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SOIL WATER CONTENT AND PLANT SUCCESSION AFTER THE HARVEST OF MATURE SPRUCE STANDS IN A MOUNTAIN CATCHMENT

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Abstract

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Since 1982, the plant succession and hydrological phenomena were studied in the Jizerka experimental catchment (1.0 km^2, the Jizera Mts, Czech Republic). After the clear-cut of spruce plantations (1984–1990), *Junco effusi-Calamagrostietum villosae* became a new dominant community there. *C. villosa* has been spreading widely with increased light incomes. In 1991–2005, the re-growth of forest stands, topsoil water content (SWC), and spontaneous plant succession have been studied at the 1,100 m hill-slope transect (elevation from 860 to 980 m). The SWC values increased with forest harvest, and they are still not significantly affected by the re-growth of stands. The canopy development of reforested sites (mainly *Picea abies* and *Pinus* sp.) is still low (horizontal canopy density of 0.05–0.25), and does not affect the succession of herbaceous vegetation. The botanical indication reflects changes of SWC in the delay of almost ten years. The Ellenberg's **F** indicator was found as a powerful tool to describe both the topsoil climate (long-time water phenomena) and the plant succession. However, it cannot address detailed hydrological processes in a short-time scale, and should be employed in combination with an adequate monitoring of environmental factors.

Key words: mountain hill-slope, clear-cut, soil water content, antecedent precipitation index, plant succession, reforestation, Ellenberg´s indicator **F**

Introduction

Humans have used forests for a long time. This has resulted in profound changes in forested environments. In temperate forests of Europe, where human influence has been strong and longlasting, some important habitat elements, structures and processes have disappeared or weakened (Björk, 2002). Moreover, since 1970s, the acid atmospheric deposition has resulted in the decline of spruce stands, leading to fragmented forests and the extensive spread of clearings in Central Europe (Fanta, 1997). Therefore, establishment of protected areas in temperate forests should be supplemented by restoration efforts (Haigh, Křeček, 2000). However, an effective restoration should be based on the detailed ecological monitoring of the site development (De Vries et al, 2003).

In 1978, the Protected Headwater Area of the Jizera Mts was proclaimed by the Czech Government to support benefits of mountain catchments in the conservation of soil and water. Unfortunately, in the 1980s, particularly the upper plain of the mountains was affected by consequences of the acid atmospheric deposition (acidification of both terrestrial and aquatic ecosystems, defoliation and die-back of spruce plantations), and commercial forestry practices (extensive clear-cut, heavy mechanisation, skidding timber by wheeled tractors). Forest plantations of Norway spruce (*Picea abies*) have been replaced by large areas overgrown by the communities *Junco effusi-Calamagrostietum villosae* (Sýkora, 1983) dominated by the invasive grass *Calamagrostis villosa*, very competitive in the process of reforestation (Pyšek, 1991).

The main aim of this paper is to document the development of plant communities at cleared forest stands in the upper plain of the Jizera Mts, as well as to study the relationships with morphology and topsoil climatology.

Study area and methods

Since 1982, the hydrological phenomena and the plant succession were studied in the Jizerka experimental catchment (area of 1.0 km^2, elevation from 860 to 980 m, NE slope, Fig. 1). In the 1990s, after the clear-cut of mature spruce stands (1984–1990), *Junco effusi-Calamagrostietum villosae* with the dominant grass *Calamagrostis villosa* spreads fast over the watershed area. Reforestation of harvested sites with coniferous trees (namely, *Picea abies*, *P. pungens*, and *Pinus mugo*) started in one year after the treatment. However, the mortality of planted trees was high (cca 60%), and investigated sites were reforested several times in 1991–2000.

Currently, both spontaneous and planted trees overgrow the Jizerka hill-slope. *Pinus mugo* (80%) and *Picea abies* (20%) dominate in the lower part of the catchment, while in the upper part, there is a mixture of *Picea pungens* (50%), *P. mariana* (14%), *Sorbus aucuparia* (7%), *Picea abies* (5%) and *Betula alba* (2%), Fig. 2.

The depth of sandy loamy to loamy podzolic forest soils varies between 0.7 and 1.2 m above the weathered bedrock (porfyritic granite). The root system dominates in the topsoil occurring up to the depth of 15 cm. The topsoil is created by litter (O_l, depth of 0–2 cm), humus layer ($O_f + O_h$, 2–10 cm), and leached horizon (A_{eh}, 10–15 cm). Mor is the most common humus (2–5 cm) there.

The response of run-off to precipitation was monitored in the catchment scale (area of 1.0 km^2 instrumented by the climate station, four standard rain-gauges, and V-notch weir with automatic water level recorder). The monitoring of soil moisture climatology included twelve spots of the botanical inventory along the main hill-slope (Fig. 3). Near surface soil moisture (volumetric water content up to the depth of 15 cm) was measured *in situ* by a sensitive electrode (Kelway, HB-2), and tested by the standard gravimetric method (Miller, Garnier, 1998). The measurement of soil moisture was carried out in monthly intervals of the warm season (May–October). While the surface of the hill-slope at Jizerka is quite variable, rich in local depressions and elevations, the system of ten readings of *in situ* soil moisture at each investigated patch has been practiced.

The fluctuation of soil moisture content (SWC) in daily intervals was approximated by the antecedent precipitation index (API) widely used in hydrological studies to describe the pre-event wetness (Doeing et al., 1994). Generally, the API values are calculated as a weighted summation of daily precipitation amounts, where the weight given each day's precipitation is usually assumed to be an exponential or reciprocal function of time with the most recent precipitation receiving the greatest weight.

$$API_t = P_t + K_t\, API_{t-1}, \tag{1}$$

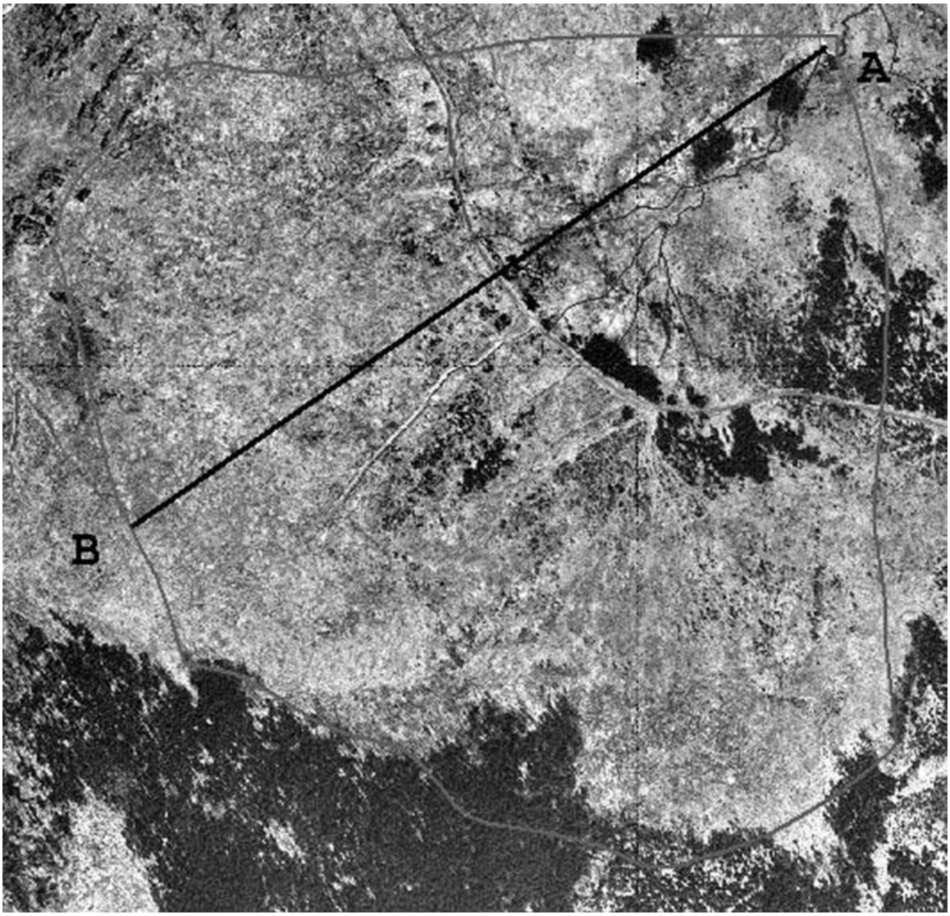

Fig. 1. The Jizerka experimental catchment, 2005 (A – outlet, AB – investigated transect).

where, API_t – antecedent precipitation index on ‘t’ the day (mm), API_{t1} – antecedent precipitation index on ‘t-1’ the day (mm), P_t – precipitation on ‘t’ the day (mm), K_t – recession constant.

The recession constant K_t was calculated following the approach of Choudhary and Blanchard (1983, in Bothale et al., 1994):

$$K_t = EXP(-PET_t/AWC_t)\ , \tag{2}$$

where, PET_t – potential evaporation on ‘t’ the day (mm), and AWC_t – soil water content available to plants on ‘t’ the day (mm).

$$AWC_t = SWC_t - PWP, \tag{3}$$

where, SWC_t – soil water content on ‘t’ the day (mm), and PWP – water content adequate to the permanent wilting point (mm).

Fig. 2. Reforestation of the investigated hill-slope, 2005.

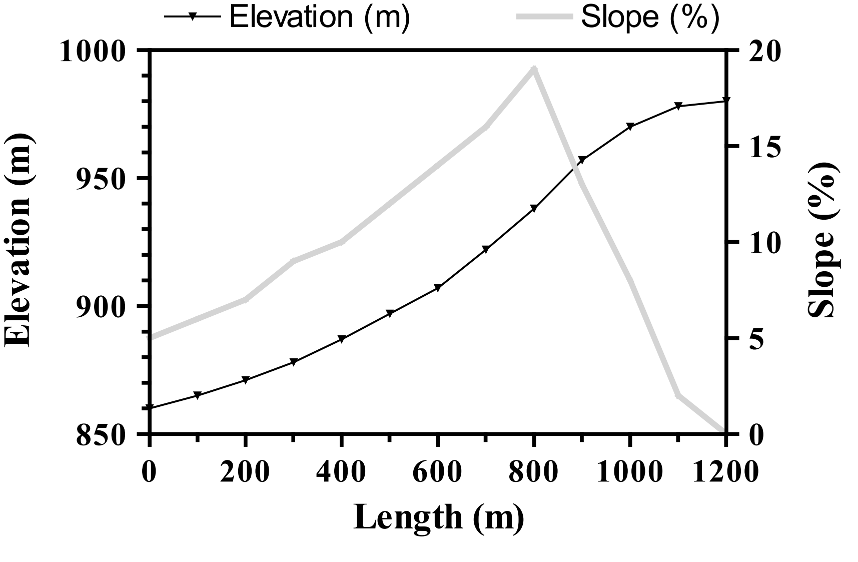

Fig. 3. Topography of the Jizerka hill-slope.

Detailed botanical investigations were carried out in vegetation seasons of 1991, 1998, 2002, and 2005. The phytosociological relevès (4x4 m, Braun-Blanquet´s seven-point scale) were taken at each of the twelve-point transect situated along the main slope of the basin in the step of 100 m. To include the impact of all species abundance, the data were transformed from the Braun-Blanquet´s scale to a nine-point scale according to the approach of van der Maarel (1979), Table 1. For each relevè, the Ellenberg's indicator value for soil moisture (a twelve-point scale 'water value', **F**) was calculated as the weighted average of all the registered species (Ellenberg, 1979). The re-growth of reforested stands was documented by observing the average height, horizontal canopy density and number of trees inside of 100 m^2 surrounding squares, in corresponding time intervals of 1991–2005.

T a b l e 1. The abundance of species.

Braun-Blanquet´s scale	r	+	1	2	3	4	5
van der Maarel´s transformation	1	2	3	5	7	8	9

The ANOVA statistics was used to analyse the relationship between observed changes in the ground vegetation, site morphology, forest re-growth, and water phenomena. For each relevè, the following parameters were considered: Ellenberg's indicator value **F**, elevation (E), slope gradient (S), slope length (L), horizontal canopy density (C), and soil water content (SWC).

Results

Soil water content

Easy *in situ* reading of the volumetric moisture by the Kelway HB-2 electrode provided us with relatively good information about the water content in the topsoil. Comparing *in situ* values with the standard laboratory moisture, a relatively good correlation ($r = 0.92$, standard error: 3.9) as well as not a significant departure from linearity by ANOVA statistics ($F = 127.3$, $P = 0.59$) were found. An effective pairing of those values was confirmed also by the Wilcoxon matched – pairs signed ranks test (30 pairs, Spearman $r_s = 0.89$, two-tailed $P = 0.23$).

The rate of soil moisture depletion given by the recession constant K_t (equation 5) varies between 0.81 and 0.97 (mean daily $K_t = 0.92$). Values of API_t correlate significantly with SWC values observed *in situ* (48 pairs, $r_s = 0.69$, $P < 0.001$), Fig. 4.

After the clear-cut of mature spruce stands, SWC values increased adequately to the drop in evapotranspiration (Křeček, Hořická, 2006). Physical parameters of forest soil were not affected by the forest harvest at the investigated patches of the Jizerka hill-slope. Therefore, a simple simulation of the water content in topsoil of a mature spruce stand can include just the reduced depth of net precipitation reaching the soil surface (Fig. 5). In 1991–2005, the trend of seasonal precipitation and mean soil water content is not statistically significant (Fig. 6). The topsoil SWC correlates dominantly with the slope gradient ($r = - 0.62$, $F = 6.45$) in periods of 'moderate' moisture conditions. During both 'dry' and 'wet' events, such a relationship is not significant (Fig. 7).

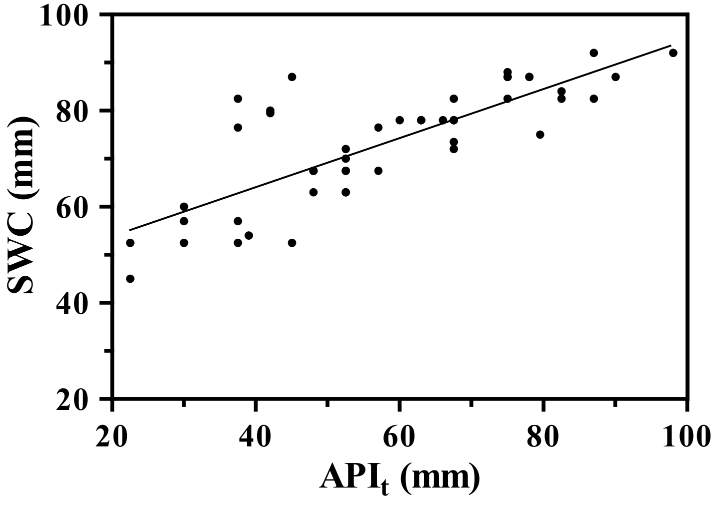

Fig. 4. Observed soil water content SWC and calculated index API$_t$.

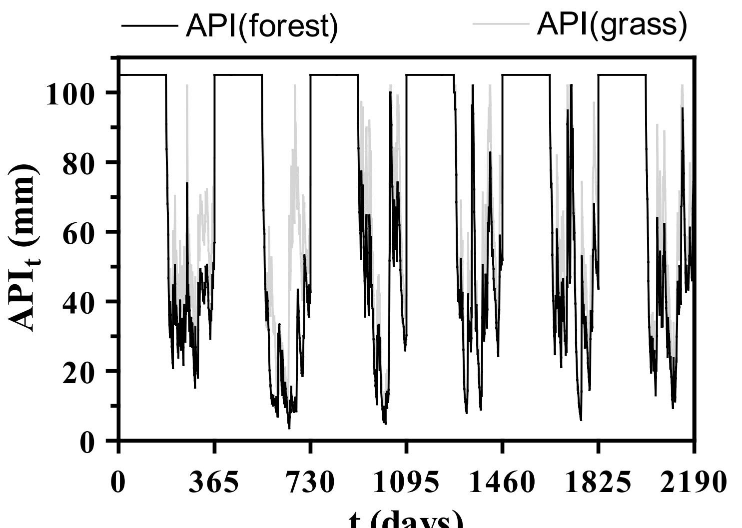

Fig. 5. The progressing soil water content after the clear-cut, 1991–1996.

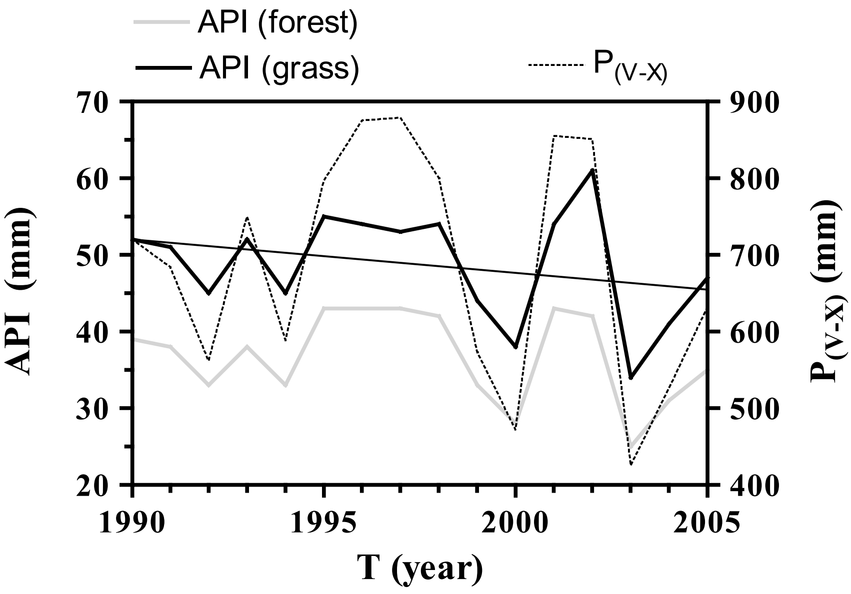

Fig. 6. Seasonal precipitation (P_{V-X}) and mean topsoil water content (API), 1991–2005.

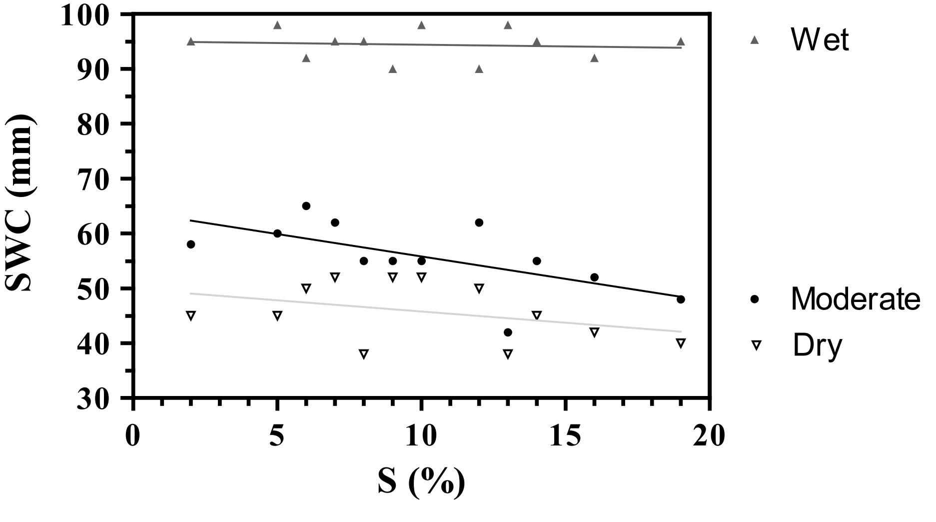

Fig. 7. Soil water content SWC and slope-gradient S at the Jizerka transect.

Calamagrostis villosa has been developing already under the canopy of spruce stands. Its cover has been supported by the decline and defoliation of *Picea abies* forests in the late 1980s. After the clear-cut, *Calamagrostis villosa* has been spreading widely with the increased light income. The composition of herb layer identified at the investigated transect has been changing successively in the period of 1991–2005. The changes of dominant species are shown in Table 2.

T a b l e 2. The dominated plant species of twelve investigated spots at the Jizerka hill-slope (Braun-Blanquet´s cover values of individual species are given as: *2*: 5–25%; *3*: 25–50%; *4*: 50–75%).

Stand	1991	1998	2005
1	*Calamagrostis villosa 4*	*Calamagrostis villosa 4*	*Calamagrostis villosa 2, Deschampsia caespitosa 2, Juncus effusus 2*
2	*Deschampsia caespitosa 3, Calamagrostis villosa 3*	*Calamagrostis villosa 3*	*Eriophorum vaginatum 3-4*
3	*Molinia caerulea 3, Calamagrostis villosa 3*	*Molinia caerulea 3, Carex nigra 3, Calamagrostis villosa 2*	*Molinia caerulea 4, Eriophorum vaginatum 2*
4	*Avenella flexuosa 4, Calamagrostis villosa 2*	*Avenella flexuosa 4, Molinia caerulea 3*	*Molinia caerulea 4*
5	*Calamagrostis villosa 3, Avenella flexuosa 3*	*Calamagrostis villosa 3, Avenella flexuosa 2*	*Calamagrostis villosa 4, Eriophorum vaginatum 2*
6	*Calamagrostis villosa 3, Avenella flexuosa 3*	*Calamagrostis villosa 4, Avenella flexuosa 1*	*Calamagrostis villosa 4, Avenella flexuosa 2*
7	*Calamagrostis villosa 3, Avenella flexuosa 3*	*Calamagrostis villosa 3, Avenella flexuosa 2*	*Calamagrostis villosa 4*
8	*Calamagrostis villosa 3, Avenella flexuosa 3*	*Avenella flexuosa 4, Calamagrostis villosa 3*	*Calamagrostis villosa 3, Avenella flexuosa 3*
9	*Calamagrostis villosa 5*	*Calamagrostis villosa 3, Avenella flexuosa 3*	*Calamagrostis villosa 4, Avenella flexuosa 3*
10	*Calamagrostis villosa 3, Avenella flexuosa 3*	*Calamagrostis villosa 3, Avenella flexuosa 2*	*Calamagrostis villosa 3, Avenella flexuosa 2, Vaccinium myrtillus 2*
11	*Avenella flexuosa 3, Calamagrostis villosa 2*	*Avenella flexuosa 4, Calamagrostis villosa 3*	*Calamagrostis villosa 3, Avenella flexuosa 3*
12		*Avenella flexuosa 4, Calamagrostis villosa 2*	*Calamagrostis villosa 2, Avenella flexuosa 2, Vaccinium myrtillus 2*

Corresponding changes of the Ellenberg's indicator values **F** of plant communities are given in Fig. 8. The length of the transect (0–1,100 m, measured from the basin outlet), is related to the number of stands 1 – 12 (Fig. 3).

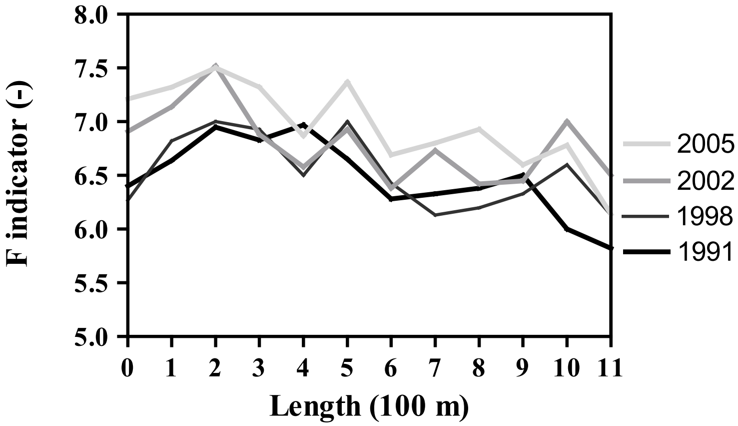

Fig. 8. Ellenberg's indicator values **F** of plant communities at the Jizerka transect, 1991–2005.

Only in the years 1991 and 2005, the decreasing trend of the **F** indicator with the length of transect was statistically significant (r = 0.50 and 0.67, and F = 9.88 and 20.65, respectively).

While the soil water content correlates most significantly with the slope of the investigated transect (Fig. 7), the Ellenberg's indicator **F** reflects mostly the length of transect (elevation), 66% of variance can be explained by elevation, and 27% by soil water content. The correlation matrix is shown in Table 3.

T a b l e 3. The correlation matrix (**F –** Ellenberg's indicator of moisture**,** S – slope-gradient, E – elevation, C – horizontal canopy density, SWC – soil water content).

	F (-)	**S (%)**	**E (m)**	**C (-)**	**SWC (mm)**
F (-)	1	-0.015	-0.81	0.17	0.52
S (%)	-0.015	1	0.15	-0.21	-0.63
E (m)	-0.81	0.15	1	-0.46	-0.58
C (-)	0.17	-0.21	-0.46	1	-0.21
SWC (mm)	0.52	-0.63	-0.58	-0.21	1

Thus, the Ellenberg's indicator **F** values can be expressed by the multiple regression:

$$\mathbf{F} = 13.6 - 0.0075\ E + 0.0033\ SWC \quad (4)$$

The equation (4) explains 68% of the variance (48 values, multiple R = 0.83, F = 9.75, P = 0.0056, while multicollinearity of included variables is not significant).

Discussion and conclusion

The Ellenberg's **F** values were used to indicate the environment and plant succession at the clear-cut hill-slope in the period of 1991–2005. The detailed botanical study has been confronted with the data on soil climatology and reforestation.

Calamagrostis villosa as a diagnostic species of *Piceion excelsae* community has been developing already in spruce forests affected by their decline and defoliation in the late 1980s. In the investigated catchment of Jizerka, after the clear-cut, *Calamagrostis villosa* has been spreading widely with the increased light income. Similar situation was documented e.g. by Möllerová (2004), and spreading of *C. arundinacea* at clear-cut areas by Vykouková (2003). Fanta (1997) reported the temporary phenomenon of the grass dominance related particularly to the thickness of humus layers. When the humus is reduced, *C. villosa* spreads slowly and acidophilous species (e.g. *Avenella flexuosa*) increase their cover. Thus, the species diversity is increasing. However, at the investigated sites such a reduction in humus layers was not observed.

The other important factor in reduction of *Calamagrostis villosa* dominance is the succession of tree species (mainly *Picea abies* and *Pinus* sp.) followed with a lowered light income (Möllerová, 2004). In 2005, at the investigated hill-slope, the horizontal canopy density of reforested stands is still rather low and varies from 0.25 (lower part) to 0.05 (upper part). Dwarf pine (80%) and Norway spruce (20%) dominate in the lower part of the catchment, while in the upper part, there is a mixture of Colorado blue spruce (50%), black spruce (14%), mountain ash (7%), Norway spruce (5%) and birch (2%). The ANOVA statistics (Table 3) did not show a significant effect of the horizontal canopy density on the Ellenberg's indicator **F**.

The water content in topsoil (SWC) has increased immediately after the harvest of spruce stands (Figs 5 and 6). This fact corresponds to the observed drop in evapotranspiration (Křeček, Hořická, 2006). During the investigated period (1991– 2005), SWC values reflect the regime of precipitation, and the antecedent precipitation index API_t (Figs 4, 5 and 6). The topsoil SWC values correlate most significantly with the slope-gradient in periods of 'moderate' soil moisture. During 'dry' or 'wet' conditions, the effect of slope-gradient seems not to be significant (Fig. 7).

Currently, the plants of wet stands (*Calamagrostis villosa*, *Deschampsia caespitosa, Molinia caerulea, Juncus effusus, Carex nigra, Eriophorum vaginatum*, etc.) are spreading over the investigated transect (Table 2). The increase in Ellenberg's indicator **F** has been manifested since the year 2000, e.g. some 10 years after the clear-cut (Fig. 8). The values of Ellenberg's indicator **F** are decreasing with the altitude, and increasing with the time of plant succession (Fig. 8). The multiple regression (Table 3, equation 4) shows the importance of elevation and soil water content on the plant succession at the investigated site.

Ellenberg's indicator for moisture **F** (Ellenberg, 1979), describes plant species ecological optimum for environmental factors in Central Europe. **F** indicator values are widely and successfully used to characterize environmental conditions within a stand (Pieterse et al., 1998; Grandin, 2004). The plant succession is a long time process. We found the Ellenberg's **F** indicator as a powerful tool to describe both the topsoil climate (long-time water phenomena) and the plant succession. However, it cannot address detailed hydrological processes in a short-time scale, and should be employed in combination with an adequate monitoring of environmental factors. Similarly, Mountford et al. (2005) shows the **F** indicator as a good preliminary pointer to site conditions, but, reports also fundamental weaknesses in using **F** values for assessing short-term hydrological changes.

Translated by the authors

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