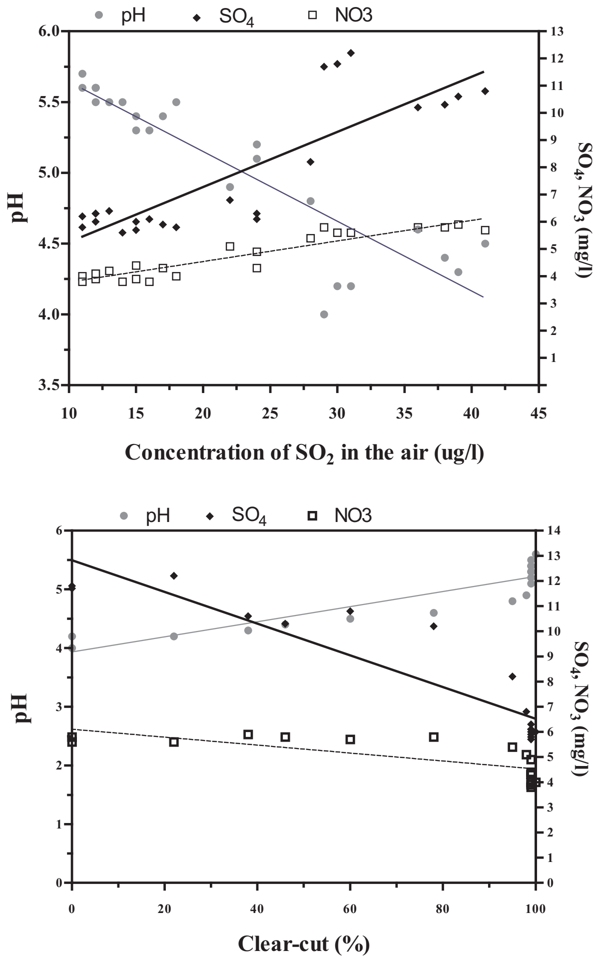

Figure 6. The effects of drop in SO_2 emissions and clear-cut on stream-water chemistry (Jizerka catchment): regression analysis (compatring the effect of clear-cut on the drop of sulphate $r^2_{0.05}$ = 0.86; for the effect of reduced SO_2 emissions on the drop of sulphate $r^2_{0.05}$ = 0.72).

In surface waters, the first signs of a recovery were observed already in the early 1990s as a consequence of reduction in the leaf area (and the atmospheric deposition under the canopy) of spruce plantations.

After the clear-cut of spruce stands, significant changes in stream-water chemistry of the Jizerka catchment were found (Figure 5 and Figure 6): mean annual values of pH increased from 4.0 to 5.3, concentration of sulphate decreased (from 13.0 to 6.0 mg/l) as well as nitrate (from 6.0 to 4.0 mg/l).

3.4. REINTRODUCTION OF FISH

Since the 1950s, surface waters of the upper plain of the Jizera Mts. were fishless as a result of the extremely acidified environment and the related high content of toxic metals. Ideas of a possible fish reintroduction were initiated by an improvement in physical and chemical parameters of the waters observed in the early 1990s (Table 4).

Pollutants	**Content** (mg/kg) **muscles**	**liver**	**Hygienic limit** (mg/kg)
Mercury	0.04 - 2.6	0.05 - 6.2	0.01
Cadmium	0.1 - 0.4	0.4 - 6.2	0.05
Lead	1.4 - 2.7	1.3 - 7.0	1.0
Aluminium	6.6 -18.2	13.1 –90.7	30.0

Table 2. Pollutants in brook char of the Bedrichov and Sous reservoirs, 1996-2000.

In 1991, brook char (= brook trout, *Salvelinus fontinalis*, the most acid-tolerant species) and brown trout (*Salmo trutta* morpha *fario*) were experimentally reintroduced to the inlets of the Bedrichov reservoir. The char could survive and reproduce: a sufficient amount of food and well proportioned age structure and individual growth in the population were observed in the following years. The individuals of brown trout evidently starved and did not reproduce. In 1996, the Sous reservoir and its inflows were stocked with 30,000 fingerlings of brook char; this population also survives successfully. However, the concentration of aluminium and heavy metals in the fish still exceeds the hygienic standard (Table 2). The high content of Al and heavy metals in fish tissues originates from the dominant component of food - benthic Ephemeroptera (mayflies) and Trichoptera (caddisflies, *Hydropsyche* sp. dominating) in which extremely high values were found: 150-218 mg/kg of aluminium, 0.1-0.5 mg/kg of mercury, 0.3-4.0 mg/kg of cadmium, and 1-54 mg/kg of lead.

The survival of fish in surface waters of the upper plain of the Jizera Mts. seems to be limited by episodic drops in pH values and the level of toxic forms of aluminium (free as well as inorganic complexes of Al). For a rapid mobilisation of the toxic aluminium from the soil, the limit of pH seems to be 5.3. According to the survival of fish, the critical value of the toxic aluminium 300 µg/l is considered. In surface waters, both limits are still exceeded during the snowmelt and rain-storms. Headwater pet-lands play an important role in fixing the free Al^{3+} in organic complexes not toxic for fish [6].

4. Conclusion

The contemporary improvement of surface water quality in the Jizera Muntains is a consequence of both the decrease in air pollution and the reduction of leaf area (and, roughness of the canopy) by the clear-cut of spruce stands. The natural succession of the herb layer play an important role in the stabilisation of slopes, and controlling run-off genesis and water quality, as well as the environment of forested wetlands.

5. Acknowledgements

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