CONTRIBUTION TO KNOWLEDGE OF NATURAL GROWTH AND DEVELOPMENT OF MOUNTAIN NORWAY SPRUCE SEEDLINGS

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Abstract

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Influence of the climatic and pollution stress, soil substrates, mosses and dominant herb species on the Norway spruce (*Picea abies* L. K a r s t.) seedling development and their cohort growth was investigated in six permanent research plots in the Krkonoše Mts from 1995 to 1997.

The results showed dependence of seedling development on the synergic influence of the multiple stress. The highest number of seedling cohorts was observed in the least damaged plots (the Modrý důl and the Slunečné údolí plots), where climatic conditions are not so severe, the canopy cover is high and consequently litter coverage is high, too. On the contrary, no seedlings were found in the heavily damaged Mumlavská hora plot and only a few seedlings were observed in the Alžbětinka plot (the north exposition and also relatively high polluted plot).

One of the important secondary stress factors is an expansive growth of some dominant plants species. The majority of seedlings was germinating and growing in patches covered by litter. The seedling development in other substrates (as mosses and some herb layer communities) was much less frequent.

Key words: climax, natural regeneration, Krkonoše Mts, *Picea abies*, seedlings

Introduction

Mountain Norway spruce forest ecosystems in the Central Europe have been dying during the course of last decades. The combined influence of the climatic and pollution stress factors are considered to be a primary cause. The main source of pollution is an industry burning-brown coal, containing a high percentage of sulphur. The released sulphur dioxide is oxidised in the atmosphere. Resulted in acidic rain reactions, changes in soil properties (increased pH, nutrient leaching) and a consequently damage to the trees (defoliation, fructification decrease, ...).

The spontaneous regeneration is one of important factors with an influence on the existence and survival of autochthonous forests. The fructification of mature trees and the seedling growth and development are not optimal in the upper mountain edge of the Krkonoše Mts. The intervals between periods of full fructification are usually 8 -14 years and even longer. The seeds do not have enough time to become mature and their germinating ability is consequently low. The young seedlings are destroyed by early frosts, by the movement of the snow cover in the spring time and are also damaged by summer rainfalls (Vacek, 1981).

The changes in temperature and moisture, vegetation cover and biting caused by animals are among other factors having an important influence on the spontaneous regeneration. The temperature and moisture conditions are determined by a character of a site conditions (Minor, 1986), the third factor is the structure of an herb layer cover. Damage caused by deer is considered to be an important limiting factor of the spontaneous regeneration in the Krkonoše Mts as well (Vacek, Lokvenc, 1991; Roon, 1993). This paper is focused on seedling germination, growth and development in several research plots in the Krkonoše Mts in the context of specific factors (altitude, exposition, slope, canopy cover, pollution stress level). This study may bring a particular knowledge about natural restoration in climax forests.

Methods

The fieldwork was performed from autumn 1995 to autumn 1997. Six permanent research plots (50x50 m) of various site conditions and under different multiple stress impact were founded in 1994 in the Krkonoše Mts (table 1). Two of them (the Mumlavská hora and the Alžbětinka plots) are situated in the west part of the mountains, the Pudlava plot in the middle and another plots in the east part of mountains. Plots are situated with altitudes diverging from 1140 m (the Pudlava plot) to 1317 m (the Pašerácký chodníček plot).

T a b l e 1. Site characteristics of the observed research plots

Location	Altitude	Exp.	Slope	Rock	Soil		Trees			Canopy cover
	[m]		[°]		type	pH	age [year]	number	dead [%]	[%]
Mumlavská hora	1185	SW	5	granite	humic podzol	3.47	180	133	91	5
Alžbětinka	1192	NW	14	granite	cambisol, cryptopodzol	3.60	200	129	51	35
Pudlava	1140	S	17	granite	podzol	3.00	102	191	56	50
Modrý důl	1237	S	22	mica schist	podzolic cambisol	3.74	121	149	32	65
Slunečné údolí	1241	SW	31	mica schist	cambisol, cryptopodzol	3.71	154	130	34	60
Pašerácký chodníček	1317	SW	18	mica schist	cambisol, cryptopodzol	3.50	145	259	46	50

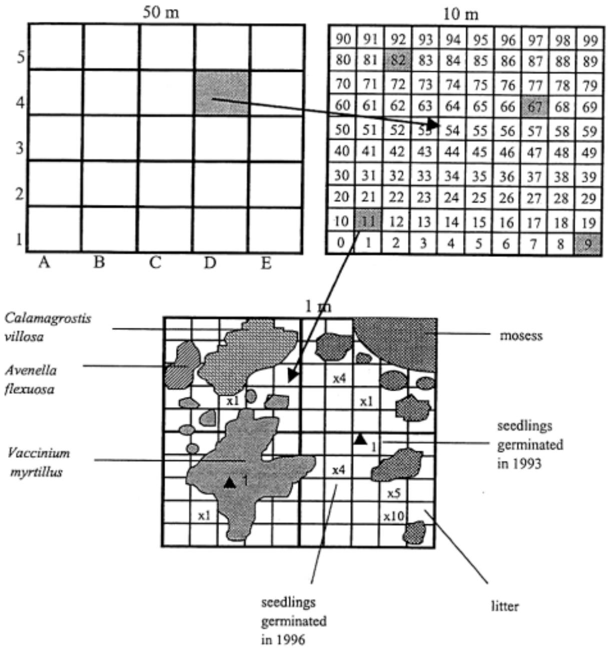


Fig. 1. The first division of the research plot into 25 squares (100 m²), the consequent division into the net of squares (1 m²), randomy selected 4 squares and the way of the registration of seedlings and herb layer.

The Norway spruce seedling populations were studied there for growth, development, and dying. One hundred small squares (each 1 m²) were selected in the six research plots. Each research plot was divided into 25 squares (10 x 10 m). Four small squares (1 x 1 m) were accidentally situated in each 100 m² squares, i.e. 100 small squares per one research plot (Fig. 1). The cover of several soil surface types (litter, decayed to decomposed wood, other substrates), mosses and dominant species of a herb layer (*Avenella flexuosa*, *Calamagrostis villosa*, *Vaccinium myrtillus* and other herbs and grasses) was recorded in the squares as well as seedling occurrence in different substrates, mosses and herb layer species. Other possible factors (canopy cover, soil pH, defoliation, …) were researched by Cudlín et al. (1995) and Cudlín, Chmelíková (1996).

T a b l e 2. Values of the basic statistical parameters calculated from the number of Norway spruce seedlings germinated in small squares in 1993 (A) and 1996 (B)

A

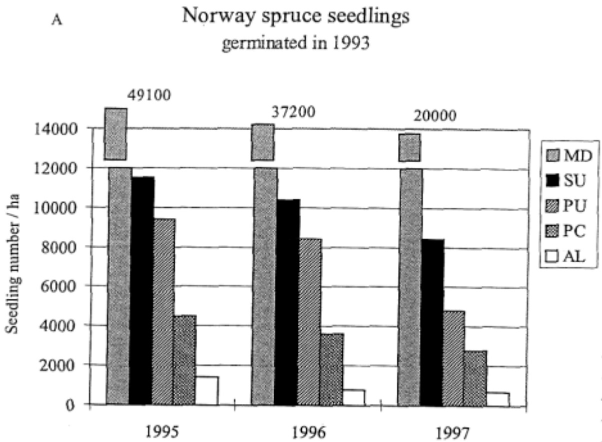
Location	Date	Mean	Median	Min.	Max.	Coef. Var.	Stand. Dev.
Ažbětinka	1995/X	0.13	0	0	8	0.70	0.84
	1996/X	0.08	0	0	6	0.38	0.62
	1997/X	0.07	0	0	5	0.27	0.52
Pudlava	1995/X	0.96	0	0	12	5.74	2.39
	1996/X	0.62	0	0	12	3.77	1.94
	1997/X	0.61	0	0	12	3.78	1.94
Modrý důl	1995/X	5.60	1	0	47	86.46	9.30
	1996/X	3.83	1	0	41	45.98	6.78
	1997/X	2.44	0	0	23	20.33	4.51
Slunečné údolí	1995/X	1.37	0	0	21	12.60	3.55
	1996/X	1.04	0	0	13	6.40	2.53
	1997/X	0.74	0	0	10	3.77	1.94
Pašerácký chodníček	1995/X	0.47	0	0	6	1.38	1.18
	1996/X	0.26	0	0	6	0.80	0.89
	1997/X	0.23	0	0	6	0.66	0.81

B

Location	Date	Mean	Median	Min.	Max.	Coef. Var.	Stand. Dev.
Ažbětinka	1996/X	1.14	0.0	0.0	13	4.44	2.11
	1997/X	0.41	0.0	0.0	6	1.17	1.08
Pudlava	1996/X	2.94	1.0	0.0	23	24.48	4.95
	1997/X	0.84	0.0	0.0	12	4.31	2.08
Modrý důl	1996/X	166.59	148.5	5.0	642	18062.51	134.40
	1997/X	8.57	2.0	0.0	152	340.49	18.45
Slunečné údolí	1996/X	22.6	12.5	0.0	121	597.49	24.44
	1997/X	0.62	0.0	0.0	12	3.53	1.88
Pašerácký chodníček	1996/X	6.23	2.0	0.0	57	100.42	10.02
	1997/X	0.98	0.0	0.0	23	9.51	3.08

The basic statistical parameters (mean, median, minimum and maximum values, coefficient of variation, standard deviation) and also standard variables for life table were calculated based on observed numbers of seedlings. The variables of life table were following: lx – percentage of seedling survival, meaning proportion of original surviving cohort to the beginning of each period of observation, dx – one-year mortality, as a proportion of original cohort dying during each period of observation, qx – mortality rate, as a measure of the intensity of mortality, px – probability of survival, kx – killing power, indicating the intensity or rate of mortality (Begon et al., 1997). In addition, the statistical comparison of seedling occurrence in the individual research plots was performed by one-way ANOVA.

A



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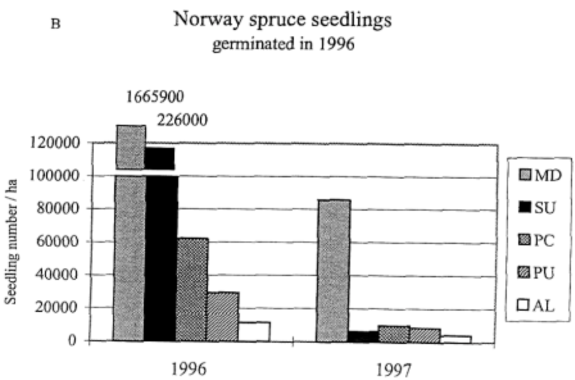


;. 2. Number of seedlings germinated in 1993 (A) and in 1996 (B) per 1 ha.
;end: MD = Modrý důl, SU = Slunečné údolí, PC = Pašerácký chodníček, PU = Pudlava, AL = Alžbětinka.

Results and discussion

Large of seedling cohorts

The highest effect of pollution stress on tree vitality is obvious in the Mumlavská hora plot with low canopy cover and majority of dead trees (Table 1). There is hardly any spontaneous regeneration present in the plot. The plot was excluded from the following investigations because no germinating seedlings were observed there neither in 1993 and nor in 1996. On the contrary, relatively the most protected and least damaged localities are the Modrý důl and the Slunečné údolí plots (Table 1).

Two Norway spruce seedling cohorts were predominant in all five plots: the Norway spruce seedlings germinated in 1993 and in 1996. The highest amount of the both of mentioned seedling groups was recorded in the Modrý důl plot. Lower, but still relatively high number of seedlings, was also observed in the Slunečné údolí and the Pudlava plots. Less seedlings were found in the Pašerácký chodníček and the Alžbětinka plots (Fig. 2). The large number of seedlings is likely caused by rich mosaic structure and microclimatic conditions on these plots. Those conditions are probably more favourable for germination, growth and development of seedlings. On the other hand, the lower number of seedlings is probably in relation with damage to plots, expressed by percentage of dead trees (Table 1).

The numbers of seedlings showed a high asymmetry and significant differences between distant single values (Table 2). That is why the non-parametric way of ANOVA test was used. The ANOVA test showed highly significant difference in numbers of seedlings in both seedling groups among all plots ($P < 0{,}001$). The numbers of seedlings, recorded every year, were very strongly reduced (Fig. 2).

Life table of seedlings

The presented life tables (Table 3) illustrate seedling survival at particular localities. All characteristics of life table show high variability when the research plots are being compared. The most of the seedlings were observed in the Modrý důl plot and the least in the Alžbětinka plot. It is interesting, that the least of the seedling survival and the high mortality (d_x, q_x, k_x) were in the Modrý důl plot (Tables 3A, 3B).

The average value of the killing power (k_x) during three years in seedlings germinated in 1993 was 0.270. The increasing trend of the k_x-values can be seen (with the exception of the Alžbětinka plot). The three and four years old seedlings were more likely to die in the course of following years. This trend corresponds with other mortality variables (d_x, q_x). The values of the killing power, based on seedlings germinated in 1996, were much higher comparing to foregoing seedling group.

If we consider the number of seedlings entering the process of the spontaneous regeneration, seedling survival, mortality rate, and killing power, than the best situation is in the Slunečné údolí plot and the worse in the Alžbětinka plot. This trend corresponds with other site characteristics presented in Table 1 (e.g. NW exposition, pH of soil horizon, age, sparse

T a b l e 3. Standard variables calculated for the living tables on the base of number of seedlings germinated in 1993 (A) and in 1996 (B) which had been observed in permanent plots during the period from 1995 to 1997

A

Location	year/x	a_x	l_x	d_x	q_x	p_x	log 10 (a_x)	k_x
	1995/2	1400	1.000	0.429	0.429	0.571	3.146	0.243
Ažbětinka	1996/3	800	0.571	0.071	0.125	0.875	2.903	0.058
	1997/4	700	0.500	–	–	–	2.845	–
	1995/2	9400	1.000	0.106	0.106	0.894	3.973	0.049
Pudlava	1996/3	8400	0.894	0.383	0.429	0.571	3.924	0.243
	1997/4	4800	0.511	–	–	–	3.681	–
	1995/2	49100	1.000	0.242	0.242	0.785	4.691	0.121
Modrý důl	1996/3	37200	0.758	0.350	0.462	0.538	4.571	0.270
	1997/4	20000	0.407	–	–	–	4.301	–
	1995/2	11500	1.000	0.096	0.096	0.904	4.061	0.044
Slunečné údolí	1996/3	10400	0.904	0.174	0.192	0.808	4.017	0.093
	1997/4	8400	0.730	–	–	–	3.924	–
	1995/2	4500	1.000	0.200	0.200	0.800	3.653	0.097
Pašerácký chodníček	1996/3	3600	0.800	0.200	0.250	0.750	3.556	0.125
	1997/4	2700	0.600	–	–	–	3.431	–

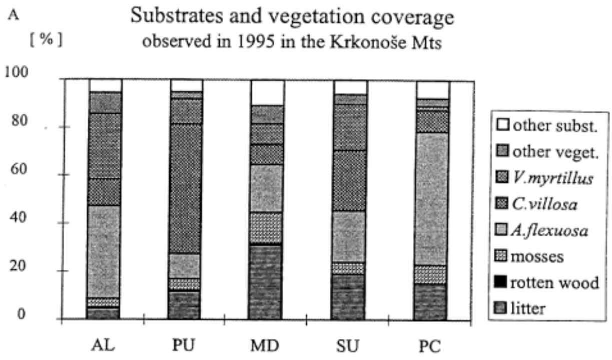
B

Location	year/x	a_x	l_x	d_x	q_x	p_x	log 10 (a_x)	k_x
Ažbětinka	1996/1	11400	1.000	0.400	0.400	0.600	4.057	0.444
	1997/2	4100	0.600	–	–	–	3.613	–
Pudlava	1996/1	29400	1.000	0.710	0.710	0.290	4.468	0.544
	1997/2	8400	0.290	–	–	–	3.924	–
Modrý důl	1996/1	1665900	1.000	0.949	0.949	0.051	6.222	1.289
	1997/2	85700	0.051	–	–	–	4.933	–
Slunečné údolí	1996/1	226000	1.000	0.973	0.973	0.027	5.354	1.562
	1997/2	6200	0.027	–	–	–	3.792	–
Pašerácký chodníček	1996/1	62300	1.000	0.843	0.843	0.157	4.794	0.803
	1997/2	9800	0.157	–	–	–	3.991	–

Explanation: x – seedling age, a_x - seedling number, l_x ($=a_x/a_0$) – seedlings which survived during one–year period, d_x ($=l_x - l_{x+1}$) – one–year mortality, q_x ($=d_x/l_x$) – mortality rate, k_x ($=\log10 (a_x/a_{x+1})$) – killing power

canopy cover) and with the classification of the research plots into categories from stands with low to very high multiple stress exceedance (Ardö et al., 1997). Multiple stress, expressed by percentage of dead trees, corresponds with spontaneous regeneration.

The highest mortality was observed in the Slunečné údolí and the Modrý důl plots and the lowest in the Alžbětinka plot. However, it ought to be said that the number of seedlings



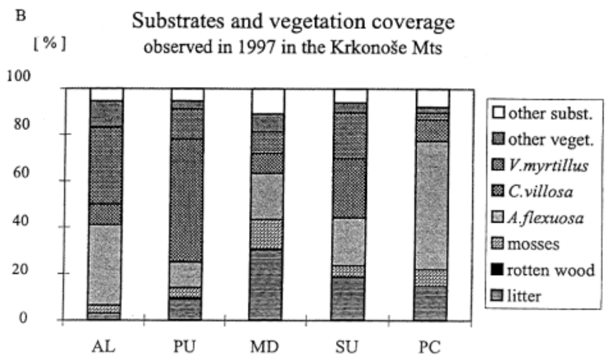


Fig. 3. Substrate, mosses and dominant herb layer species coverage observed in plots in the autumn 1995 (A and 1997 (B).
Legend: AL = Alžbětinka, PU = Pudlava, MD = Modrý důl, SU = Slunečné údolí, PC = Pašerácký chodníček.

recorded in the Slunečné údolí plot in 1996 was nearly twenty times higher than that observed in the Alžbětinka plot and number of seedling observed in the Modrý důl plot was even more than one hundred times higher (Fig. 2, Table 3).

The variables of seedling mortality obtained from the data recorded in the Modrý důl plot show certain inconsistency in existing trends. The recorded number of seedling was the highest, but their mortality also reached the maximum values. Multiple stress level is the lowest if compared to the other plots Cudlín, Chmelíková (1996). The question is whether such a high seedling production of this least damaged forest stand is typical or exceptional and whether the lower number of seedlings (e.g. recorded in the Slunečné údolí plot) is more typical. The higher number of seedlings is possibly caused by higher competition and, as a result, higher mortality as well.

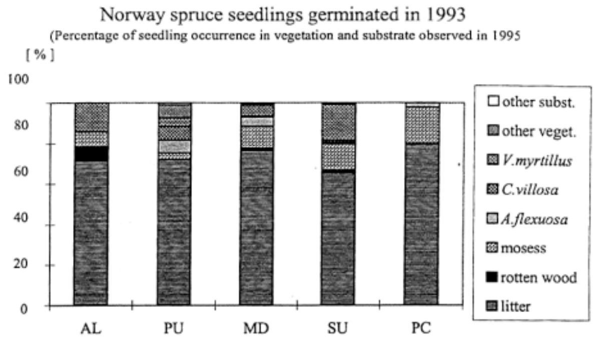
Seedling development in different cover of surface

Based on the observed coverage of soil surface substrates, mosses and of dominant plant species it can be said that the highest occurrence of litter and mosses was found in the Modrý důl plot (Fig. 3). A dense canopy cover at this locality (Table 1) could be the reason. Analogous situation can be seen in the Slunečné údolí plot, where the coverage of litter and dominant herb layer species is of the similar value there. On the contrary, considerable dominance of *Avenella flexuosa* was observed in the Alžbětinka (40%) and in the Pašerácký chodníček (55 %) plots. An important species of the herb layer in the Alžbětinka plot was also *Vaccinium myrtillus* with 27% coverage. The sparse canopy cover (caused, among others, by extreme climatic conditions) and the low litter coverage were observed for both of these plots. Dominance of *Calamagrostis villosa* was observed in the Pudlava plot. This grass covers more than a half of the area of an herb layer (Fig. 3).

The most of Norway spruce seedlings germinated in 1993 were found in litter and this substrate appears to be the most favourable for seedling survival. In spite of the fact that the litter cover was lower compared to *Avenella flexuosa*, *Calamagrostis villosa* and *Vaccinium myrtillus* coverage, the percentage of seedling occurrence in litter observed in all plots in 1995 was higher than 65% (Fig. 4A). This amount decreased during the observed period. The only exception is the Modrý důl plot where the percentage of seedling occurrence in litter decreased negligibly (Fig. 4B, 4C). As a potentially favourable substrate could be also considered spots covered by decomposed or by decayed wood. However, area of this substrate was too small to draw any serious conclusion. Relatively high seedling occurrence was also recorded in mosses, though it was much lower compared to litter. A very low seedling occurrence was observed in dominant grasses (*Avenella flexuosa*, *Calamagrostis villosa*) and in *Vaccinium myrtillus* in 1997. These species are preventing the seedling germination, growth and survival due to their light, water and nutrient competition. Minimum number of seedlings was also observed in other substrates (stumps, fallen tree trunks, stones).

The occurrence of Norway spruce seedlings germinated in 1996 in substrates, mosses and herb layer species shows that the seedlings frequently germinated also in *Avenella flexuosa*, *Calamagrostis villosa* and in *Vaccinium myrtillus* (Fig. 4D, 4E). However, the

A



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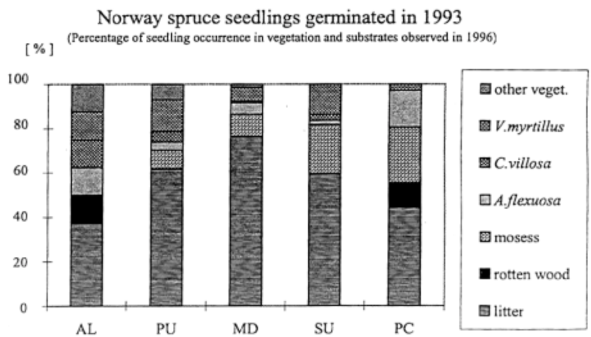
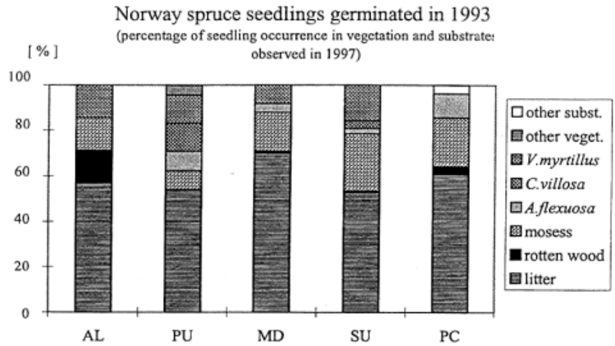
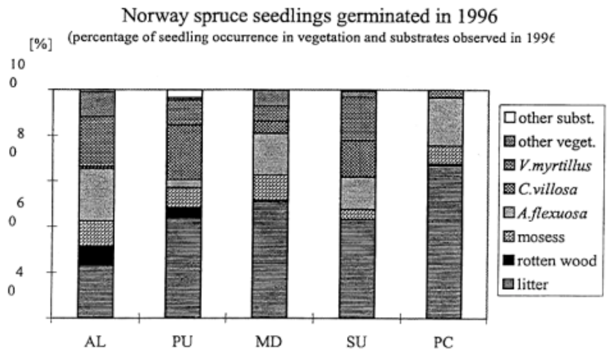


most of these seedlings have died and the percentage of seedling occurrence observed in 1997 was very close to values observed in 1995 in the case of seedlings germinated in 1993. This confirms a high probability of seedling occurrence in litter covered spots and also the above mentioned competition influence of *Avenella flexuosa*, *Calamagrostis villosa* and *Vaccinium myrtillus*.

C


Norway spruce seedlings germinated in 1993
(percentage of seedling occurrence in vegetation and substrates observed in 1997)
[%]
100
80
60
40
20
0
AL
PU
MD
SU
PC
other subst.
other veget.
V.myrtillus
C.villosa
A.flexuosa
mosess
rotten wood
litter

D


Norway spruce seedlings germinated in 1996
(percentage of seedling occurrence in vegetation and substrates observed in 1996
[%]
10
0
8
0
6
0
4
0
AL
PU
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other subst.
other veget.
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E

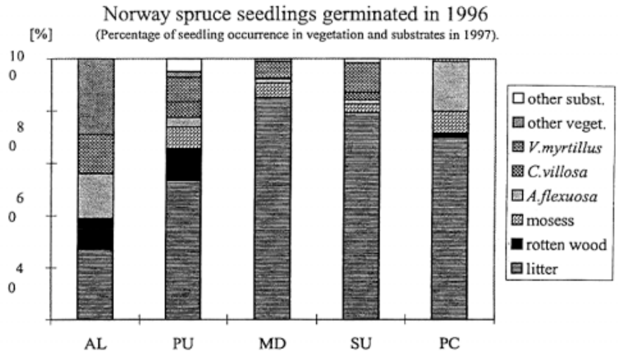
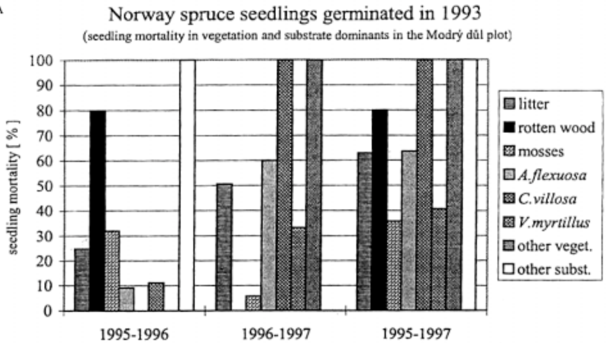


Fig. 4. Percentage of occurrence of Norway spruce seedlings germinated in 1993 observed in substrates, mosse and dominant herb layer species in 1995 (A), 1996 (B) and in 1997 (C) and percentage of occurrence of Norwa spruce seedlings germinated in 1996 observed in 1996 (D) and in 1997 (E) in individual locations.
Legend: AL = Alžbětinka, PU = Pudlava, MD = Modrý důl, SU = Slunečné údolí,
PC = Pašerácký chodníček.

The seedling mortality in substrates, mosses and herb layer dominants was calculate based on the data recorded in the Modrý důl plot only where the number of seedlings wa sufficiently high for this purpose (Fig. 5). The mortality of seedlings germinated in 199 was the lowest in mosses (35%) and in *Vaccinium myrtillus* (40%) during the whole perioc The mortality in litter reached more than 60% and the same value was observed in the cas of *Avenella flexuosa*. All seedlings have died in *Calamagrostis villosa*, in other species an substrates.

The dying of seedlings germinated in 1996 was the lowest in spots covered by litter an *Vaccinium myrtillus*, the highest in *Avenella flexuosa* and *Calamagrostis villosa*, and i other species and substrates. These data show that the growth conditions in the stand c *Vaccinium myrtillus* are relatively more favourable than those in the dominant grasse: Seedlings germinating in grasses are probably more intensively destroyed during the winte and the spring periods because the dead aboveground parts of these plants under sno cover overlies them whereas *Vaccinium myrtillus* provides a better protection for the youn seedlings. However, seedling germination in this species is relatively low comparing to th germination in litter (Fig. 4) and therefore a higher seedling occurrence cannot be expecte in the stand of *Vaccinium myrtillus* during the following years.

A



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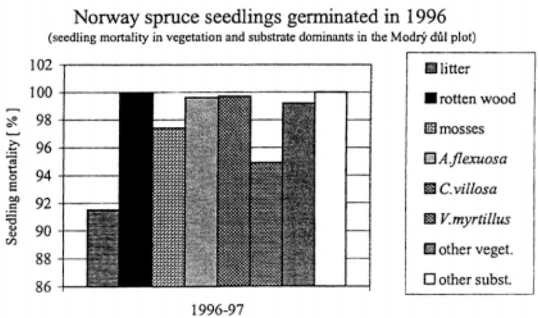

Fig. 5. Mortality of Norway spruce seedlings germinated in 1993 and in 1996 observed during the periods 1995 - 1996 and 1995 -1997 (A), and mortality of Norway spruce seedlings germinated in 1996 observed in substrates, mosses and dominant herb layer species in the Modrý důl plot during the period 1996-1997 (B).

Conclusions

The results showed that the highest potential of the spontaneous regeneration of research plots was probably in the Slunečné údolí plot and the lowest in the Alžbětinka plot (if the Mumlavská hora plot is not considered). The most of the seedlings were germinating and growing in litter cover and the least favourable growth conditions were observed in cover with dominant grasses (*Avenella flexuosa*, *Calamagrostis villosa*). From this it follows that seedling development in individual research plots depends on the structure of an herb layer and on the occurrence of above mentioned dominant species. A canopy cover of individual sites influences their coverage of dominant herb layer species, among others. However, a more general conclusion could be drawn after a consideration of influence of other abiotic factors (e.g. meteorological and soil conditions) and after more detailed and long-term observation of biotic factors (competition of herb layer communities, the health status of mature trees etc.).

The observed spontaneous regeneration in these research plots generally corresponds with the development of other degradation and regeneration processes which have been observed there for several years. It shows that the problem of a restoration of mountain Norway spruce forests should be studied and solved in a context of the whole ecosystem. Future investigations should determine and also specify practical steps leading to improvement of the tree fructification and to creation of favourable conditions for the seedling germination, growth and development.

Translated by the authors

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Šerá B., Falta V., Cudlín P., Chmelíková E.: **Príspevok k poznaniu vzrastu a vývoja semenáčikov smreka stepilého.**

Na šiestich trvalých plochách v Krkonošiach sme sledovali počas rokov 1995 až 1997 vplyv niektorých faktorov (emisie, pôdu, machové poschodie a dominantné byliny) na vývoj semenáčikov smreka stepilého. Z výsledkov vidieť, že úspešnosť usadenia semenáčikov závisí od synergického pôsobenia viacerých stresových faktorov. Najväčší počet úspešných semenáčikov sme sledovali na plochách, ktoré boli najmenej stresované a narušené (Modrý důl, Slnečné údolie). Ako vhodné životné podmienky sa javili: priaznivejšia klíma, nízke poškodenie korún stromov a vysoká pokryvnosť opadu. Naopak, nízky počet semenáčikov sme zistili na viacej poškodených a stresových lokalitách (Alžbetinka zo severnej expozície a relatívne vysokým emisným stresom). Na lokalite Mumlavská hora, v poslednom štádiu rozpadu smrekového ekosystému, nezaznamenali sme ani jediného semenáčika.

Ako druhotný následok mnohonásobného stresu sa javí konkurenčný vplyv niektorých dominantných rastlín. Zistili sme, že najviac semenáčikov vzklíčilo a rástlo na prostom opade ihličia. Počet úspešných semenáčikov bol v ostatných typoch substrátov (machy, niektoré byliny) oveľa nižší.