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RESULTS OF THINNING EXPERIMENTS WITH NEGATIVE AND POSITIVE SELECTION IN NORWAY SPRUCE STANDS AFTER 40 YEARS OF INVESTIGATION – SERIES ESTABLISHED IN 1958

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ABSTRACT

Since 1956, new experimental basis for thinning research in Forestry and Game Management Research Institute Jíloviště–Strnady has been created. Total 46 experimental series were founded in Norway spruce (*Picea abies* /L./ Karst.) and only 24 series persisted to the present time. Presented contribution is oriented on the first time group of series, established in young Norway spruce stands in 1958 (Rumburk, Mostek, Vimperk I, Vimperk II and Nisa). The thinning experiment was projected in order to compare two basic ways of thinning: positive selection from above (2a) and negative selection from below (3b or 5b). The test element of each experimental series is control plot (1c) without intentional thinning. Final evaluation of the 1st group of series concentrated on observed common phenomena because of high initial differences (especially in initial density of stands) between series. The most pronounced effect of thinning consisted in decreased amount of basal area, which had to be removed as salvage cut. While on all thinned plots, the salvage cut in the period of investigation varied from 6 % to 29 %, the salvage cut on control plots 1c without thinning represented 60 – 107 % of period basal area increment. The expectation, that by positive selection from above diameter distribution will be wider with higher abundance of surviving thin trees, was not confirmed. Effect of thinning by positive selection from above lasting for 40-year period of investigation resulted in by 10 – 45 % decreased abundance of trees in lower diameter classes comparing to control plots. On the other hand, negative selection from below resulted in more pronounced decrease of thin trees abundance (by 50 - 69 % comparing to control plots). Abundance of thick trees (mostly with diameter of 30 cm and more) increased on all comparative plots with thinning by 5 – 50 %. Static stability characterized by h/d ratio of mean stem and h/d ratio of dominant trees (200 thickest trees per hectare) was influenced by thinning mostly positively (final value of h/d ratio found by the last revision was principally lower).

INTRODUCTION

Investigation of effect of various thinning method on forest stands depends on sufficient amount of permanent research plots and its regular and long-term observation, preferably at last for the period of one rotation. The theoretical problems of thinning in the forest stands of the Czech Republic before 1955 were partly solved in a small scale research on Forestry Faculties of Czech universities. Attention was paid to a few experiments founded by Institute in Mariabrunn (Austria) before the World War I or several experiments founded after the World War II. The experimental basis was small and insufficient, mostly with short-time period of investigation and therefore, the received results were not representative and applicable for practical purposes.

For that reason, it was decided to create new experimental basis with the aim of receiving exact experimental data for the thinning strategy in the forest stands of the main forest tree species – Norway spruce (*Picea abies* /L./ Karst.) and Scotch pine (*Pinus sylvestris* L.). This project was delegated to Forestry and Game Management Research Institute Jíloviště–Strnady. In the framework of the project, 46 experimental series were founded in Norway spruce stands in four time groups in the period 1956 – 1973 (1st group in 1956 – 1958, 2nd in 1960, 4th in 1963 – 1964 and 5th in 1971 – 1973). One group (in chronology the 3rd) was founded in Scotch pine stands and it will be evaluated separately.

From the original 46 experimental series, only 24 persisted to the present time (Novák, Slodičák 2001). Other series were partly or completely destroyed mostly by snow and wind or other harmful factors. Since 1997, the observation of these long-term experimental series has been included into subproject Thinning of forest stands in changing growing conditions of the complex project Silviculture in ecotopes disturbed by human activities (Novák, Slodičák 2002).

Presented contribution is oriented on the first time group of series, established in young Norway spruce stands in 1958 (tab. 1).

Tab. 1: List of experimental series in Norway spruce stands of the 1st group established in 1958

Series	Name	Age	Comp. plots	Forest region	Elevation (m)	Forest vegetation zones	Soil category
1	Rumburk	37	2	20 – The Lužická pahorkatina Hills	510	fir-beech	acid
2	Mostek	38	3	23 – The Podkrkonoší Piedmont	530	fir-beech	acid
3	Vimperk I	32	2	13 – The Šumava Mts.	1020	spruce-beech	acid
4	Vimperk II	51	3	13 – The Šumava Mts.	1045	spruce-beech	acid
5	Nisa	35	3	21a – The Jizerské hory Mts.	820	spruce-beech	acid

METHOD

The methods for founding and evaluation of long-term thinning experiments are based on the common techniques and methods used in forestry research towards easier comparing with similar experiments abroad. The method was elaborated in Forestry and Game Management Research Institute in 1956 – 1957 (Pařez 1958).

The project of procedures was consulted with the eminent Czech and Slovak forest specialists: Ján Borota, Ph.D., Jiří Bozděch, Ph.D., Prof. Jaromír Čížek, Ph.D., Ján Delinga, Vlastislav Jančařík, Ph.D., Václav Jirkovský, Jaroslav Hofman, Ph.D., Prof. Josef Kantor, DrSc., Prof. Václav Korf, DrSc., Dr. Fedor Korsuň, Vladimír Krečmer, Ph.D., Jan Materna, Ph.D., Dr. Karel Matějů, Prof. Alois Mezera, DrSc., Miroslav Němec, Milan Novotný, Ph.D., Ján Oros, Josef Parkán, Prof. Antonín Pfeffer, DrSc., Dr. Jaroslav Řehák, Jiří Šindelář, Ph.D., Bohuslav Vinš, Ph.D., Prof. Miroslav Vyskot, DrSc.

Objectives of the experiment

The objectives of the experiment were to find up the effect of thinning with negative selection from below and positive selection from above on height and diameter growth and on quality, quantity and safety of production of forest stands. Partial results, especially about quantity and quality of production of forest stands, in research reports were published (Pařez 1972, 1975, 1979, 1980, 1985).

Explanation of used terms

- Experimental series is defined part of a forest stand designated for thinning experiment, i. e. for observation of one or more silvicultural treatment. Experimental series consists of two or more partial comparative plots with different thinning regimes.
- Partial comparative plot (comparative plot) is determined part of experimental series used for investigation of one silvicultural treatment and consequent comparison to other treatments and to control plot (without treatment).
- Control plot is one of the partial comparative plots left without any intentional silvicultural treatment. The only treatment is removing of dry, broken and uprooted trees, i. e. salvage cut. Control plot serves for observation of natural development of the stands and natural mortality.
- Group of experimental series is created by two or more experimental series in one climatic region in the similar elevation with the same management system, etc.
- Stand characteristics (N – number of trees, G – stand basal area) are calculated on hectare basis. For description of stand development following common abbreviation are used: d – diameter at breast height, h – mean height, h/d – quotient of slenderness, d_{200} – diameter of 200 thickest trees, h_{200} – height of 200 thickest trees, h/d_{200} – quotient of slenderness of 200 thickest trees.

Forest stand selection for investigation

As the Norway spruce stands occupy 55 % of forest area in the Czech Republic and create the main basis for wood production and for other non-wood-producing functions of forests, attention was primarily paid to this forest tree species. For founding of experimental series, even-aged, artificially (planting, sowing) or naturally regenerated pure Norway spruce stands were chosen, preferably in regions of their natural occurrence. Experimental series were established in all main Czech mountain ranges: the Šumava Mts., the Krušné hory Mts., the Jizerské hory Mts., the Krkonoše Mts., the Orlické hory Mts., the Jeseníky Mts., the Beskydy Mts. and the Českomoravská vysočina Mts., mostly in elevation above 600 m on supposed spruce sites. A part of series was established in lower elevation (below 600 m a. s. l.), i. e. on the sites where Norway spruce was introduced artificially.

The recommended initial stand age was 30 years with the aim to minimize the effect of possible different way of stand origination (planting, sowing, natural regeneration). Only high forest (of seed origin) with medium site index was acceptable.

Although all chosen experimental stands have, according to valid growth tables of Schwappach (1943), site index III, after the first revision and more precise evaluation, the site index of nearly all series had to be increased to I.

Experimental series were located in at last 3 – 4 hectares large even-aged pure and untreated stands on the same exposition, similar soil conditions and parent rock. Border stands or localities endangered by wind, snow and icing were avoided as well as heavy slopes.

Area and form of partial comparative plots

With respect of the previous experience, the basic area of partial comparative plot is 0.25 hectares, preferably the square with the sides of 50 m. Plots are situated at least 50 m from stand border and 10 – 20 m from forest roads and boundary lines. Particular comparative plots are bordered by 15 m wide isolation strips with the same treatment as on the respective plot.

All trees around the comparative plot (outside of the plot) were marked by 5 cm wide yellow belt facing inside the plot. On the corner tree, number of series and comparative plot is written by yellow colour. All trees with diameter over 4 cm on each comparative plot are numbered particularly and the points for diameter measurement are marked.

Comparability of partial plots

Before the first experimental treatment the difference between stand characteristic on particular comparative plots in number of trees – N, basal area – G, mean diameter – d, and mean height – h was tested by Student t-test ($\alpha = 0.05$). Only after having found the preliminary differences in given parameters insignificant, the experiment could be initiated.

OBSERVATION

The experimental series are surveyed as a rule in five-year periods off-vegetation-season and all trees are measured by callipers in mm over bark. Diameter of each tree is measured twice; first measurement against the label, the second perpendicularly. Height of the stands is measured by telescopic poles or Blume-Leisse altimeter on representative groups of trees (30 individuals of all tree classes) and height curves are deduced for assessing the mean and top height. After finishing of basic survey, trees for next experimental thinning or salvage cut on control plot are marked. All cut trees excluding forked and deformed individuals are measured as sample trees (height at the year of cut, annual height increment by whorls and stem diameters by 2 m sections for calculation of tree volume).

Investigated treatments

The thinning experiment was projected in order to compare two basic ways of thinning:

- positive selection from above (high thinning),
- negative selection from below (low thinning).

Some of experimental series were completed by the variant with heavy thinning, i. e. the opening up of a stand canopy. The test element of each experimental series is control plot without intentional thinning.

Positive selection from above

Thinning with positive selection from above was done along with principles of Schädelin. In young stands before the first experimental thinning, 500 – 1,500 future crop trees, i. e. the centres of stand cells were selected and released by removing of one or two the most competing individuals. Every future crop tree with the best stem and crown form was surrounded by several alternates. Crop tree (as a rule from higher tree classes) and alternates created so called stand cell. Thinning is oriented on forming of future crop trees crowns and suitable growing conditions so as high quality increment was created on the best individuals. Except the support of selected future crop trees, dead, ill or damaged trees were removed as well.

After the culmination of height growth, about 500 best crop trees were selected and their crowns kept free by removing surrounding even under-growing individuals. This process is supposed to be finished by release cutting with opening the canopy and consequent open stand increment.

This way of tending considered retaining of secondary crop consisted of retreating, suppressed and overtopped individuals. The effect of the secondary crop lays in shading of forest soil and protecting of selected best stems against direct sunshine.

Negative selection from below

Thinning with negative selection from below was oriented on removing the dead and dying trees (Kraft class 5), slowly growing trees and trees declining (Kraft class 4) and defected, mechanically injured and diseased trees of higher classes. Healthy and well shaped dominant trees were removed only in case of cutting (releasing) the groups of trees with similar dimensions and quality. Before removing of healthy dominant tree with unsatisfactory crown or stem characters, the canopy condition was taken into account to avoid the upper canopy disturbance.

In the experiment, moderate and heavy thinning grades were chosen on the basis of previous experience with quantity and quality of production.

Release cutting

Release cutting is very heavy thinning by negative selection from below with removing 30 % of volume or stand basal area by one or two consequent intermediate cuts. As a rule, all trees of worse shape and quality are removed at first and the best dominant trees are left in more or less regular spacing. The aim of release cutting is utilizing of light increment of the best individuals after the loosing of crown and root space leading to decreased competition and better moisture, light and temperature conditions.

Control plot

Control plot is used for investigation of natural mortality in a stand and for comparison with investigated thinning variants. All stand characteristics are measured in the same way as on comparative plots with thinning, but intentional silvicultural treatments are omitted. Only dry, totally broken and uprooted trees are removed. Cut trees are measured similarly as on other comparative plots.

Intensity of investigated thinning

The intensity of one thinning treatment was determined to 15 – 10 % of basal area for the first half of rotation and to 10 – 6 % of basal area for the second half of rotation. Full stocking and five-year thinning period was supposed. In case of stocking below 1.0 (for example 0.8 – 0.9), the thinning intensity decreased to 30 – 50 % of original amount. Thinning always reflected the actual state of a stand. Heavier reduction of basal area for 30 % or more was used on variants with release cuttings.

Evaluation of received data

All measured data are included into databases. Primary calculation consisted in evaluation of number of trees (N), stand basal area (G) on hectare basis, and mean diameter from basal area (d) before and after each treatment and the same data for removed trees. At the same time, the diameter d_{200} was calculated as an arithmetic mean of 200 thickest trees per hectare.

The second step was calculation of height curves for all variants of each series and periods of investigation by Näslund equation (Prodan 1965):

$$h = (d/(a + b \cdot d))^2 + 1.3$$

where: **d** – diameter, **h** – height, **a, b** – coefficients

On the basis of received equations, mean heights (h) and top heights (h_{200}) were calculated by inputting of mean d or d_{200} diameter into correspondent equation.

The data on diameter and height were used for computation of h/d and h/d_{200} ratios serving as indicators of static stability of trees, especially their resistance to stem breaks.

The third step, evaluation of diameter structure of experimental stands, consisted in comparison of diameter distribution before and after each treatment inside of particular series using 1 cm diameter classes (i. e. diameter class 15 cm includes the trees with diameter from 14.6 cm to 15.4 cm).

Investigated thinning variants could not be evaluated by statistical methods entirely, because individual variants in particular series were established without replication. For statistical evaluation of diameter growth of overage stem and dominant trees (200 trees per hectare) and changes of diameter structures, statistical system UNISTAT® (version 5.1) was used. Procedures ANOVA and sequentially Multiple Comparisons (methods: Student-Newman-Keuls and Scheffe) were applied (Grofík, Fľak 1990, Meloun, Militký 1998). Data sets (d, d_{200}) were tested by parametric tests (t-test) and by multisample nonparametric tests (Kruskal-Wallis one-way ANOVA – methods: t-distribution, comparisons against a control group - Dunnett, Dunn). Diameter distribution on partial comparative plots was analysed by goodness of fit tests (chi-square). In all analyses, confidence level 0.95 was used.

Static stability of dominant trees (h/d_{200} ratio for 200 dominant trees per hectare) was analysed separately. For all dominant trees on partial plots, height from functional analysis (by Näslund equation) was calculated. Received h/d_{200} ratio was analysed by the same methods as diameter growth data (see above).

Volume study could not be included into this report because of insufficient number of sample trees needed for volume curves calculation. And for this reason, it was compensated by more precise basal area evaluation.

As the concluding evaluation of all experiments will be done after final cutting on all series, exact volume study will be the part of the last report.

RUMBURK EXPERIMENTAL SERIES

Experimental series at Rumburk was founded in forest region 20 – the Lužická pahorkatina Hills in 1958 in 37-year old Norway spruce stand growing in Forest Management-plan Area Rumburk (stand 332 A8 according to Forest Management Plan 1996). The co-ordinates of the series are lat. 50°54´07″ N and long. 32°09´13″ E. The experimental stand is located on a gentle eastern slope (2 – 3 %) in 5th (fir-beech) forest vegetation zone in elevation of 510 m. Prevailing soil type is brown forest soil, ecological group acid – fertile, soil category I (S). The experimental stand is included into Management Unit 54 – Spruce management of fertile sites in higher locations affected by air pollution. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period of 1961 – 1990, the mean annual sum of precipitation represented 800 mm and mean annual temperature 6 °C.

The experimental series consists of two comparative plots with dimensions 50 m x 50 m, i. e. 0.25 ha each (fig. 1). Comparative plot 1c is control plot without designed thinning, where only dead, broken or uprooted trees have been removed. Comparative plot 2a is the stand with thinning by positive selection from above. In 1998 (last revision), trees for felling were marked on plot 2a with the aim of loosing canopy and consequent observation of left trees development and natural regeneration.

History of the experiment

In the period of foundation of the Rumburk series in 1958, the experimental stand was 37-year old Norway spruce monoculture with the density of 1,984 – 2,016 trees per hectare originated artificially by planting in regular spacing ca 2 m (i. e. 2,500 trees per hectare) in 1921 on clear-cut after nun moth injury. The experimental stand was not thinned before the first experimental treatment and, subsequently, it was distinctly differentiated (diameter breast height varied from 5 to 30 cm, fig. 3).

Initial diameter of the mean stem (d) on both partial plots 1c and 2a achieved 14.2 and 14.0 cm, diameter d_{200} (mean diameter of 200 thickest trees per hectare) 21.2 and 20.4 cm respectively. Also the differences in mean and top height (h 14.2 a 14.4 m and h_{200} 17.0 and 17.2 m) were minimal and differences between all investigated characters (N, G, d, h, h_{200}, d_{200}) were found statistically insignificant (tab. 2, fig. 2). On the basis of the initial evaluation of the main stand characteristics, both partial plots 1c and 2a were stated comparable.

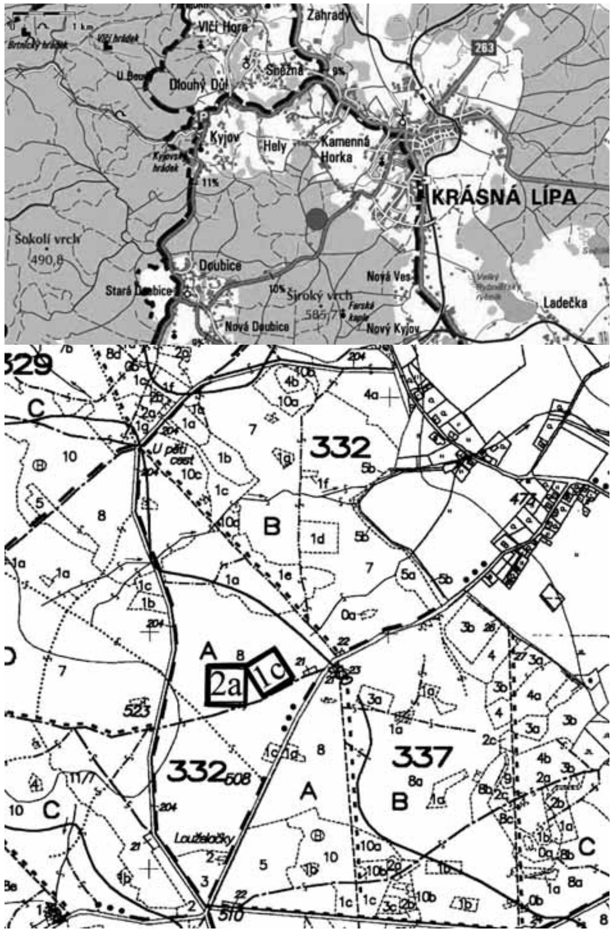


Fig . 1: Geographic location (Geobáze® 1997 – 2000) and stand map of experimental series Rumburk on Forest Management Plan 1996

Number of trees and basal area

By the first experimental thinning on the comparative plot 2a at the age of 37 years, 18 % trees (N) representing 13 % of basal area (G) were removed by positive selection from above. Treatments repeated three times in five-year periods to the age of 52 years (1973) removing 16, 33 and 25 % N (11, 18 and 15 % G). Position of the treatments in the diameter structure of experimental stands is apparent from fig. 3.

After four treatments in five-year periods, i. e. 20 years after the beginning of the observation (1978, age 57 years), number of trees per hectare decreased on:

- control plot 1c to 892 individuals (mortality 1,124 individuals),
- comparative plot 2a to 680 individuals (1,304 individuals removed by thinning).

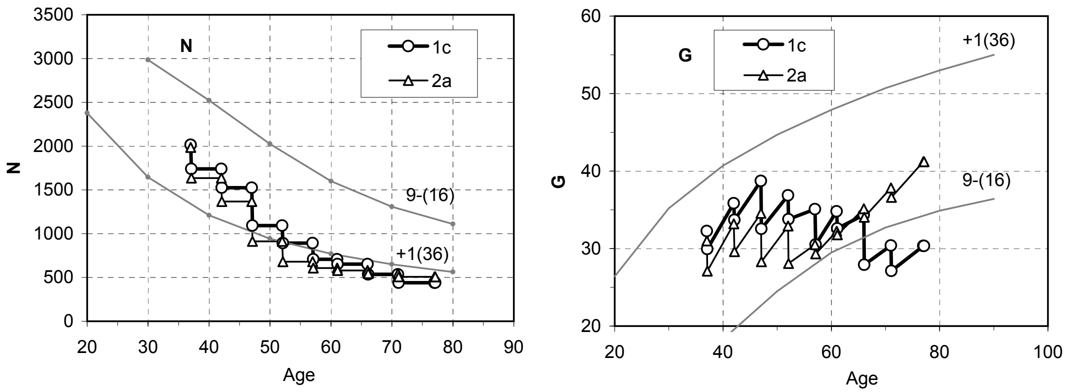


Fig. 2: Number of trees (N – pc.ha^{-1}) and basal area (G – m^2.ha^{-1}) on comparative plots of experimental series Rumburk at the age of 37 – 77 years comparing with Growth tables (Černý, Pařez, Malík 1996)

Basal area (G) per hectare achieved at the same time on:

- control plot 1c – 35.1 m^2 (increased by 2.8 m^2),
- comparative plot 2a – 31.7 m^2 (decreased by 0.7 m^2).

Periodic increment of the basal area (at the age of 37 – 57 years) represented together with basal area of intentionally removed trees by thinning on comparative plot 2a – 19.2 m^2 and it was by 16 m^2 higher than on control plot 1c without thinning (2.8 m^2).

Since the last experimental thinning at the age of 52 years (1973), both comparative stands of the experimental series have developed without intentional thinning. All treatments consist in removing of died dry and incidentally broken and uprooted trees. Number of trees per hectare to the last revision in 1998 (age 77 years) spontaneously decreased on:

- plot 1c to 440 individuals (mortality at the age of 37 – 77 years 1,576 individuals),
- plot 2a to 508 individuals (mortality at the age of 57 – 77 years 172 individuals).

Mortality in the last 20-year period (age 57 – 77 years) was influenced by air pollution stress. On more afflicted control plot 1c, 452 trees (51 % of N at the age of 57 years) had to be removed while on comparative plot 2a with positive selection from above at the age 37 – 52 years only 172 trees (25 % of N at the age of 57 years) were removed. The biggest mortality on the control plot 1c (18 % of N, i. e. 116 trees and 19 % of G, i. e. 6.5 m^2) was observed by the 6th revision at the age of 66 years (1987). The basal area of the control plot 1c decreased in that way below 28 m^2 and as the mortality in the next five-year period topped out the increment again, basal area by the 7th revision at the age of 71 years decreased to 27.1 m^2.

Basal area at the age of 77 years, i. e. 40 years after the beginning of the experiment (last revision), achieved higher level on the comparative plot 2a (41.2 m^2), while on control plot 1c decreased below the initial level to 30.4 m^2, due to enlarged mortality at the age of 57 – 77 years.

After including the basal area of all removed trees (i. e. including salvage cut), the basal area increment in the period of investigation was by 5.6 m^2 higher on comparative plot 2a with positive selection from above comparing with control plot 1c (28.3 m^2 on control plot 1c and 33.9 m^2 on plot 2a). In addition on control plot 1c, 30.2 m^2 of basal area (107 % of basal area increment) had to be

Tab. 2: Basic data on Rumburk experimental series

Rumburk		1958				1963				1968				1973				1978	1998	I. 37-77	I. 37-77-SC	SC 37-77
		37 years				42 years				47 years				52 years				57 years	77 years			
		before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	after thinning			
1c	N	2016	279	14	1740	1740	216	12	1524	1524	432	28	1092	1092	200	18	892	892	440	*	*	1576
2a	(trees.ha^{-1})	1984	348	18	1636	1636	268	16	1368	1368	456	33	912	912	232	25	680	680	508	*	*	172
1c	G	32.3	2.3	7	30.0	35.9	2.2	6	33.7	38.7	6.2	16	32.6	36.9	3.1	8	33.8	35.1	30.4	28.3	-1.9	30.2
2a	(m^2.ha^{-1})	31.0	3.9	13	27.1	33.2	3.6	11	29.6	34.6	6.3	18	28.3	32.9	4.8	15	28.1	31.7	41.2	33.9	28.8	5.1
1c	d	14.2	10.4	*	14.8	16.1	11.3	*	16.7	17.8	13.5	*	19.3	20.7l	14.0	*	21.9	22.4	29.6	10.5	*	*
2a	(cm)	14.0	11.9	*	14.5	16.0	13.1	*	16.5	17.7	13.2	*	19.6	21.4	16.3	*	22.9	24.1	32.2	12.9	*	*
1c	h	14.2	12.1	*	14.4	17.1	14.3	*	17.3	18.8	16.5	*	19.5	20.1	17.0	*	20.7	21.6	25.5	9.3	*	*
2a	(m)	14.4	13.2	*	14.6	16.7	15.2	*	16.9	18.6	15.9	*	19.5	20.2	17.7	*	20.8	22.0	26.1	9.5	*	*
1c	h/d	100	116	*	97	106	127	*	104	106	122	*	101	97	121	*	95	96	86	-1.5	*	*
2a		103	111	*	101	104	116	*	102	105	120	*	99	94	109	*	91	90	81	-9.1	*	*
1c	d_{200}	21.2	*	*	*	25.7	*	*	*	27.0	*	*	*	29.0	*	*	*	29.9	35.6	14.4	*	*
2a	(cm)	20.4	*	*	*	25.0	*	*	*	27.4	*	*	*	29.8	*	*	*	30.6	39.3	18.9	*	*
1c	h_{200}	17.0	*	*	*	20.9	*	*	*	22.3	*	*	*	23.2	*	*	*	23.8	25.5	8.5	*	*
2a	(m)	17.2	*	*	*	20.4	*	*	*	22.2	*	*	*	23.0	*	*	*	24.0	27.8	10.6	*	*
1c	h/d_{200}	80	*	*	*	81	*	*	*	83	*	*	*	80	*	*	*	80	73	-7	*	*
2a		84	*	*	*	82	*	*	*	81	*	*	*	77	*	*	*	78	72	-12	*	*

Notes: 1c – control plot without thinning, 2a – comparative plot with thinning from above, N – number of trees, G – basal area, d – breast height diameter, h – mean height, h/d - ratio of slenderness, d_{200} – diameter of 200 thickest trees, h_{200} – height of 200 thickest trees, h/d_{200} - ratio of slenderness of 200 thickest trees, T – thinning, I – increment, SC – salvage cut removed during the period of investigation as salvage cut (breaks, dry trees, etc.), whereas salvage cut on thinned plot 2a represented only 5.1 m^2 (i. e. 15 % of basal area increment).

When including basal area only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigation (age of 37 – 77 years) achieved on:

- plot 1c –1.9 m^2, i. e. the reduction of initial basal area,
- plot 2a – 28.8 m^2.

Diameter structure

Effect of thinning on diameter structure was investigated at the age of 37 – 52 years, in five-year period always to the date of experimental treatment. Diameter structure was evaluated four times for the age of 37, 42, 47 and 52 years, i. e. in the period of active treatment. The 5th final evaluation was

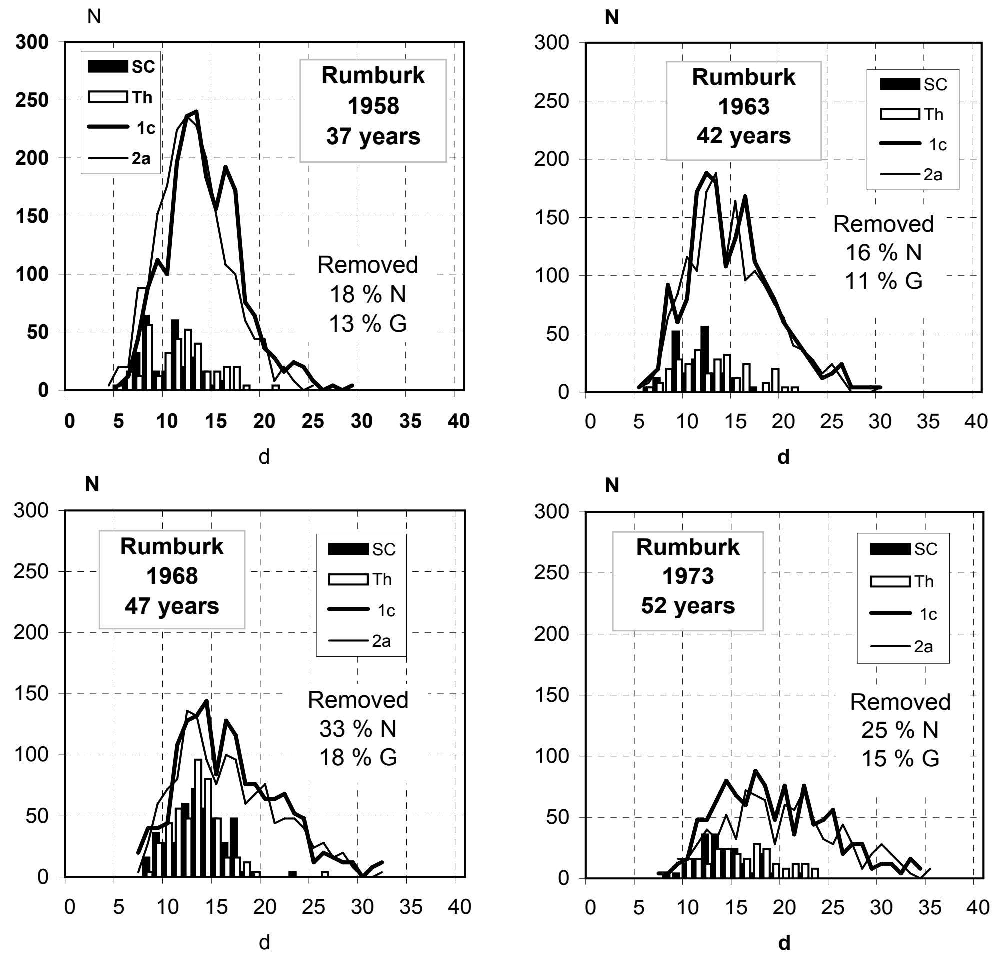


Fig. 3: Diameter structure and experimental thinning comparing with mortality on control plot 1c without thinning on Rumburk experimental series at the age of 37 – 77 years (d – diameter in cm, N – number of trees per hectare, SC – salvage cut, Th – thinning)

made on the data received by last the revision at the age of 77 years (1998).

Distribution of trees in diameter classes before thinning is exhibited by lines, thinned trees are shown by white column and mortality on control plot 1c by black column. From the figure 3 it is apparent, that the diameter structure on both comparative plots before the beginning of the experiment at the age of 37 years (1958) was statistically identical (chi–square test).

From the position of the particular treatments it is visible, that all four thinnings on comparative plot 2a were made by positive selection from above. At the same time, together with the trees of mean dimensions removed in favour of crop trees, a part of smaller individuals (broken or dying) had to be removed as well. Especially it is recognizable at the age of 57 years.

Displacement of thinning into higher diameter classes comparing to natural mortality is apparent especially in the 1st, 2nd and 4th thinning at the age of 37, 42 and 52 years. At the age of 77 years (last revision), the diameter of the trees in experimental stands varied from 14 to 53 cm (fig. 4). The lowest diameter classes 14 – 20 cm with the higher and the most unfavourable h/d ratio (110 – 140) were the most abundant on control plot 1c (72 individuals per hectare comparing with 44 individuals per hectare on comparative plot 2a with positive selection from above). On the other hand, abundance of trees with diameter 30 cm and more and with favourable h/d ratio (85 – 54) on thinned plot 2a represented 143 % of control plot 1c (184 individuals per hectare comparing with 264 individuals per hectare on comparative plot 2a with positive selection from above). Thinning effect is apparent especially on increased number of the thickest trees (diameter 40 cm and more) on comparative plot 2a, where these trees represented 200 % of control plot (72 individuals on plot 2a comparing with 36 individuals on plot 1c).

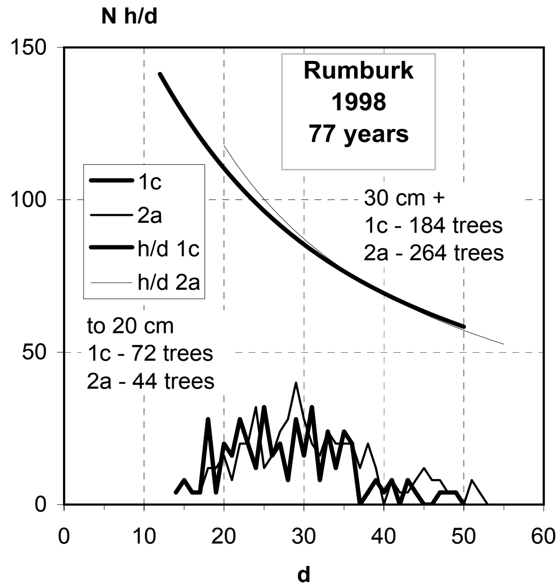


Fig. 4: Diameter structure and h/d ratio for diameter classes on experimental series Rumburk at the age of 77 years - last revision (d – diameter in cm, N – number of trees per hectare)

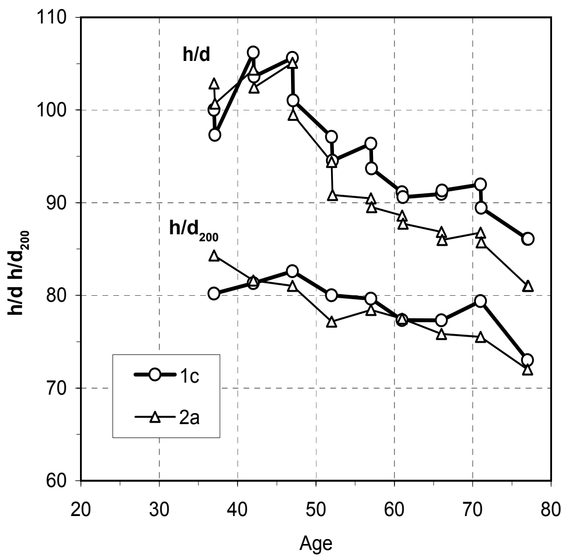


Fig. 5: Development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on experimental series Rumburk at the age of 37 – 77 years

Although thinning resulted in higher number of thickest trees and lower number of thinnest trees on comparative plot 2a, frequency distributions of diameter structure on control plot 1c and thinned plot 2a were not found statistically different (chi-square test) at the age of 77 years (last revision).

Static stability

At the beginning of observation, the static stability of experimental stands evaluated by h/d ratio of the mean stem and dominant trees (d_{200}) was relatively unfavourable in spite of relatively low initial density (fig. 2). The h/d ratio of the mean stem at the age of 37 years (1958) varied from 103 on plot 2a to 100 on plot 1c (tab. 1, fig. 5) and was in the phase of increment, which culminated on control plot 1c by the value of 106 at the age of 47 years (3rd revision). In the next period, the h/d ration of the mean stem on control plot was decreasing, partly as a result of mortality of trees with the highest h/d ratio.

Experimental thinning on comparative plot 2a did not stop the increasing tendency of the h/d ratio which culminated similarly as on control plot 1c at the age of 47 years with the value of 105. More pronounced decrease after culmination comparing with control plot was caused by higher diameter increment of trees after thinning.

Evaluating of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot), the initial h/d_{200} ratio on comparative plots 1c and 2a achieved values of 80 and 84. Next development of the slenderness ratio on control plot 1c showed increasing tendency with culmination at the age of 47 years with the value of 83 and following decrease continuing to the age of 77 years (last revision), when it reached the value of 73. On comparative plot 2a with positive selection from above, the h/d_{200} ratio has been decreasing since the beginning of experiment to the final value of 72 found by the last revision in 1998.

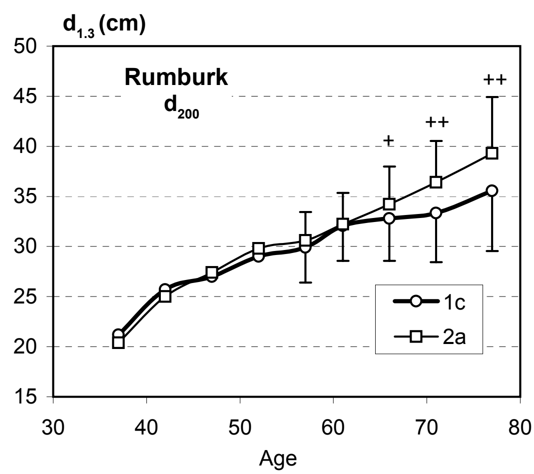


Fig. 6: Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on experimental series Rumburk in the period 1958 – 1998 (age of 37 – 77 years). Statistical analysis (t-test) – significant differences on confidence level 0.95 (+) and 0.99 (++)

Although thinning resulted in significantly higher d_{200} on the comparative plot 2a with high thinning at the age of 66, 71 and 77 years (fig. 6), h/d_{200} ratio was balanced by height increment of dominant trees and therefore the differences in h/d_{200} ratio at the age of 77 years (last revision) between control plot without thinning and plot 2a were not found statistically different.

Conclusions from the Rumburk experiment

- At the age of 37 – 47 years, the basal area of experimental Norway spruce stands was increasing on both comparative plots. On control plot 1c after that period, mortality overreached the increment and basal area per hectare sank gradually to 27.1 m^2 at the age of 71 years (1992). In the all 40-year period of investigation, totally 30.2 m^2 of basal area (107 % of increment) was removed as salvage cut (dry and broken trees) and stand basal area on control plot 1c at the age of 77 years was therefore lower by 1.9 m^2 comparing with initial value. On the other hand on comparative plot 2a with positive selection from above, the stand basal area decreased by four thinning treatments to 28.1 m^2 at the age of 52 years. Since then it has continually increased to 42.1 m^2 at the age of 77 years (1998). Periodic increment of basal area (40-year period of investigation) on this plot represented 33.9 m^2 and was by 5.6 m^2 (by 20 %) higher than on control plot and salvage cut represented only 5.1 m^2 (15 %).

- Effect of thinning by positive selection from above lasting 40 years resulted in decreased abundance of trees in lower diameter classes and increased abundance of trees in higher diameter classes comparing with control stand without thinning. Number of thin trees (diameter 20 cm and lesser) was by 39 % lower on plot 2a with thinning comparing with control plot 1c (44 trees on plot 2a and 72 trees on plot 1c). On the other hand, number of thick trees in higher diameter classes (diameter 30 cm and more) on plot 2a was by 43 % higher (264 trees on plot 2a and 184 trees on plot 1c). However, differences between frequency distributions of diameter structure on control plot 1c and thinned plot 2a were not found statistically significant.
- Development of h/d ratio of mean stem since beginning of observation was similar on both comparative plots. The reason is applied selection from above on plot 2a, i. e. removing the trees with mean dimensions and leaving of smaller trees with unfavourable static stability. Culmination of h/d ratio was observed at the age of 47 years (1c – 106, 2a – 105). Thinning resulted in more pronounced decrease of h/d ratio after culmination ending on value of 81 on plot 2a comparing with value of 86 on control plot without thinning at the age of 77 years.
- The slenderness ratio of the dominant trees h/d_{200} (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot) on control plot 1c showed increasing tendency with culmination at the age of 47 years (from initial value of 80 to value of 83) and following decrease continuing to the age of 77 years (value of 73). On comparative plot 2a with positive selection from above, the h/d_{200} ratio has been decreasing since the beginning of experiment from the initial value of 84 to the final value of 72 found by the last revision in 1998. The difference between the final values of h/d_{200} ratio on both comparative plots was not significant.

MOSTEK EXPERIMENTAL SERIES

Experimental series at Rumburk was founded in forest region 23 – the Podkrkonoší Piedmont in 1958 in 38-year old Norway spruce stand growing in Forest Management Area Hostinné (stand 627 C1 according to Forest Management Plan 1993). The co-ordinates of the series are lat. 50°29´22˝ N and long. 33°20´35˝ E. The experimental stand is located on a gentle western slope (3 – 4 %) in the 5th (fir-beech) forest vegetation zone in elevation of 530 m. Prevailing soil type is gleyic brown forest soil, ecological group acid, soil category K. The experimental stand is included into Management Unit 53 – Spruce management of acid sites in higher locations. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period of 1961 – 1990, the mean annual sum of precipitation represented 700 mm and mean annual temperature 7 °C.

The experimental series consists of three comparative plots with dimensions 50 m x 50 m, i. e. 0.25 ha each (fig. 7). Comparative plot 1c is control plot without designed thinning, where only dead, broken or uprooted trees have been removed. Comparative plots 3b and 5b are the stands with thinning by negative selection from below (3b – moderate thinning, 5b – heavy thinning). In 1998 (last revision), trees for felling were marked on plots 3b and 5b with the aim of loosing canopy and consequent observation of left trees development and natural regeneration.

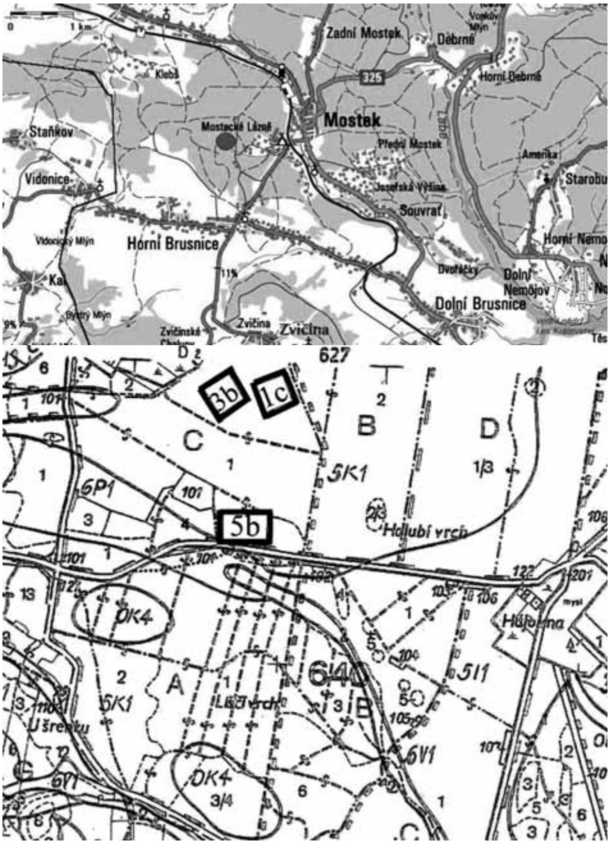


Fig. 7: Geographic location (Geobáze® 1997 – 2000) and stand map of experimental series Mostek on Forest Management Plan 1993

History of the experiment

In the period of foundation of the Mostek series in 1958, the experimental stand was 38-year old Norway spruce monoculture with the density of 2,072 – 2,404 trees per hectare. With respect to the initial deep diameter differentiation (tree diameters before the first experimental thinning differentiated from 3 to 25 cm), it was supposed, that the experimental stand originated by natural regeneration or by planting restocked by self-seeding and it was not thinned before the first experimental treatment.

On the basis of the initial evaluation of the main stand characteristics, all three partial comparative plots 1c, 3b and 5b were stated comparable. Especially plots 1c and 3b were nearly identical. Initial diameter of the mean stem (d) on these partial plots achieved 12.4 and 12.7 cm, diameter d_{200} (mean diameter of 200 thickest trees per hectare) 19.0 and 18.6 cm respectively. The stand on comparative plot 5b differed from previous two stands by lower number of trees especially in mean diameter classes. The total number of trees per hectare on plot 5b achieved 2,072, i. e. by 330 less than in the control stand 1c. The initial mean diameter 13.1 cm was not found statistically distinct and differences in mean height (12.8 m, 13.5 m and 13.6 m in stands 1c, 3b and 5b respectively) were accepted (tab. 3, fig. 8). Additional evaluation of d_{200} showed, that dominant trees on plot 5b have differed significantly since the beginning of observation (fig. 12) probably as a result of previous undocumented thinning.

Number of trees and basal area

By the first experimental thinning at the age of 38 years, 23 % trees (N) representing 9 % of basal area (G) were removed by negative selection from below in the stand of the comparative plot 3b and 35 % N and 13 % G in the stand of comparative plot 5b.

Treatments with negative selection from below repeated three times in five-year periods to the age of 53 years (1973) removing 18, 27 and 27 % N (7, 20 and 17 % G) on comparative plot 3b and 24, 31 and 27 % N (9, 20 and 15 % G) on comparative plot 5b. Position of the treatments in the diameter structure of experimental stands is apparent from figure 9.

Tab. 3: Basic data on Mostek experimental series

Mostek		1958				1963				1968				1973				1978	1998	I 38-78	I 38-78-SC	SC 38-78
		38 years				43 years				48 years				53 years				58 years	78 years			
		before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	after thinning			
1c	N	2404	212	9	2192	2192	304	14	1888	1888	564	30	1324	1324	272	21	1052	1052	592	*	*	1812
3b	($trees.ha^{-1}$)	2388	540	23	1848	1848	328	18	1520	1520	412	27	1108	1108	300	27	808	808	656	*	*	152
5b		2072	736	35	1336	1336	320	24	1016	1016	316	31	700	700	188	27	512	512	468	*	*	44
1c	G	29.1	1.2	4	27.9	33.2	1.6	5	31.6	36.2	6.8	19	29.3	34.8	3.4	10	31.5	35.8	43.8	37.9	14.7	23.1
3b	($m^2.ha^{-1}$)	30.2	2.7	9	27.4	32.9	2.4	7	30.6	34.4	6.8	20	27.6	32.4	5.4	17	27.0	31.5	43.6	35.0	30.8	4.2
5b		27.9	3.6	13	24.2	30.0	2.6	9	27.4	32.0	6.3	20	25.7	30.8	4.6	15	26.2	30.3	44.0	35.3	33.2	2.1
1c	d	12.4	8.4	*	12.7	13.9	8.3	*	14.6	15.6	12.4	*	16.8	18.3	12.6	*	19.5	20.8	30.7	10.4	*	*
3b	(cm)	12.7	8.0	*	13.8	15.1	9.6	*	16.0	17.0	14.6	*	17.8	19.3	15.2	*	20.6	22.3	29.1	11.0	*	*
5b		13.1	7.9	*	15.2	16.9	10.2	*	18.5	20.0	16.0	*	21.6	23.7	17.2	*	25.5	27.4	34.6	13.9	*	*
1c	h	12.8	9.9	*	13.0	15.1	10.1	*	15.6	17.1	14.9	*	17.9	19.3	15.2	*	20.0	21.8	28.9	11.8	*	*
3b	(m)	13.5	9.5	*	14,3	16.6	12.0	*	17.3	18.3	16.7	*	18.8	20.8	18.1	*	21.5	23.0	28.4	11.8	*	*
5b		13.6	9.3	*	15.0	17.1	12.1	*	18.0	19.6	17.2	*	20.4	22.1	19.0	*	22.8	24.6	29.5	11.9	*	*
1c		103	118	*	102	109	122	*	107	109	120	*	107	105	121	*	102	105	94	*	*	*
3b	h/d	106	118	*	104	110	126	*	108	108	115	*	106	108	119	*	104	103	98	*	*	*
5b		104	118	*	99	101	119	*	97	98	108	*	94	93	108	*	89	90	85	*	*	*
1c	d_{200}	19.0	*	*	*	21.2	*	*	*	23.2	*	*	*	26.1	*	*	*	28.2	36.9	17.9	*	*
3b	(cm)	18.6	*	*	*	20.8	*	*	*	22.6	*	*	*	25.2	*	*	*	27.2	35.0	16.4	*	*
5b		21.9	*	*	*	24.3	*	*	*	26.8	*	*	*	29.9	*	*	*	32.0	40.6	18.7	*	*
1c	h_{200}	16.0	*	*	*	19.5	*	*	*	21.0	*	*	*	23.1	*	*	*	25.1	31.3	15.3	*	*
3b	(m)	17.1	*	*	*	20.0	*	*	*	21.3	*	*	*	23.6	*	*	*	25.4	30.9	13.8	*	*
5b		18.3	*	*	*	20.6	*	*	*	22.6	*	*	*	24.2	*	*	*	26.0	31.4	13.1	*	*
1c		84	*	*	*	92	*	*	*	91	*	*	*	89	*	*	*	89	85	*	*	*
3b	h/d_{200}	92	*	*	*	96	*	*	*	94	*	*	*	94	*	*	*	93	88	*	*	*
5b		84	*	*	*	85	*	*	*	84	*	*	*	81	*	*	*	81	77	*	*	*

Notes: 1c – control plot without thinning, 3b, 5b – comparative plot with thinning from below, N – number of trees, G – basal area, d – breast height diameter, h – mean height, h/d - ratio of slenderness, d_{200} – diameter of 200 thickest trees, h_{200} – height of 200 thickest trees, h/d_{200} – ratio of slenderness of 200 thickest trees, T – thinning, I – increment, SC – salvage cut

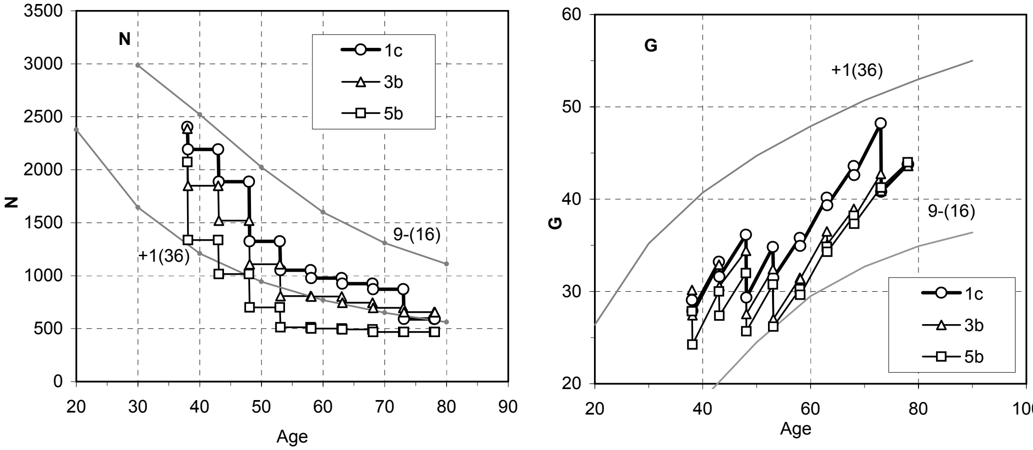


Fig. 8: Number of trees (pc.ha^{-1}) and basal area (G – m^2.ha^{-1}) on comparative plots of Mostek experimental series at the age of 38 – 78 years comparing with Growth tables (Černý, Pařez, Malík 1996)

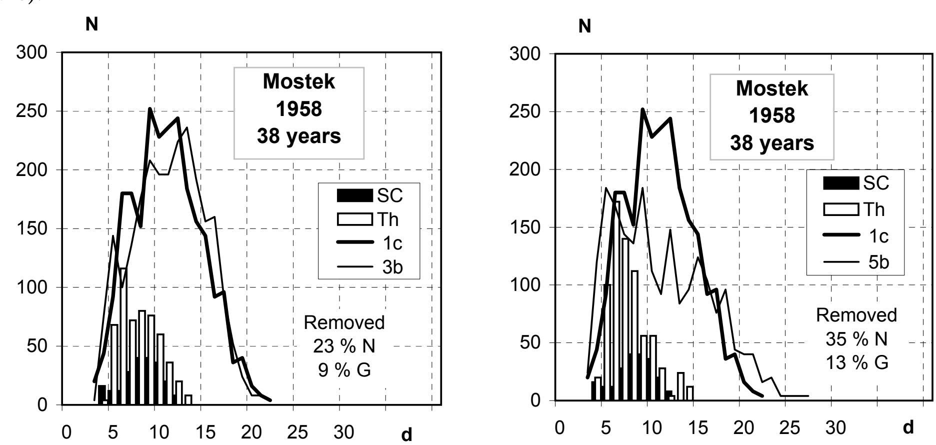
After four treatments in five-year periods, i. e. 20 years after the beginning of the observation (1978, age 58 years), number of trees per hectare decreased on:

- control plot 1c to 1,052 individuals (mortality 1,352 individuals),
- comparative plot 3b to 808 individuals (1,580 individuals removed by thinning),
- comparative plot 5b to 512 individuals (1,560 individuals removed by thinning).

Basal area (G) per hectare achieved at the same time on:

- control plot 1c – 35.8 m^2 (increased by 7.9 m^2),
- comparative plot 3b – 31.5 m^2 (increased by 4.1 m^2),
- comparative plot 5b – 30.3 m^2 (increased by 6.1 m^2).

Periodic increment of the basal area (at the age of 38 – 58 years) represented together with basal area of intentionally removed trees by thinning on comparative plots 3b and 5b – 18.7 and 19.6 m^2 and it was by more than 10 m^2 higher than usable basal area increment on control plot 1c without thinning where 11.8 m^2 of increment represented mostly unmarketable waste (dry trees and breaks).



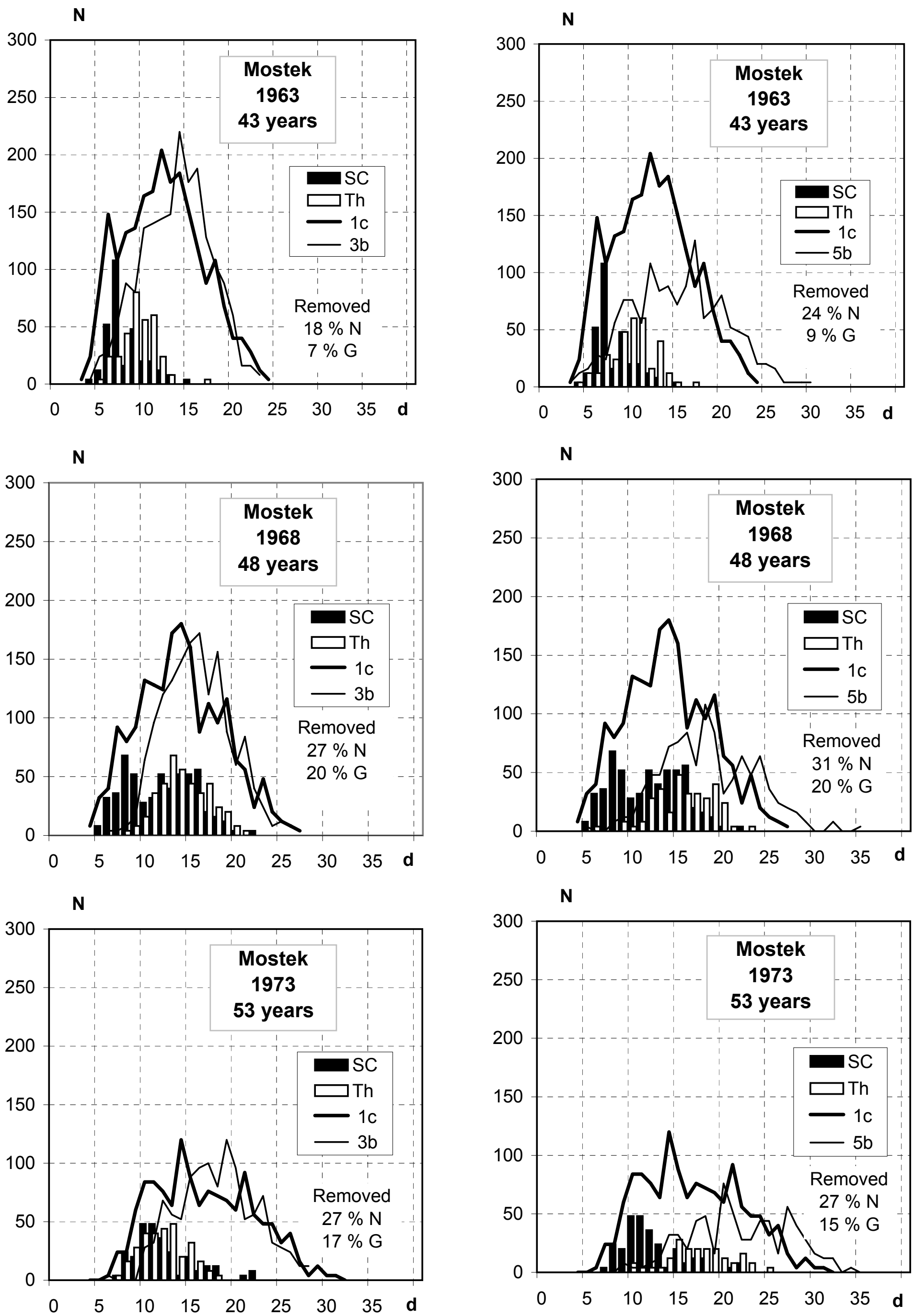


Fig. 9: Diameter structure and experimental thinning on comparative plot 3b (moderate low thinning – left) and on comparative plot 5b (heavy low thinning – right) comparing with mortality on control plot 1c without thinning on Mostek experimental series at the age of 38 – 53 years (d – diameter in cm, N – number of trees per hectare, SC – salvage cut, Th – thinning)

Since the last experimental thinning at the age of 53 years (1973), all three comparative stands of the experimental series have developed without intended thinning. All treatments consisted in removing of died dry and incidentally broken and uprooted trees. Number of trees per hectare to the last revision in 1998 (age 78 years) spontaneously decreased on:

- plot 1c to 592 individuals (mortality at the age of 38 – 78 years 1,812 individuals),
- plot 3b to 656 individuals (mortality at the age of 58 – 78 years 152 individuals),
- plot 5b to 468 individuals (mortality at the age of 58 – 78 years 44 individuals).

Basal area G at the age of 78 years, i. e. 40 years after the beginning of the experiment achieved on all comparative plots nearly 44 m^2 per hectare (tab. 3, fig. 8). During the period of investigation (age of 38 - 78 years) increased:

- on plot 1c by 14.7 m^2,
- on plot 3b by 13.4 m^2,
- on plot 5b by 16.1 m^2.

After including the basal area of all removed trees (i. e. including salvage cut), the period basal area increment on thinned plots represented 35 m^2. The period basal area increment on control plot 1c was higher - 38 m^2, but more than 23 m^2 of the increment (60 %) had to be removed during the period of investigation as salvage cut (breaks, dry trees, etc.), whereas salvage cut on thinned plots 3b and 5b represented only 4.2 and 2.1 m^2 (i. e. 12 % and 6 % of increment).

When including basal area only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigation (age of 38 – 78 years) achieved on:

- on plot 1c - 14.7 m^2,
- on plot 3b – 30.8 m^2,
- on plot 5b – 33.2 m^2.

Diameter structure

Effect of thinning on diameter structure was investigated at the age of 38 – 53 years in five-year periods always to the date of experimental treatment. Diameter structure was evaluated four times for the age of 38, 43, 48 and 53 years, i. e. in the period of active treatment. The 5th final evaluation was made on the data received by the last revision at the age of 78 years (1998).

Distribution of trees in diameter classes before thinning is exhibited by lines; thinned trees are shown by white column and mortality on control plot 1c by black column. From the figure 9 it is apparent, that the diameter structure on comparative plots 1c and 3b before the beginning of the experiment at the age of 38 years (1958) was statistically identical. Frequency distribution of diameter structure on thinned plot 5b was found significantly different (chi-square test) from control plot 1c and thinned plot 3b.

The stand on comparative plot 5b differed from previous two stands by lower incidence of trees in diameter classes 9 – 15 cm (less by 40 %) and higher incidence of trees in diameter classes 18 – 24 cm (by more than 74 %). From the position of the particular treatments it is visible, that thinned trees on plots 3b and 5b belonged to higher diameter classes comparing to natural mortality on control plot 1c. Displacement of thinning into higher diameter classes comparing to natural mortality is apparent especially in the 2nd, 3rd and 4th thinning at the age of 43, 48 and 53 years.

At the age of 78 years (last revision), the diameter of the trees in experimental stands varied from 15 to 54 cm (fig. 10). The lowest diameter classes 15 – 29 cm with the higher and the most unfavourable h/d ratio (92 – 126) were the most abundant on comparative plots 1c and 3b (276 and 372 individuals per hectare respectively comparing with 136 individuals on comparative plot 5b with heavy thinning by negative selection from below).

Abundance of trees with diameter 30 cm and more with favourable h/d ratio (96 – 57) was on all comparative plots 1c, 3b and 5b nearly the same (316, 284, 332 respectively). The differences between comparing thinning regimes appeared only in abundance of trees with diameter 40 cm and more only in case of heavy low thinning (plot 5b). On control plot 1c and on plot with moderate low thinning 3b, the number of these thickest trees represented 36 and 16, whereas on plot 5b with heavy low thinning 112 (more than threefold higher comparing with control plot). Thinning effect on frequency distributions of diameter structure on plot 3b with moderate low thinning at the age of 78 years was not found statistically significant as well as on comparative plot 5b with heavy low thinning.

Static stability

At the beginning of observation, the static stability of experimental stands evaluated by h/d ratio of the mean stem and upper tree layer (d_{200}) was relatively unfavourable in spite of relatively low initial density (fig. 2). The h/d ratio of the mean stem at the age of 38 years (1958) varied from 103 on plot 1c to 106 on plot 3b (tab. 3, fig. 11) and was in the phase of increment culminating on control plot 1c by the value of 109 at the age of 43 years (2nd revision) and on plot 3b with the value of 108 at the age of 48 years (3rd revision).

Next development of h/d ratio on control plot 1c and plot 3b with moderate low thinning was nearly identical with decreasing tendency, and at the age of 78 years (last revision) it achieved the values of 94 and 98 respectively. The more pronounced descent of the ratio on control plot 1c was caused by increased mortality at the age of 68 – 78 years, when more than 32 % of trees (mostly dry and broken) with very disadvantageous static attributes had to be removed.

The volume of h/d ratio of mean stem on comparative plot 5b was different and showed decreasing tendency from the beginning of observation, mainly as a result of heavy low thinning at the age of 38, 43, 48 and 53 years removing nearly all thin unstable individuals. Applied heavy low thinning resulted in acceleration of diameter increase of left trees and consequently in very favourable low h/d ratio (value of 85 at the age of 78 years). Initially the same mean diameter on plot 5b was higher by 3 cm at the age of 43 years, by 4.5 cm at the age of 48 years, by 5.3 at in the age of 53 years and by 6.6 cm at the age of 58 years comparing to mean diameter on control plot 1c.

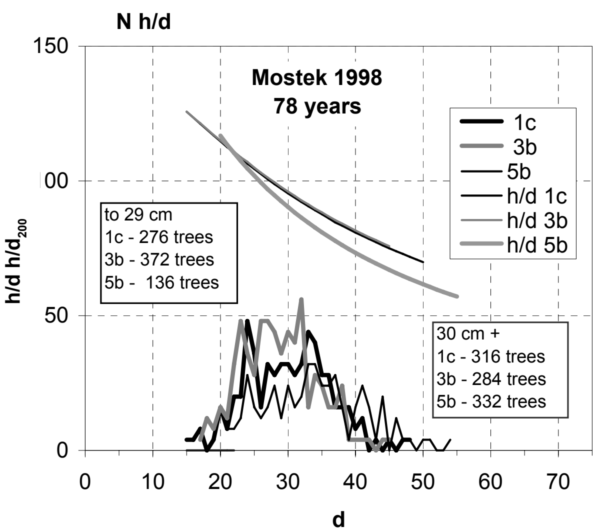


Fig. 10: Diameter structure and h/d ratio for diameter degrees on Mostek experimental series at the age of 78 years - last revision (d – diameter in cm, N – number of trees per hectare)

Evaluating of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot), the initial h/d_{200} ratio on comparative plots 1c and 5b achieved the same value of 84 and on plot 3b the value of 92. Next development of the slenderness ratio on control plot 1c showed increasing tendency with culmination at the age of 43 years with the values of 92, 96 and 85 on plots 1c, 3b and 5b respectively. Following decrease continued to the age of 78 years (last revision), when h/d ratio on plot with moderate low thinning 3b reached the value of 88, which was significantly higher than value of 85 on control plot 1. Positive effect of thinning on static stability of dominant trees was recognized only in case of heavy low thinning investigated on plot 5b where the final h/d ratio of dominant trees was the lowest (77) and significantly different from other two comparative variants (1c and 3b). Development of h/d_{200} ratio depended on d_{200}, which was at the age 38 – 78 years significantly higher on comparative plot 5b and significantly lower on plot 3b comparing to control plot 1c without thinning (fig. 12). So, positive effect of thinning on static stability of dominant trees consisted in lower height increment and higher diameter increment after very heavy thinning from below on comparative plot 5b comparing to control plot 1c without thinning.

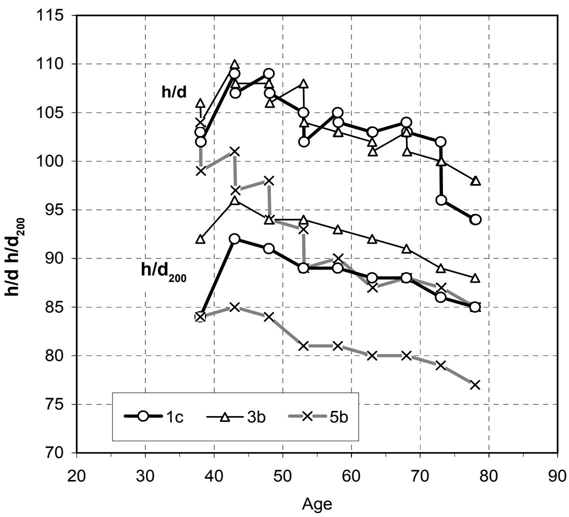


Fig. 11: Development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Mostek experimental series at the age of 38 – 78 years

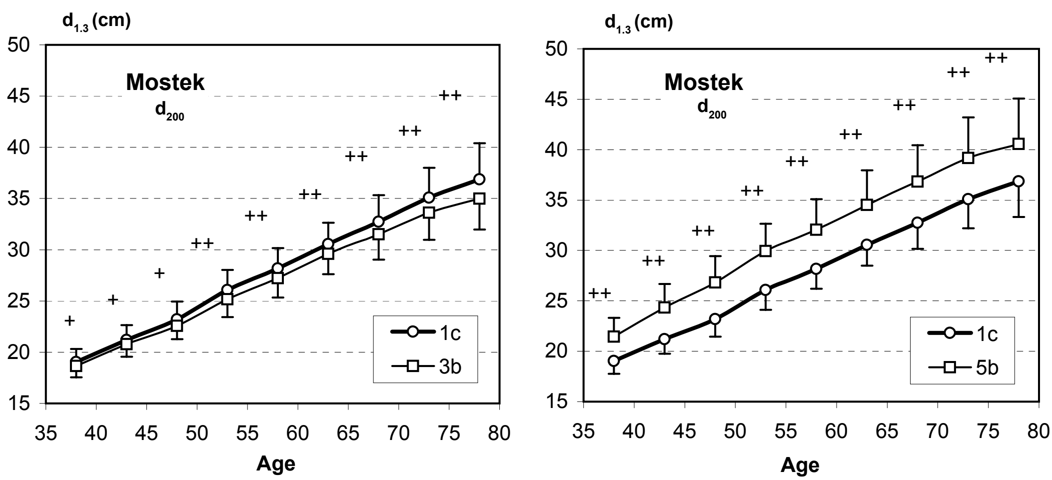


Fig. 12: Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on experimental series (1c/3b – left, 1c/5b – right) Mostek in the period 1958 – 1998 (age of 38 – 78 years). Statistical analysis (t-test) - significant differences on confidence level 0.95 (+) and 0.99 (++)

Conclusions from the Mostek experiment

- In the period of investigation (age of 38 – 78 years), the basal area increased on control plot 1c without thinning by 38 m^2. Of this amount more than 23 m^2 (60 %) represented dry and broken trees (salvage cut). On comparative plots 3b (moderate low thinning) and 5b (heavy low thinning), the stand basal area increased by 35 m^2 and salvage cut on these plots represented only 4.2 and 2.1 m^2 (i. e. 12 % and 6 % of increment).
- Effect of thinning on diameter structure by negative selection from below lasting 40 years was apparent only on comparative plot 5b with heavy low thinning, where the abundance of thickest trees with diameter 40 cm and more represented more than 300 % of control plot (112 individuals comparing with 36 and 16 individuals on plot 1c and 3b). At the same time, the abundance of small-sized individuals (diameter classes 15 – 29 cm) was on plot 5b twice lower comparing to control plot 1c and thrice lower comparing to plot 3b (136 on plot 5b, 276 and 372 on plots 1c and 3b). But, differences between variants in frequency distributions of diameter structure were not found statistically significant.
- Static stability characterized by h/d ratio of mean stem was influenced by thinning only on comparative plot 5b with heavy low thinning. The volume of h/d ratio of mean stem was decreasing after culmination as a result of removing mostly thin unstable individuals on all comparative plots. Applied heavy low thinning on plot 5b resulted in acceleration of diameter increase of left trees and consequently in very favourable low h/d ratio (value of 85 at the age of 78 years).
- The static stability of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot) stem was significantly influenced by thinning only in case of heavy low thinning on comparative plot 5b. The increase of h/d_{200} ratio on this plot reduced after the first thinning and after culmination at the age of 43 years with the values of 85 continually decreased to the significantly different value of 77 at the age of 78 years (last revision). The h/d_{200} ratio on comparative plots 1c and 3b culminated at the age of 43 years with the values of 92, 96 and decreased to the last revision to the value of 85 and 88 (difference insignificant).

VIMPERK I EXPERIMENTAL SERIES

Experimental series at Vimperk (I) was founded in forest region 13 – the Šumava Mts. in 1958 in 32-year old Norway spruce stand growing in Forest Management Area Vimperk (stand 413 C5 according to Forest Management Plan 1997). The co-ordinates of the series are lat. 49°03´11˝ N and long. 31°21´53˝ E. The experimental stand is located on a moderate western slope (7 %) in the 6th (spruce-beech) forest vegetation zone in elevation of 1,020 m. Prevailing soil type is brown forest soil, ecological group acid, soil category K. The experimental stand is included into Management Unit 53 – Spruce management of acid sites in higher locations. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period of 1961 – 1990, the mean annual sum of precipitation represented 1,000 mm and mean annual temperature 4 ˚C.

The experimental series consists of two comparative plots with dimensions 50 m x 50 m, i. e. 0.25 ha each (fig. 13). Comparative plot 1c is control plot without designed thinning, where only dead, broken or uprooted trees have been removed. Comparative plot 3b is the stand with thinning by negative selection from below. In 1999 (last revision), trees for felling were marked on plot 3b with the aim of loosing canopy and consequent observation of left trees development and natural regeneration.

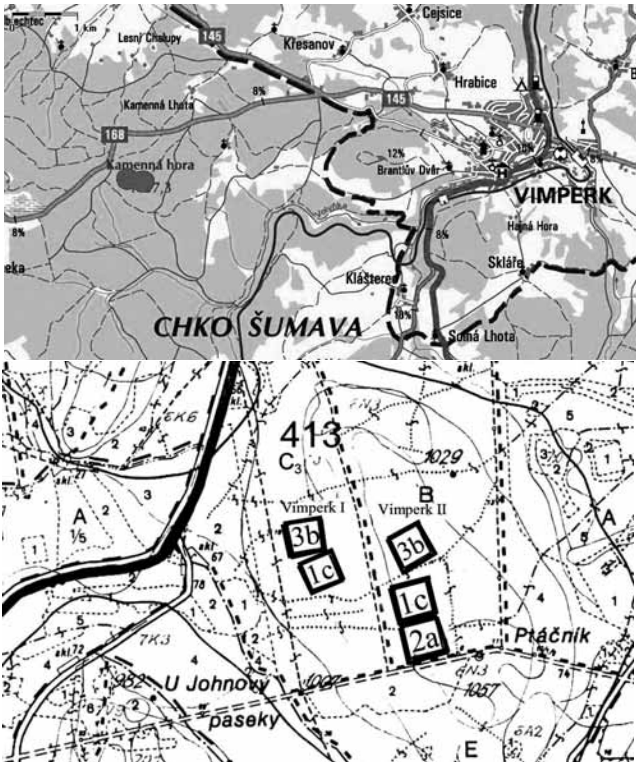


Fig. 13: Geographic location (Geobáze® 1997 – 2000) and stand map of experimental series Vimperk I on Forest Management Plan 1997

History of the experiment

In the period of foundation of the Vimperk I series in 1958, the experimental stand was 32-year old Norway spruce monoculture with the density of 4,332 – 4,632 trees per hectare originated artificially by planting in regular spacing ca 1.25 – 1.5 m (i. e. 5,000 – 6,000 trees per hectare) in the period of 1920 – 1930 clearcut. The experimental stand was not thinned before the first experimental treatment and, subsequently, it was distinctly differentiated (diameter breast height varied from 3 to 23 cm, fig. 15).

Initial diameter of the mean stem (d) on both partial plots 1c and 3b achieved 10.6 and 11.0 cm and also the differences in mean and top height (h 10.4 and 10.5 m and h_{200} 13.8 and 14.4 m) were minimal. On the basis of the initial evaluation of the main stand characteristics (N, G, d, h, h_{200}, d_{200}), both partial plots 1c and 3b were stated comparable (tab. 4, fig. 14). Additional evaluation of d_{200} (mean diameter of 200 thickest trees per hectare) showed, that dominant trees on plot 3b have differed significantly since the beginning of observation (fig. 18)

Number of trees and basal area

By the first experimental thinning on the comparative plot 3b at the age of 32 years, 25 % trees (N) representing 11 % of basal area (G) were removed by negative selection from below. Treatments repeated three times in five-year periods to the age of 46 years (1972) removing 14, 26 and 32 % N (5, 13 and 20 % G). Position of the treatments in the diameter structure of experimental stands is apparent from figure 15.

After four treatments in five-year periods, i. e. 20 years after the beginning of the observation (1978, age 52 years), number of trees per hectare decreased on:

- control plot 1c to 2,620 individuals (mortality 2,012 individuals),
- comparative plot 3b to 1,396 individuals (2,936 individuals removed by thinning).

Basal area (G) per hectare achieved at the same time on:

- control plot 1c – 57.5 m^2 (increased by 16.8 m^2),
- comparative plot 3b – 42.4 m^2 (increased by 1.7 m^2).

Tab. 4: Basic data on Vimperk I experimental series

Vimperk I		1958				1963				1968				1972				1978	1998	I 32-73	I 32-73-SC	SC 32-73
		32 years				37 years				42 years				46 years				52 years	73 years			
		before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	after thinning			
1c	N	4632	476	10	4156	4156	520	13	3636	3636	444	12	3192	3192	572	18	2620	2620	1248	*	*	3384
3b	(trees.ha^{-1})	4332	1104	25	3228	3228	440	14	2788	2788	724	26	2064	2064	668	32	1396	1396	928	*	*	468
1c	G	40.7	1.9	5	38.9	46.7	1.5	3	45.2	51.6	2.5	5	49.2	56.5	4.3	8	52.2	57.5	63.4	56.6	22.7	34.0
3b	(m^2.ha^{-1})	40.7	4.5	11	36.3	43.5	2.1	5	41.4	46.9	6.3	13	40.6	46.6	9.5	20	37.1	42.4	54.7	47.0	36.0	11.0
1k	d	10.6	7.0	*	10.9	12.0	6.1	*	12.6	13.5	8.4	*	14.0	15.0	9.8	*	15.9	16.6	25.4	9.4	*	*
3p	(cm)	11.0	7.2	*	12.0	13.1	7.8	*	13.8	14.6	10.5	*	15.8	17.0	13.4	*	18.4	19.6	27.4	11.9	*	*
1c	h	10.4	7.8	*	10.2	12.5	7.8	*	12.8	13.6	9.8	*	13.9	15.8	11.8	*	16.3	17.8	24.2	11.2	*	*
3b	(m)	10.5	7.5	*	11.1	13.3	9.1	*	13.7	14.3	11.5	*	15.0	17.4	15.3	*	18.2	19.8	25.6	12.5	*	*
1c	h/d	98	111	*	98	104	128	*	102	101	116	*	99	105	121	*	102	106	95	13	*	*
3b		96	104	*	93	102	117	*	99	98	109	*	95	103	114	*	99	101	94	7	*	*
1c	d_{200}	17.1	*	*	*	19.3	*	*	*	21	*	*	*	23.3	*	*	*	24.6	33.5	16.4	*	*
3b	(cm)	18.3	*	*	*	20.5	*	*	*	22.3	*	*	*	24.3	*	*	*	25.8	34.4	16.1	*	*
1k	h_{200}	13.8	*	*	*	15.8	*	*	*	17.3	*	*	*	19.7	*	*	*	21.7	27.3	13.5	*	*
3p	(m)	14.4	*	*	*	16.8	*	*	*	17.9	*	*	*	20.7	*	*	*	22.4	28.1	13.6	*	*
1c	h/d_{200}	81	*	*	*	82	*	*	*	82	*	*	*	85	*	*	*	87	82	1	*	*
3p		79	*	*	*	82	*	*	*	80	*	*	*	85	*	*	*	87	82	3	*	*

Notes: 1c – control plot without thinning, 3b – comparative plot with thinning from below, N – number of trees, G – basal area, d – breast height diameter, h – mean height, h/d - ratio of slenderness, d_{200} – diameter of 200 thickest trees, h_{200} – height of 200 thickest trees, h/d_{200} – ratio of slenderness of 200 thickest trees, T – thinning, I – increment, SC – salvage cut

Periodic increment of the basal area (at the age of 32 – 52 years) together with basal area of intentionally removed trees by thinning represented on comparative plot 3b – 24.1 m² and it was by 7 m² higher than on control plot 1c without thinning.

Since the last experimental thinning at the age of 46 years (1972), both comparative stands of the Vimperk I experimental series have developed without designed thinning. The treatment consists in removing of died dry and incidentally broken and uprooted trees. Number of trees per hectare to the last revision in 1999 (age 73 years) spontaneously decreased on:

- plot 1c to 1,248 individuals (mortality at the age of 32 – 73 years 3,384 trees),
- plot 3b to 928 individuals (mortality at the age of 52 – 73 years 468 trees).

Basal area at the age of 73 years, i. e. 41 years after the beginning of the experiment (last revision), achieved higher level on control plot 1c (63.4 m²) and was by 9 m² higher than on comparative plot 3b with low thinning (54.7 m²).

After including the basal area of all removed trees (i. e. including salvage cut), the basal area increment in the period of investigation was by 9.6 m² higher on control plot 1c comparing with comparative plot 3b with negative selection from below (56.6 m² on control plot 1c and 47.0 m² on plot 3b). But on control plot 1c, 34.0 m² of basal area (60 % of basal area increment) had to be removed during the period of investigation as salvage cut (breaks, dry trees, etc.), whereas salvage cut on thinned plot 3b represented only 11 m² (i. e. 23 % of basal area increment).

When including basal area only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigation (age of 32 – 73 years) achieved on:

- control plot 1c – 22.6 m²,
- comparative plot 3b – 36.0 m².

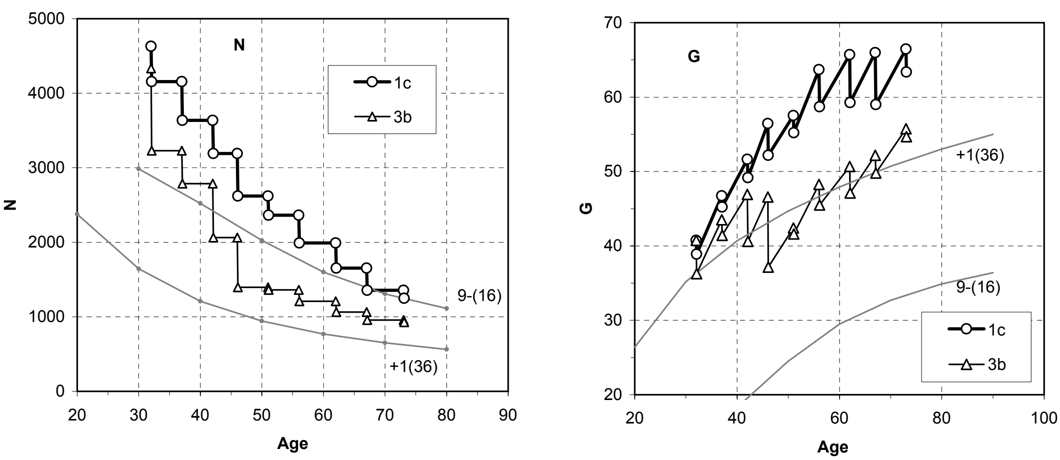


Fig. 14: Number of trees (N - pc.ha^{-1}) and basal area (G – m^2.ha^{-1}) on comparative plots of Vimperk I experimental series at the age of 32 – 73 years comparing with Growth tables (Černý, Pařez, Malík 1996) (1c - control plot, 3b – thinning from below)

Diameter structure

Effect of thinning on diameter structure was investigated at the age of 32 – 46 years, in five-year period always to the date of experimental treatment. Diameter structure was evaluated four times for the age of 32, 37, 42 and 46 years, i. e. in the period of active treatment. The 5th final evaluation was made on the data received by the last revision at the age of 73 years (1999).

Distribution of trees in diameter classes before thinning is exhibited by lines, thinned trees are shown by white column and mortality on control plot 1c by black column. From the figure 15 it is apparent, that the diameter structure on both comparative plots before the beginning of the experiment at the age of 32 years (1958) was nearly identical, especially in upper and lower part of structure. Some differences (significance confirmed by chi-square test) consisted in higher incidence of trees in diameter classes 10 – 13 cm (by 17 %) on control plot 1c.

From the position of the particular treatments it is visible, that all four thinnings on comparative plot 3b were made by negative selection from below. Displacement of thinning into higher diameter classes comparing to natural mortality is apparent in all four treatments.

At the age of 73 years (last revision), the diameter of the trees in experimental stands varied from 12 to 41 cm (fig. 16). The lowest diameter classes 12 – 20 cm with the higher and the most unfavourable h/d ratio (110 – 130) were the most abundant on control plot 1c (400 individuals per hectare comparing with 124 individuals per hectare on comparative plot 3b with negative selection from below). On the other hand, abundance of trees with diameter 30 cm and more and with favourable h/d ratio (90 – 75) on thinned plot 3b represented 107 % of control plot 1c (300 individuals comparing with 280 individuals per hectare on control plot 1c). Differences in frequency distributions of diameter structure were found significant.

Static stability

At the beginning of observation, the static stability of experimental stands evaluated by h/d ratio of the mean stem and dominant trees (d_{200}) was relatively unfavourable in spite of relatively low initial density (fig. 14). The h/d ratio of the mean stem at the age of 32 years (1958) was on both comparative plots 1c and 3b similar and varied from 98 to 96 (tab. 4, fig. 17) and culminated on control plot 1c by the value of 106 at the age of 52 years (4th revision). In the next period, the h/d ration of the mean stem on control plot was decreasing, partly as a result of mortality of trees with the highest h/d ratio.

Experimental thinning on comparative plot 3b did not stop the increasing tendency of the h/d ratio which culminated at the age of 47 years with the value of 103. Decrease of h/d ratio after culmination was on both comparative plot similar and at the age of 73 years, the ratio reached the value 95 (1c) and 94 (3b). Relatively rapid descend of slenderness quotient of mean stem on control plot 1c was caused mostly by increased natural mortality at the age of 52 – 73 years, when 1,372 trees (52 %) had to be removed in salvage cuts (dry and broken individuals with unfavourable static attributes). The salvage cuts on comparative plot 3b with low thinning represented in the same time only 464 individuals (33 %).

Evaluating of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot), the initial h/d_{200} ratio on comparative plots 1c and 3b achieved values of 81 and 79. Next development of the slenderness ratio on both comparative plots showed increasing tendency with culmination at the age of 52 years with the value of 87 and following decrease continuing to the age of 73 years (last revision), when it reached the same value of 82 on both variants.

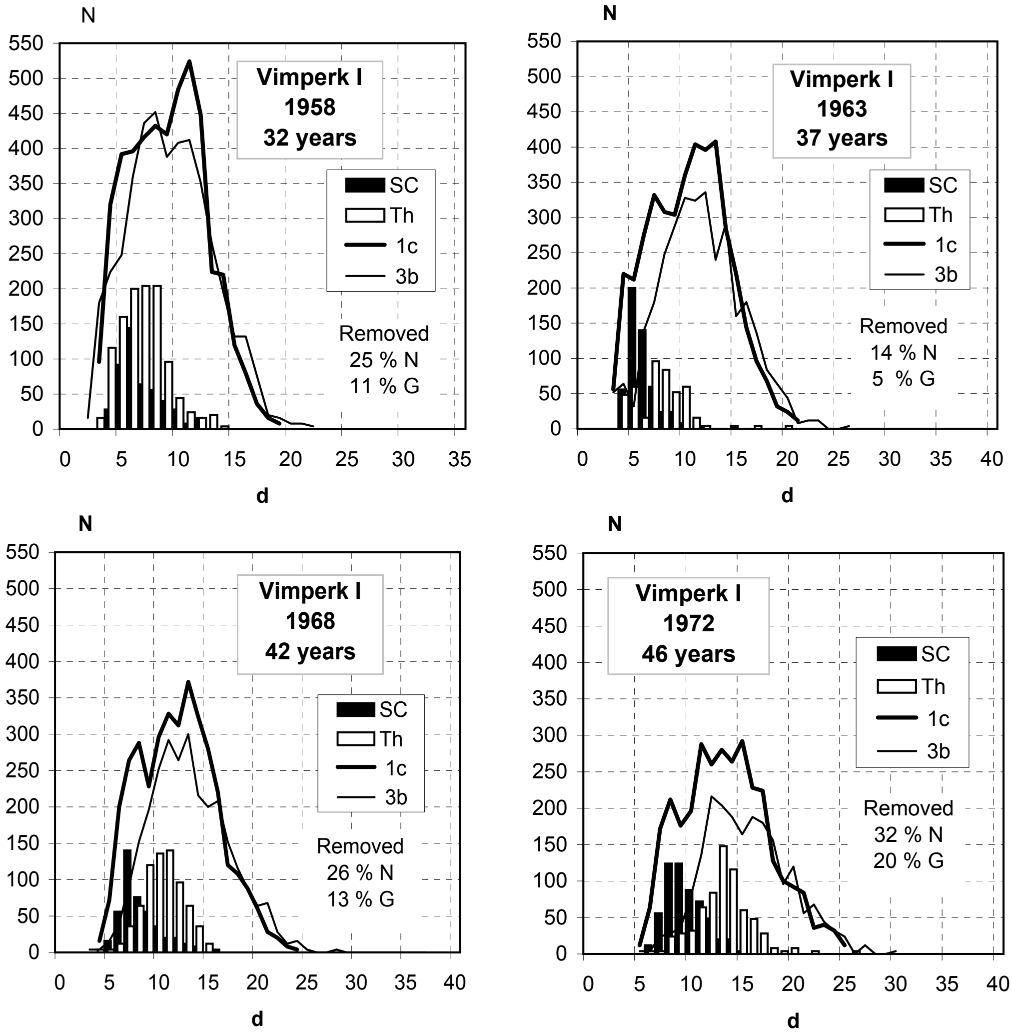


Fig. 15: Diameter structure and experimental thinnings 3b (thinning from below) comparing with mortality on control plot 1c without thinning on Vimperk I experimental series at the age of 32 – 46 years (d – diameter in cm, N – number of trees per hectare, SC – salvage cut, Th – thinning)

Because of the similar development of d_{200} (significantly higher on the comparative plot 3b with low thinning in all observed periods, (fig. 18), the differences in h/d_{200} ratio at the age of 73 years (last revision) between control plot without thinning and plot 3b was not found statistically different.

Conclusions from the Vimperk I experiment

- In the period of investigation (age of 32 – 73 years), the basal area of experimental Norway spruce stands of Vimperk I series was above the Growth tables values for the best site index +1 (36). During 41 years of observation, the stand basal area increased on control plot 1c by

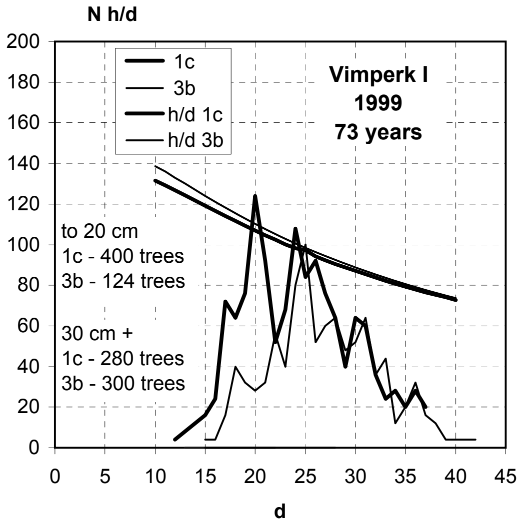


Fig. 16: Diameter structure and h/d ratio for diameter degrees on Vimperk I experimental series at the age of 73 years - last revision (d – diameter in cm, N – number of trees per hectare)

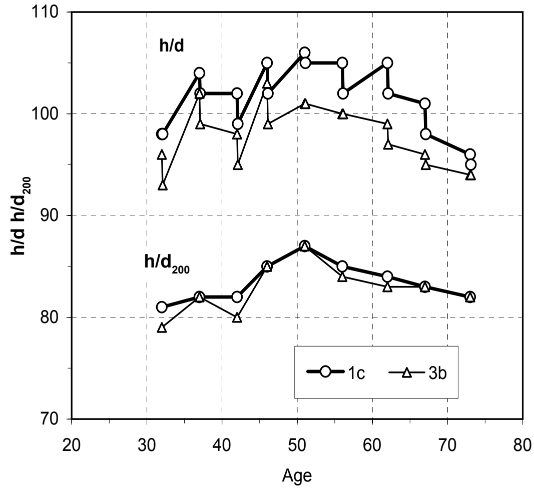


Fig. 17: Development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Vimperk I experimental series at the age of 32 – 73 years (1c – control plot, 3b – thinning from below)

56.6 m^2, but 34.0 m^2 of this amount (60 %) had to be removed as salvage cut (breaks, dry trees, etc.). At the same time, on comparative plot 3b with low thinning basal area increment represented 47.0 m^2 and salvage cut reached only 11 m^2 (23 % of basal area increment). After including the basal area of all removed trees (i. e. including salvage cut), increment in the period of investigation was by 9.6 m^2 higher on control plot 1c, but when including only basal area intentionally removed trees (salvage cut excluded), the periodic increment was by 13.4 m^2 higher on comparative plot 3b.

- Effect of thinning by negative selection from below lasting 41 years resulted in decreased abundance of trees in lower diameter classes and increased abundance of trees in higher diameter classes on plot 3b comparing with control stand 1c without thinning. Number of thin trees (diameter 20 cm and lesser) was by 69 % lower on plot 3b with thinning comparing with control plot 1c (124 trees on plot 3b and 400 trees on plot 1c). On the other hand, number of

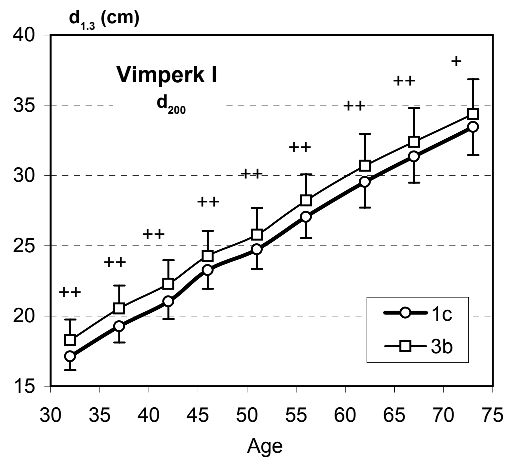


Fig. 18: Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on experimental series Vimperk I in the period 1958 – 1999 (age of 32 – 73 years). Statistical analysis (t-test) - significant differences on confidence level 0.95 (+) and 0.99 (++)

thick trees in higher diameter classes (diameter 30 cm and more) on plot 3b was by 7 % higher (300 trees on plot 3b and 280 trees on plot 1c). Especially difference in number of thin trees resulted in significant differences in frequency distributions of diameter structure on control plot 1c and thinned plot 3b at the age of 73 years.

- Static stability of experimental stands of Vimperk I experimental series assessed by development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot) was not influenced by thinning. Lower values of h/d ratio of mean stem on comparative plot 3b with thinning from below comparing to control plot was caused mainly by calculation shifts after removing thin and unstable individuals. At the age of 73 years (last revision), h/d ratio of mean stem reached nearly the same values 95 and 94 and h/d ratio of dominant trees the same value of 82 on both unthinned and thinned plots.

VIMPERK II EXPERIMENTAL SERIES

Experimental series at Vimperk (II) was founded in forest region 13 – the Šumava Mts. in 1958 in 51-year old Norway spruce stand growing in Forest Management Area Vimperk (stand 413 B1 according to Forest Management Plan 1997). The co-ordinates of the series are lat. 49°03´11˝ N and long. 31°22´03˝ E. The experimental stand is located on a moderate western slope (11 %) in the 6th (spruce-beech) forest vegetation zone in elevation of 1,045 m. Prevailing soil type is brown forest soil, ecological group acid, soil category K. The experimental stand is included into Management Unit 53 – Spruce management of acid sites in higher locations. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period of 1961 – 1990, the mean annual sum of precipitation represented 1,000 mm and mean annual temperature 4 °C.

The experimental series consists of three comparative plots with dimensions 50 m x 50 m, i. e. 0.25 ha each (fig. 19). Comparative plot 1c is control plot without designed thinning, where only dead, broken or uprooted trees have been removed. Comparative plot 2a is the stand with thinning by positive selection from above and plot 3b is the stand with thinning by negative selection from below. In 1999 (last revision), trees for felling were marked on plots 2a and 3b with the aim of loosing canopy and consequent observation of left trees development and natural regeneration.

History of the experiment

In the period of foundation of the Vimperk II series in 1958, the experimental stand was 51-year old Norway spruce monoculture with the density of 4,828 – 4,988 trees per hectare originated artificially by planting on clearcut in regular spacing ca 1.25 – 1.5 m (i. e. 5,000 – 6,000 trees per hectare) in the period of 1902 – 1907. The experimental stand was not thinned before the first experimental treatment and, subsequently, it was distinctly differentiated (diameter breast height varied from 3 to 21 cm, fig. 21).

On the basis of the initial evaluation of the main stand characteristics, all three partial comparative plots 1c, 2a and 3b were stated comparable. Especially plots 1c and 3b were nearly identical. Initial diameter of the mean stem (d) on these partial plots achieved 11.2 cm, top diameter (mean diameter of 200 thickest trees per hectare – d_{200}) 18.2 and 18.1 cm respectively. The differences between the mean and top height were also minimal (h 11.7 m and 11.5 m, h_{200} 14.8 m and 14.5 m).

The stand on comparative plot 2a differed from previous two stands first of all by initial higher number of trees (4,988 per hectare, i. e. by 160 trees more than on control plot 1c). The initial mean diameter 10.9 cm was only by 3 mm and mean height 11.4 m by 30 cm lower and was not found statistically significant as well as differences in other investigated characteristics (tab. 5, fig. 20).

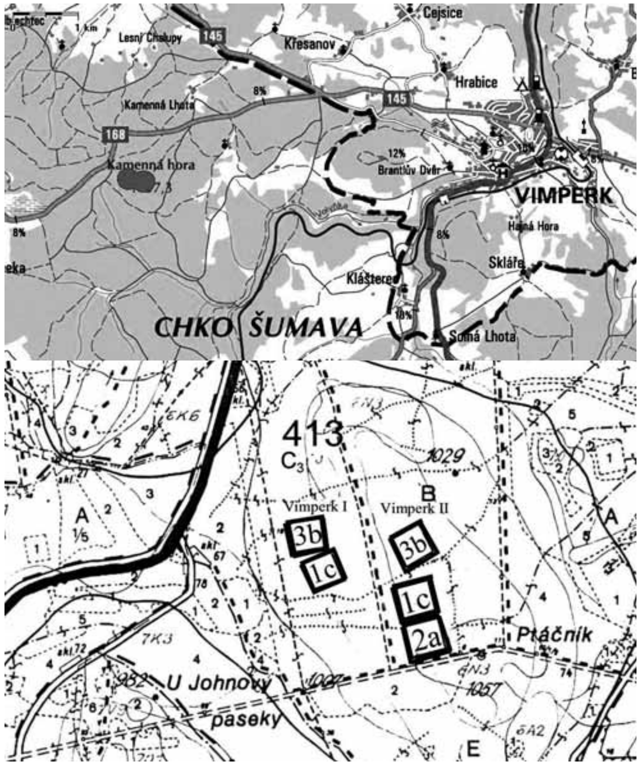


Fig. 19: Geographic location (Geobáze® 1997 – 2000) and stand map of Vimperk II experimental series on Forest Management Plan 1997

Number of trees and basal area

By the first experimental thinning at the age of 51 years, 15 % trees (N) representing 11 % of basal area (G) were removed by positive selection from above in the stand of the comparative plot 2a and 23 % N and 10 % G by negative selection from below in the stand of comparative plot 3b.

Treatments repeated three times in five-year periods to the age of 66 years (1973) removing 15, 19 and 36 % N (8, 12 and 26 % G) on comparative plot 2a by positive selection from above and 19, 28 and 30 % N (8, 16 and 20 % G) on comparative plot 3b by negative selection from below. Position of the treatments in the diameter structure of experimental stands is apparent from figure 21.

After four treatments in five-year periods, i. e. 20 years after the beginning of the observation (1978, age 71 years), number of trees per hectare decreased on:

- control plot 1c to 2,948 individuals (mortality 1,880 individuals),
- comparative plot 2a to 1,856 individuals (3,132 trees removed by high thinning),
- comparative plot 3b to 1,556 individuals (3,396 trees removed by low thinning).

Basal area (G) per hectare achieved at the same time on:

- control plot 1c – 57.5 m^2 (increased by 10.1 m^2),
- comparative plot 2a – 40.2 m^2 (decreased by 6.3 m^2),
- comparative plot 3b – 30.3 m^2 (decreased by 6.7 m^2).

Periodic increment of the basal area in the first 20 years of investigation (at the age of 51 – 71 years) represented together with basal area of intentionally removed trees by thinning on comparative plots 2a and 3b – 20.9 m^2 and 20.3 m^2 and it was by more than 10 m^2 higher than usable basal area increment on control plot 1c without thinning (10.1 m^2).

Since the last experimental thinning at the age of 66 years (1973), all three comparative stands of the experimental series have developed without intended thinning. All treatments consisted in

Tab. 5: Basic data on Vimperk II experimental series

Vimperk II		1958				1963				1968				1973				1978	1999	I 51-92	I 51-92-sc	SC 51-92
		51 years				56 years				61 years				66 years				71 years	92 years			
		before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	after thinning			
1c	N	4828	488	10	4340	4340	568	13	3772	3772	412	11	3360	3360	412	12	2948	2948	1584	*	*	3244
2a	(trees.ha^{-1})	4988	740	15	4248	4248	644	15	3604	3604	684	19	2920	2920	1064	36	1856	1856	1096	*	*	760
3b		4952	1156	23	3796	3796	728	19	3068	3068	864	28	2204	2204	648	30	1556	1556	1108	*	*	448
1c	G	47.4	1.9	4	45.5	49.9	2.2	4	47.8	53.4	2.4	4	51.1	56.5	3.1	6	53.4	57.5	59.2	38.0	11.8	26.2
2a	(m^2.ha^{-1})	46.5	5.3	11	41.2	47.4	3.1	8	43.8	48.6	5.7	12	42.8	48.3	12.5	26	35.8	40.2	50.2	40.8	30.8	10.0
3b		48.6	4.9	10	43.8	49.5	4.1	8	45.4	51.7	8.3	16	43.3	48.2	9.7	20	38.5	41.9	52.5	41.0	30.8	10.1
1c	d	11.2	7.1	*	11.6	12.1	7.0	*	12.6	13.4	8.5	*	13.9	14.6	9.8	*	15.2	15.8	21.8	5.5	*	*
2a	(cm)	10.9	9.5	*	11.1	11.9	8.5	*	12.4	13.1	10.3	*	13.7	14.5	12.2	*	15.7	16.6	24.2	7.7	*	*
3b		11.2	7.3	*	12.1	12.9	8.5	*	13.7	14.6	11.1	*	15.8	16.7	13.8	*	17.8	18.5	24.6	7.9	*	*
1c	h	11.6	8.7	*	11.9	12.7	9.2	*	13.1	13.7	10.6	*	13.9	15.4	12.3	*	15.7	17.3	22.7	8.5	*	*
2a	(m)	11.4	10.5	*	11.5	12.3	10.0	*	12.7	13.6	11.7	*	13.9	15.4	13.9	*	16.1	17.4	23.7	9.4	*	*
3b		11.5	8.8	*	12.0	13.0	10.1	*	13.4	14.1	12.0	*	14.6	16.3	14.8	*	16.7	18.2	24.0	9.9	*	*
1c		104	122	*	103	105	132	*	103	102	124	*	100	106	125	*	104	110	104	0	*	*
2a	h/d	104	111	*	103	103	118	*	101	103	114	*	101	106	114	*	103	105	98	-6	*	*
3b		103	120	*	99	101	119	*	98	96	109	*	93	97	108	*	94	98	98	-5	*	*
1c	d_{200}	18.2	*	*	*	19.6	*	*	*	21.2	*	*	*	22.5	*	*	*	23.8	29.9	11.7	*	*
2a	(cm)	17.8	*	*	*	19.5	*	*	*	21.0	*	*	*	22.3	*	*	*	24.1	32.1	14.3	*	*
3b		18.1	*	*	*	19.7	*	*	*	21.3	*	*	*	22.7	*	*	*	23.9	31.0	12.9	*	*
1c	h_{200}	14.8	*	*	*	15.6	*	*	*	16.7	*	*	*	18.6	*	*	*	20.5	25.8	11.0	*	*
2a	(m)	14.1	*	*	*	15.6	*	*	*	17.0	*	*	*	19.1	*	*	*	20.9	26.3	12.1	*	*
3b		14.5	*	*	*	15.7	*	*	*	16.7	*	*	*	18.4	*	*	*	20.3	26.1	11.5	*	*
1c		81	*	*	*	80	*	*	*	79	*	*	*	83	*	*	*	86	86	5	*	*
2a	h/d_{200}	79	*	*	*	80	*	*	*	81	*	*	*	86	*	*	*	87	82	3	*	*
3b		80	*	*	*	80	*	*	*	78	*	*	*	81	*	*	*	85	84	4	*	*

Notes: 1c – control plot without thinning, 2a – comparative plot with thinning from above, 3b – comparative plot with thinning from below, N – number of trees, G – basal area, d – breast height diameter, h – mean height, h/d - ratio of slenderness, d_{200} – diameter of 200 thickest trees, h_{200} – height of 200 thickest trees, h/d_{200} - ratio of slenderness of 200 thickest trees, T – thinning, I – increment, SC – salvage cut removing of died dry and incidentally broken and uprooted trees. Number of trees per hectare to the last revision in 1999 (age 92 years) spontaneously decreased on:

- plot 1c to 1,584 individuals (mortality at the age of 51 – 92 years 3,244 trees),
- plot 2a to 1,096 individuals (mortality at the age of 71 – 92 years 760 trees),
- plot 3b to 1,108 individuals (mortality at the age of 71 – 92 years 448 trees).

Basal area G at the age of 92 years, i. e. 41 years after the beginning of the experiment, achieved higher level on control plot 1c (59.2 m^2) and was by 9 m^2 higher than on comparative plot 2a with high thinning (50.2 m^2) and by 6.7 m^2 on plot 3b with low thinning (52.2 m^2).

After including the basal area of all removed trees (i. e. including salvage cut), the period basal area increment on thinned plots 2a and 3b by ca 3 m^2 was higher than on control plot 1c (38 m^2 on plot 1c and 40,8 and 41 m^2 on plots 2a and 3b). But on control plot 1c, 26.0 m^2 of basal area (69 % of basal area increment) had to be removed during the period of investigation as salvage cut (breaks, dry trees, etc.), whereas salvage cut on both thinned plots 2a and 3b represented only 10 m^2 (i. e. 24 % of basal area increment). When including basal area only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigation (age of 51 – 92 years) achieved on:

- on plot 1c - 11.8 m^2,
- on plot 2a – 30.8 m^2,
- on plot 3b – 30.9 m^2.

Diameter structure

Effect of thinning on diameter structure was investigated at the age of 51 – 66 years in five-year periods always to the date of experimental treatment. Diameter structure was evaluated four times for the age of 51, 56, 61 and 66 years, i. e. in the period of active treatment. The 5th final evaluation was made on the data received by the last revision at the age of 92 years (1999).

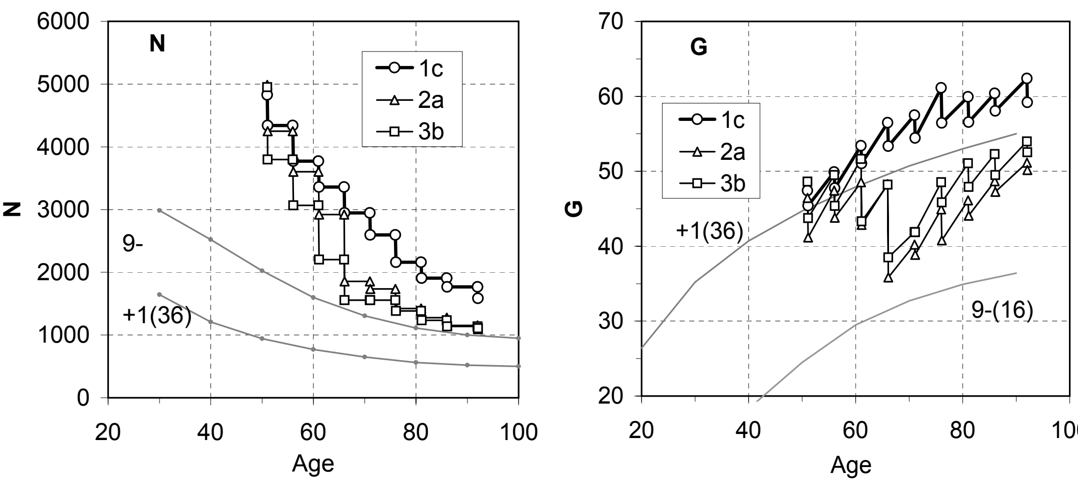
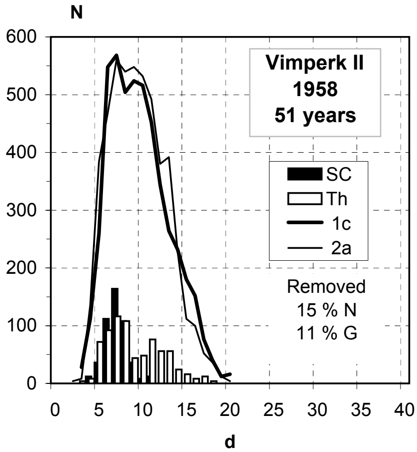
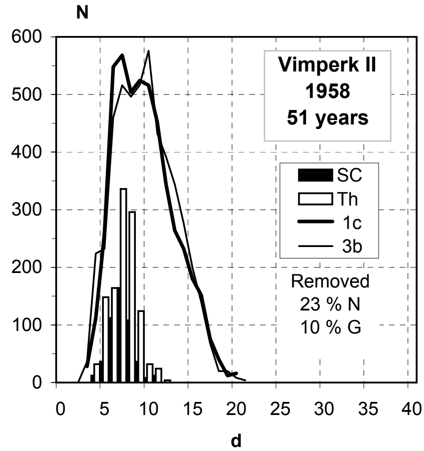
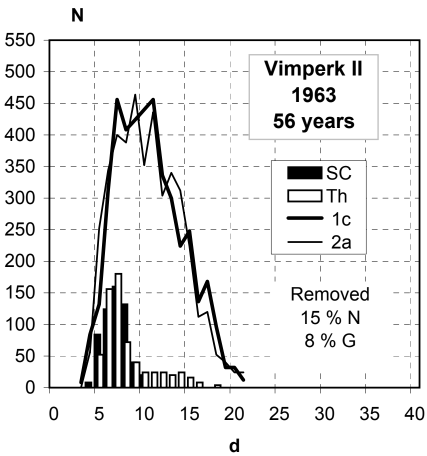
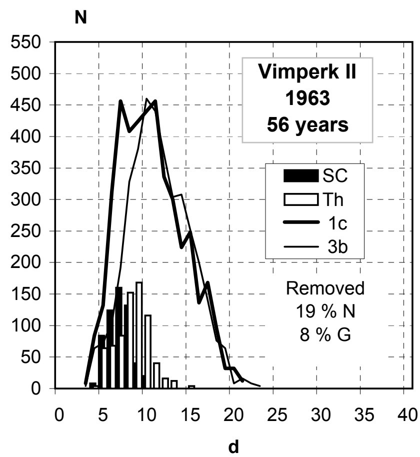


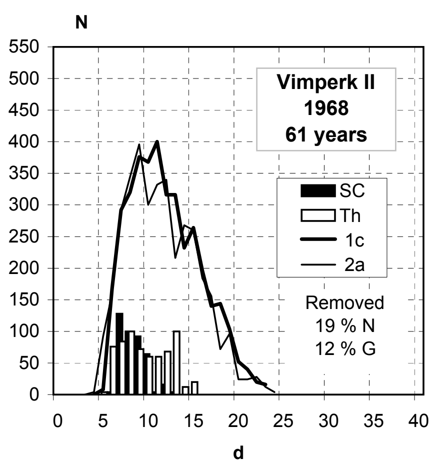
Fig. 20: Number of trees (N – $pc.ha^{-1}$) and basal area (G – $m^2.ha^{-1}$) on comparative plots of Vimperk II experimental series at the age of 51 – 92 years comparing with Growth tables (Černý, Pařez, Malík 1996)

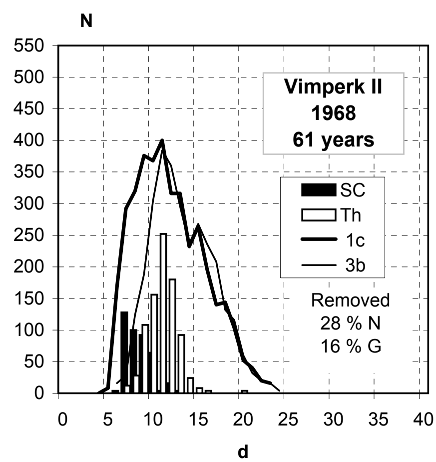

N
Vimperk II
1958
51 years
SC
Th
1c
2a
Removed
15 % N
11 % G
d


N
Vimperk II
1958
51 years
SC
Th
1c
3b
Removed
23 % N
10 % G
d


N
Vimperk II
1963
56 years
SC
Th
1c
2a
Removed
15 % N
8 % G
d


N
Vimperk II
1963
56 years
SC
Th
1c
3b
Removed
19 % N
8 % G
d


N
Vimperk II
1968
61 years
SC
Th
1c
2a
Removed
19 % N
12 % G
d


N
Vimperk II
1968
61 years
SC
Th
1c
3b
Removed
28 % N
16 % G
d

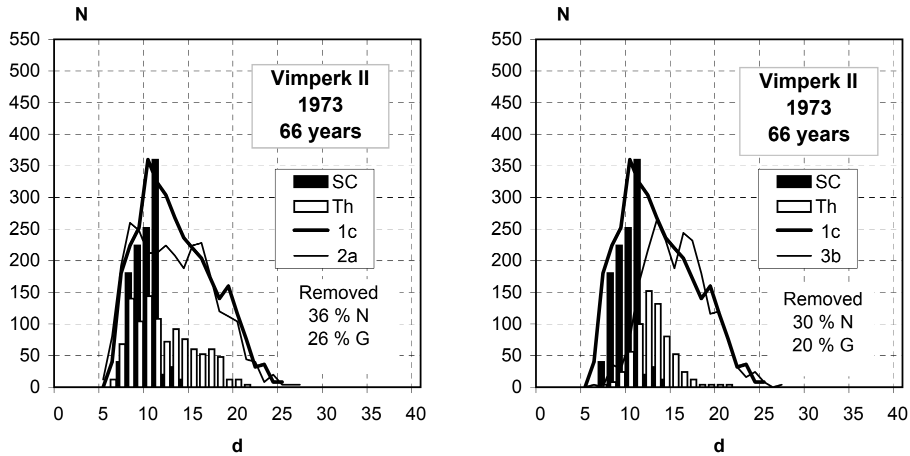


Fig. 21: Diameter structure and experimental thinning comparing with mortality on control plot 1c without thinning on Vimperk II experimental series at the age of 51 – 66 years (d – diameter in cm, N – number of trees per hectare, SC – salvage cut, Th – thinning)

Distribution of trees in diameter classes before thinning is exhibited by lines; thinned trees are shown by white column and mortality on control plot 1c by black column. From the figure 21 it is apparent, that the diameter structure on all three comparative plots was before the beginning of the experiment at the age of 51 years (1958) nearly identical. Significantly different (chi-square test) frequency distribution of diameter structure was found only between thinned plots 2a and 3b.

From the position of the particular treatments in diameter structure of the particular stand it is visible, that all four thinnings on comparative plot 2a were made by positive selection from above and on plot 3b by negative selection from below. By the experimental thinning, numerous breaks and declining individuals had to be removed as well, and so the distribution of thinned trees on comparative plot 2a with high thinning has one peak in the left part and the other in the middle part of distribution. Displacement of thinning into higher diameter classes comparing to natural mortality is apparent in all four treatments, but especially in the 2^{nd} and 4^{th} thinning at the age of 56 and 66 years.

At the age of 92 years (last revision), the diameter of the trees in experimental stands varied from 10 to 40 cm (fig. 22). The lowest diameter classes 10 – 20 cm with the higher and the most unfavourable h/d ratio (110 – 143) were the most abundant on comparative plots 1c and 2a (752 trees). On comparative plot 2a with positive selection from above, the number of these thin trees decreased to 416 (55 % of control) and on comparative plot 3b with negative selection from below it decreased to 248 (33 % of control). On the other hand, abundance of trees with diameter 30 cm and more with relatively favourable h/d ratio (86 – 70) on thinned plot increased and represented on comparative plot 2a with high thinning 150 % of control and on comparative plot 3b with low thinning 117 % of control (120, 180 and 140 on plots 1c, 2a and 3b respectively). Differences in frequency distributions of diameter structure on all investigated variants at the age of 78 years (last revision) were found statistically significant (chi-square test).

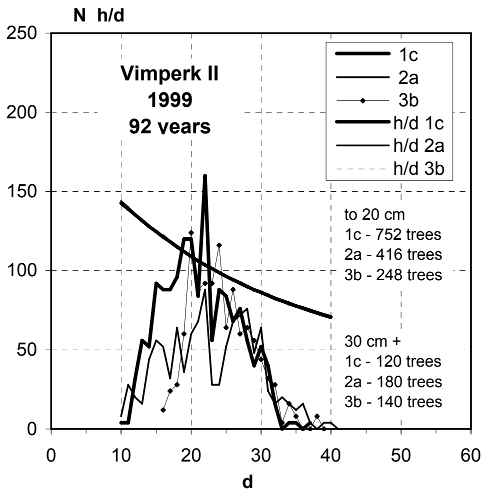


Fig. 22: Diameter structure and h/d ratio for diameter degrees on Vimperk II experimental series at the age of 92 years - last revision (d – diameter in cm, N – number of trees per hectare)

Static stability

At the beginning of observation, the static stability of experimental stands evaluated by h/d ratio of the mean stem and dominant trees (d_{200}) was relatively unfavourable because of very high initial stand density (tab. 5, fig. 20). The h/d ratio of the mean stem at the age of 51 years (1958) varied from 103 on plot 3b to 104 on plots 1c and 2a (tab. 5, fig. 23) and on control plot 1c, it was in the phase of increment culminating by the value of 110 at the age of 71 years (4^{th} revision). Next development of h/d ratio on control plot 1c is characterized by decreasing tendency caused mainly by natural mortality of trees with very disadvantageous static attributes (high h/d ratio).

Increment of h/d ratio on comparative plot 2a was reduced by relatively heavy thinning with positive selection from above and culminated in the same age (71 years) as on control plot, but by lower value of 105. Decrease of quotient after culmination was more pronounced due to improved diameter growth of loose target trees.

Development of h/d ratio of mean stem on comparative plot 3b with low thinning differed from other two variants. Applied relatively heavy low thinning at the age of 51, 61 and 66 years with removing thin unstable individuals resulted in stepwise decrease of quotient by calculation shifts and its slower increase to the value of 96 at the age of 76 years. Next period (age 76 – 92 years), h/d ratio of mean stem on this plot stagnated, and reached the final value of 98, similarly as h/d ratio of mean stem on comparative plot 2a, while on control plot 1c without thinning, the final value of h/d ratio of mean stem reached 104.

Evaluating the static stability of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot), the initial h/d_{200} ratio on all comparative plots was nearly equal and differs from 79 on comparative plot 2a to 81 on control plot 1c. Culmination of h/d_{200} ratio was registered similarly as on h/d ratio of mean stems at the age of 71 years, when it reached the values from 85 (3b) to 87 (2a).

In the next period, h/d_{200} ratio on control plot 1c stagnated on the value of 86 and on comparative plots 2a and 3b with thinning showed decreasing tendency finishing with the significantly different values of 82 on plot 2a and 84 on plot 3b at the age of 92 years (last revision). Development of h/d_{200} ratio was influenced by significantly higher d_{200} at the age 81 – 92 year (last three revisions) on thinned plots 2a and 3b comparing with control plot 1c without thinning (fig. 24).

Conclusions from the Vimperk II experiment

- In the period of investigation (age of 51 – 92 years), the basal area of experimental Norway spruce stands of Vimperk II series was above the Growth tables values for the best site index +1 (36). During 41 years of observation, the stand basal area increased on control plot 1c by 38.0 m^2, but 26.2 m^2 of this amount (69 %) had to be removed as salvage cut (breaks, dry trees, etc.). At the same time, on comparative plot 2a with high thinning and 3b with low thinning basal area increased by 40.8 m^2 and 41.0 m^2 and salvage cut reached only 10 and 10.1 m^2 (24 % of basal area increment). Positive effect of thinning on basal area increment was observed on Vimperk II series. Periodic basal area increment was on both thinned variants (2a and 3b) by ca 3 m^2 higher than on control plot 1c and, after excluding salvage cut, the differences between thinned and unthinned variants increased to ca 19 m^2 in favour of thinned stands.

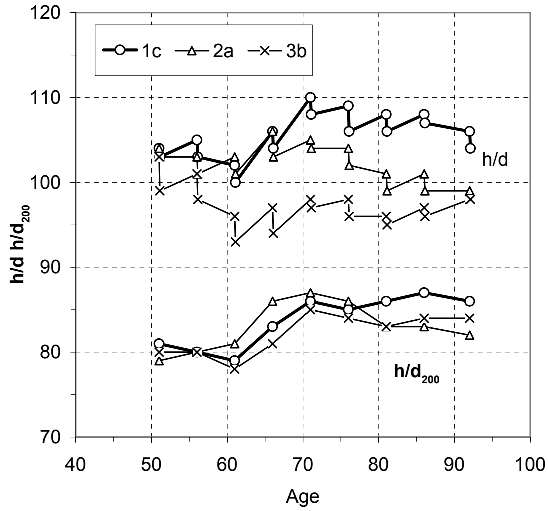


Fig. 23: Development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Vimperk II experimental series at the age of 51 – 92 years

- Effect of thinning by negative selection from below and positive selection from above lasting 41 years resulted in decreased abundance of trees in lower diameter classes and increased abundance of trees in higher diameter classes on both thinned variants (2a and 3b) comparing with control stand 1c without thinning. Number of thin trees (diameter 20 cm and lesser) was by 45 % lower on plot 2a with high thinning and by 67 % lower on plot 3b with low thinning comparing with control plot 1c (752, 416 and 248 thin trees on plots 1c, 2a and 3b). On the other hand, number of thick trees in higher diameter classes (diameter 30 cm and more) increased on plot 2a by 50 % and on plot 3b by 17 % comparing to control plot 1c (120, 180 and 140 thick trees

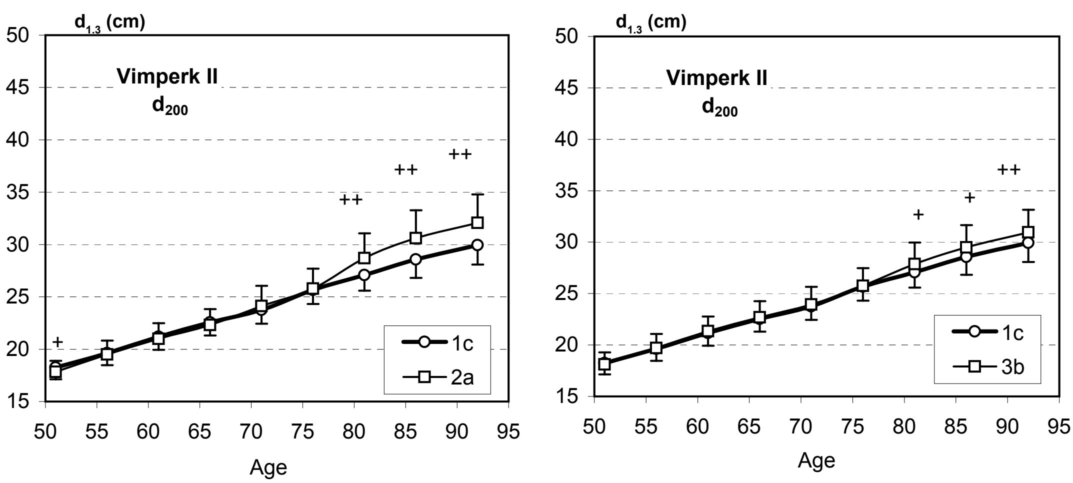


Fig. 24: Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on experimental series (1c/2a – left, 1c/3b – right) Vimperk II in the period 1958 – 1999 (age of 51 – 92 years). Statistical analysis (t-test) - significant differences on confidence level 0.95 (+) and 0.99 (++)

on plots 1c, 2a and 3b). Differences between frequency distributions of diameter structure on all investigated variants at the age of 78 years (last revision) were found statistically significant.

- Static stability of experimental stands of Vimperk II experimental series assessed by development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot) was influenced by both variants of thinning. Lower values of h/d ratio of mean stem on comparative plot 3b with low thinning comparing to control plot was caused partly by calculation shifts after removing thin and unstable individuals and partly by better diameter increment. The volume of h/d ratio of mean stem on comparative plot 2a with high thinning was initially (age 51 – 66 years) similar as on control plot 1c, then higher diameter increase resulted in improved stability. At the age of 91 years (last revision) h/d ratio of mean stem on both thinned plots reached the value 98 (control plot 104).
- Static stability of experimental stands of Vimperk II experimental series assessed by development of h/d_{200} ratio of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot) developed similarly on all three comparative plots to the age of 71 years. After then, h/d_{200} ratio on control plot 1c stagnated on the value ca 86 and on plot 3b with low thinning decreased to significantly different value of 84. The best final h/d_{200} ratio (82), significantly different from other variants, was found on comparative plot 2a with positive selection from above.

NISA EXPERIMENTAL SERIES

Experimental series at Nisa was founded in forest region 21a – the Jizerské hory Mts. in 1958 in 35-year old Norway spruce stand growing in Forest Management Area Nisa (stand 547 B8 according to Forest Management Plan 1993). The co-ordinates of the series are lat. 50°48´02″ N and long. 32°55´55″ E. The experimental stand is located on a 20 % northern slope in the 6th (spruce-beech) forest vegetation zone in elevation of 820 m. Prevailing soil type is brown forest soil, ecological group acid, soil category K. The experimental stand is included into Management Unit 52 – Spruce management of acid sites in higher locations under air-pollution stress. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period of 1961 – 1990, the mean annual sum of precipitation represented 1,200 mm and mean annual temperature 4 ˚C.

The experimental series consists of three comparative plots with dimensions 50 m x 50 m, i. e. 0.25 ha each (fig. 25). Comparative plot 1c is control plot without designed thinning, where only dead, broken or uprooted trees have been removed. Comparative plot 2a is the stand with thinning by positive selection from above and plot 3b is the stand with thinning by negative selection from below. In 1998 (last revision), trees for felling were marked on plots 2a and 3b with the aim of loosing canopy and consequent observation of left trees development and natural regeneration.

History of the experiment

In the period of foundation of the Nisa series in 1958, the experimental stand was 35-year old Norway spruce monoculture with the density of 2,604 – 2,860 trees per hectare. With respect to the initial deep diameter differentiation (tree diameters before the first experimental thinning differentiated from 3 to 25 cm), it was supposed, that the experimental stand originated by natural regeneration or by planting restocked by self-seeding and it was not thinned before the first experimental treatment (fig. 27).

For the Nisa experimental series, primary data have been lost for the period 1958 – 1973, so this period was reconstructed on the basis of available preliminary evaluation. For this reason, dominant trees are characterized by 100 thickest individuals per hectare used in the preliminary tables instead of generally used 200 thickest individuals.

On the basis of the initial evaluation of the main stand characteristics, all three partial comparative plots 1c, 2a and 3b were stated comparable. Initial diameter of the mean stem (d) on all three partial plots achieved 12.5 cm (1c, 3b) and 12.3 cm (2a) and diameter d_{100} (mean diameter of 100 thickest trees per hectare) 21.2 cm (1c, 2a) and 20.7 cm (3b). The differences between the mean and top height were also minimal (h 10.8 m – 11.4 m, h_{100} 14.3 m - 14.7 m) and were not found statistically significant as well as differences in other investigated characteristics (tab. 6, fig. 26).

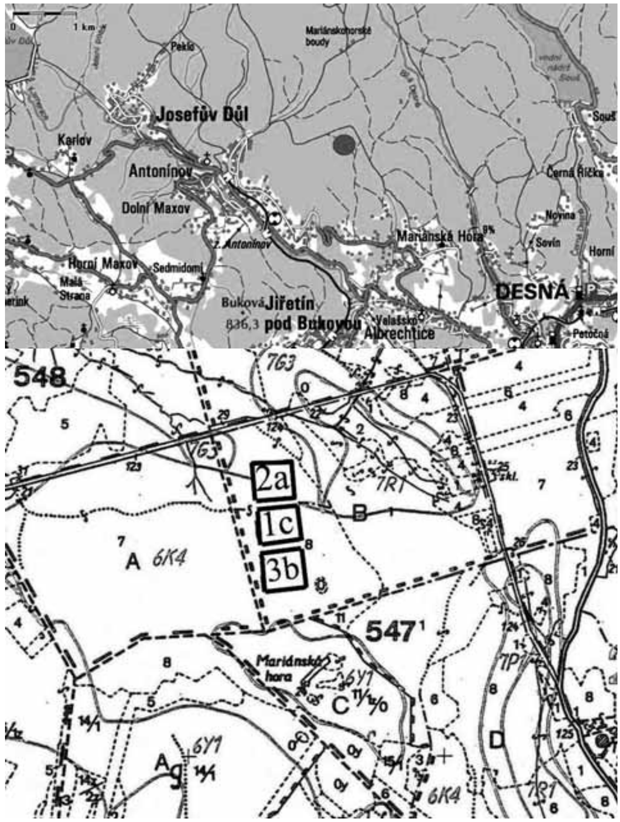


Fig. 25: Geographic location (Geobáze® 1997 – 2000) and stand map of Nisa experimental series on Forest Management Plan 1993

Number of trees and basal area

By the first experimental thinning at the age of 35 years, 13 % trees (N) representing 10 % of basal area (G) were removed by positive selection from above in the stand of the comparative plot 2a and 33 % N and 16 % G by negative selection from below in the stand of comparative plot 3b.

Treatments repeated three times in five-year periods to the age of 50 years (1973) removing 27, 41 and 24 % N (11, 21 and 14 % G) on comparative plot 2a by positive selection from above and 23, 49 and 11 % N (9, 36 and 7 % G) on comparative plot 3b by negative selection from below. Position of the treatments in the diameter structure of experimental stands is apparent from figure 27.

After four treatments in five-year periods, i. e. 20 years after the beginning of the observation (1978, age 55 years), number of trees per hectare decreased on:

- control plot 1c to 996 individuals (mortality 1,608 individuals),
- comparative plot 2a to 768 individuals (1,888 trees removed by high thinning),
- comparative plot 3b to 668 individuals (2,175 trees removed by low thinning).

Basal area (G) per hectare achieved at the same time on:

- control plot 1c – 38,2 m^2 (increased by 6.1 m^2),
- comparative plot 2a – 31,5 m^2 (decreased by 0.1 m^2),
- comparative plot 3b – 30.3 m^2 (decreased by 5.5 m^2).

Tab. 6: Basic data on experimental series Nisa

Nisa		1958				1963				1968				1973				1978	1998	I. 35-75	I. 35-75 -SC	SC 35-75
		35 years				40 years				45 years				50 years				55 years	75 years			
		before thinnig	T	$T_{\%}$	after thinning	before thinnig	T	$T_{\%}$	after thinning	before thinnig	T	$T_{\%}$	after thinning	before thinning	T	$T_{\%}$	after thinning	before thinning	after thinning			
1c	N	2604	416	16	2188	2188	408	19	1780	1780	708	40	1072	1072	76	7	996	996	552	28.3	*	2052
2a	(trees.ha^{-1})	2656	348	13	2308	2308	620	27	1688	1688	684	41	1004	1004	236	24	768	768	536	26.9	*	232
3b		2860	940	33	1920	1920	432	23	1488	1488	736	49	752	752	84	11	668	668	480	27.6	*	188
1c	G	32.1	1.5	5	30.6	37.6	2.2	6	35.5	39.9	9.3	23	30.6	34.8	1.5	4	33.3	38.2	32.1	28.3	0.0	28.3
2a	(m^2.ha^{-1})	31.6	2.9	9	28.6	35.3	3.8	11	31.4	35.6	7.6	21	27.7	32.7	4.6	14	28.0	31.5	31.7	26.9	19.1	7.7
3b		33.7	5.4	16	28.3	35.1	3.3	9	31.8	36.2	13.0	36	23.2	27.3	2.0	7	25.3	28.2	30.5	27.6	20.5	7.1
1c	d	12.5	6.8	*	13.3	14.8	8.3	*	15.9	16.9	12.9	*	19.0	20.3	15.7	*	20.7	22.1	27.2	8.1	*	*
2a	(cm)	12.3	10.2	*	12.6	14.0	8.9	*	15.4	16.3	11.9	*	18.7	20.4	15.8	*	21.6	22.9	27.5	8.4	*	*
3b		12.5	8.5	*	13.7	15.3	9.9	*	16.5	17.6	15.0	*	19.9	21.5	17.5	*	21.8	23.2	28.4	9.6	*	*
1c	h	11.0	6.6	*	11.4	13.1	8.4	*	13.7	15.2	12.7	*	16.2	17.3	14.8	*	17.5	*	20.3	7.1	*	*
2a	(m)	10.8	9.5	*	11.0	12.6	8.9	*	13.4	14.9	11.9	*	16.1	17.2	14.7	*	17.7	*	20.8	7.3	*	*
3b		11.4	8.6	*	12.3	13.3	9.9	*	14.0	15.1	13.8	*	16.0	16.8	15.0	*	17.0	*	20.2	6.2	*	*
1c		88	97	*	86	89	106	*	86	90	98	*	85	85	94	*	85	*	74	-14	*	*
2a	h/d	88	93	*	87	90	100	*	87	91	100	*	86	84	93	*	82	*	76	-12	*	*
3b		91	101	*	90	88	100	*	85	86	92	*	80	78	86	*	78	*	71	-20	*	*
1c	d_{100}	21.2	*	*	*	24.2	*	*	*	26.3	*	*	*	28.9	*	*	*	*	35.7	14.5	*	*
2a	(cm)	21.2	*	*	*	24.2	*	*	*	26.0	*	*	*	28.6	*	*	*	*	34.6	13.4	*	*
3b		20.7	*	*	*	23.3	*	*	*	25.5	*	*	*	27.5	*	*	*	*	35.6	14.9	*	*
1c	h_{100}	14.6	*	*	*	17.0	*	*	*	19.1	*	*	*	20.2	*	*	*	*	22.6	8.0	*	*
2a	(m)	14.3	*	*	*	17.0	*	*	*	18.9	*	*	*	20.0	*	*	*	*	22.4	8.1	*	*
3b		14.7	*	*	*	16.4	*	*	*	17.p	*	*	*	18.8	*	*	*	*	22.0	7.3	*	*
1c		69	*	*	*	70	*	*	*	73	*	*	*	70	*	*	*	*	63	*	*	*
2a	h/d_{100}	67	*	*	*	70	*	*	*	73	*	*	*	70	*	*	*	*	65	*	*	*
3b		71	*	*	*	70	*	*	*	70	*	*	*	68	*	*	*	*	61	*	*	*

Notes: 1c – control plot without thinning, 2a – comparative plot with thinning from above, 3b – comparative plot with thinning from below, N – number of trees, G – basal area, d – breast height diameter, h – mean height, h/d - ratio of slenderness, d_{100} – diameter of 100 thickest trees, h_{100} – height of 100 thickest tree, h/d_{100} - ratio of slenderness of 100 thickest trees, T – thinning, I – increment, SC – salvage cut

Periodic increment of the basal area in the first 20 years of investigation (at the age of 35 – 55 years) represented together with basal area of intentionally removed trees by thinning on comparative plots 2a and 3b – 18.8 and 18.2 m² and it was by more than 12 m² higher than usable basal area increment on control plot 1c without thinning (6.1 m²).

Since the last experimental thinning at the age of 50 years (1973), all three comparative stands of the experimental series have developed without intended thinning. All treatments consisted in removing of died, dry and incidentally broken and uprooted trees. Number of trees per hectare to the last revision in 1998 (age 75 years) spontaneously decreased on:

- plot 1c to 552 individuals (mortality at the age of 35 – 75 years 2,052 trees),
- plot 2a to 536 individuals (mortality at the age of 55 – 75 years 232 trees),
- plot 3b to 480 individuals (mortality at the age of 55 – 75 years 188 trees).

Basal area G at the age of 75 years, i. e. 40 years after the beginning of the experiment), was on all three comparative plots comparable (32.1, 31.7 and 30.5 m²).

After including the basal area of all removed trees (i. e. including salvage cut), the period basal area increment on comparative plots 1c, 2a and 3b represented 28.3, 26.9 and 27.6 m². But on control plot 1c, all produced basal area had to be removed during the period of investigation as salvage cut (breaks, dry trees, etc.), whereas salvage cut on both thinned plots 2a and 3b represented only 7.7 and 7.1 m² (i. e. 29 and 26 % of basal area increment).

When including basal area only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigation (age of 35 – 75 years) achieved on:

- on plot 1c – 0 m²,
- on plot 2a – 19.1 m²,
- on plot 3b – 20.5 m².

Diameter structure

Effect of thinning on diameter structure was investigated at the age of 35 – 50 years in five-year periods always to the date of experimental treatment. Diameter structure was evaluated four times

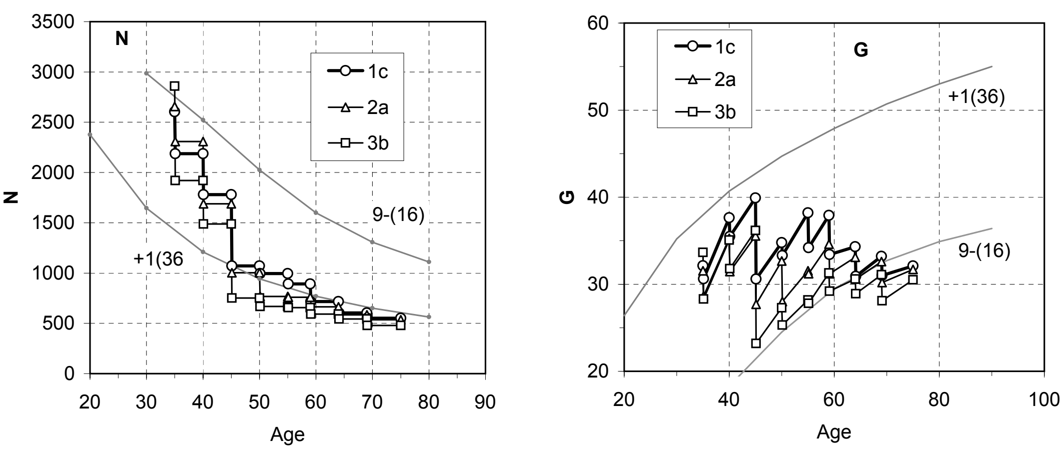


Fig. 26: Number of trees (N – pc.ha⁻¹) and basal area (G – m².ha⁻¹) on comparative plots of Nisa experimental series at the age of 35 – 75 years comparing with Growth tables (Černý, Pařez, Malík 1996)

for the age of 35, 40, 45 and 50 years, i. e. in the period of active treatment. The 5th final evaluation was made on the data received by the last revision at the age of 75 years (1998).

Distribution of trees in diameter classes before thinning is exhibited by lines; thinned trees are shown by white column and mortality on control plot 1c by black column. From the figure 27 it is apparent, that the diameter structure on all three comparative plots was before the beginning of the experiment at the age of 35 years (1958) similar.

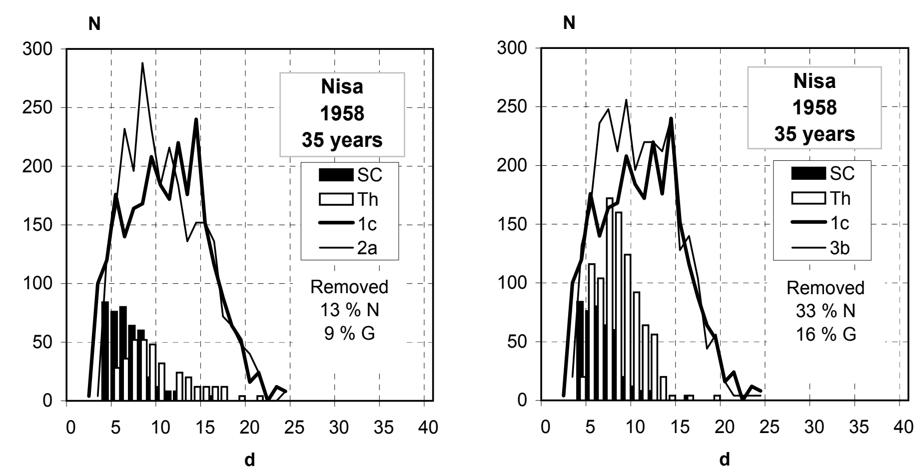
Higher incidence of trees (by ca 15 %) in diameter classes 8 – 10 cm on plots 2a and 3b (diameter distribution significantly different from control plot 1c) was rearranged by the first experimental thinning at the age of 35 years.

From the position of the particular treatments in diameter structure of the particular stand it is visible, that typical character of positive selection on comparative plot 2a could be kept only in the first treatment in 1958. In the 2nd, 3rd and 4th experimental treatments, numerous breaks and declining individuals had to be removed as well, and so the distribution of thinned trees had a left-sided form typical for low thinning on comparative plot 3b. Displacement of thinning into higher diameter classes comparing to natural mortality is apparent on plot 2a only in the 1st thinning and on plot 3b in all four treatments.

At the age of 75 years (last revision), the diameter of the trees in experimental stands varied from 14 to 47 cm (fig. 28). The lowest diameter classes 10 – 20 cm with the higher and relatively unfavourable h/d ratio (85 – 91) were the most abundant on comparative plots 1c and 2a (80 and 72). On comparative plot 3b with negative selection from below it decreased to 40 (50 % of control). On the other hand, abundance of trees with diameter 30 cm and more with favourable h/d ratio (65 – 50) on thinned plot slightly increased and represented on comparative plot 2a with high thinning 108 % of control and on comparative plot 3b with low thinning 110 % of control (160, 172 and 176 on plot 1c, 2a and 3b respectively). Low effect of thinning after 40 years (at the age of 75 years) was confirmed by analysis of distribution of diameter structures (chi-square test), when statistical significant differences between control plot 1c and thinned plots 2a and 3b were not found.

Static stability

The h/d ratio of the mean stem at the age of 35 years (1958) varied from 88 on plots 1c and 2a to 91 on plot 3b (tab. 6, fig. 29) and it was in the phase of increment culminating by the value of 88



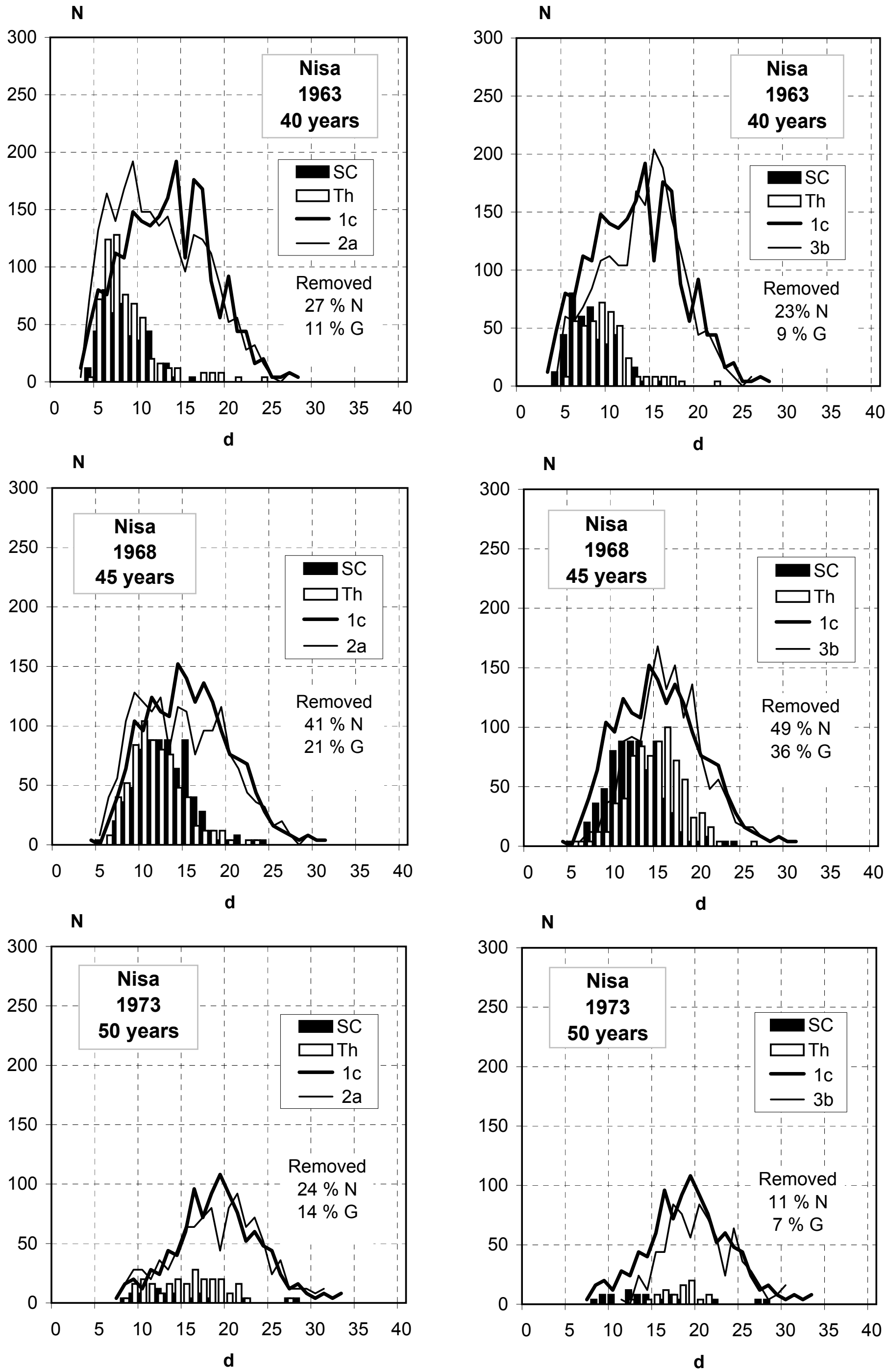


Fig. 27: Diameter structure and experimental thinning comparing with mortality on control plot 1c without thinning on Nisa experimental series at the age of 35 – 50 years (d – diameter in cm, N – number of trees per hectare, SC – salvage cut, Th – thinning)

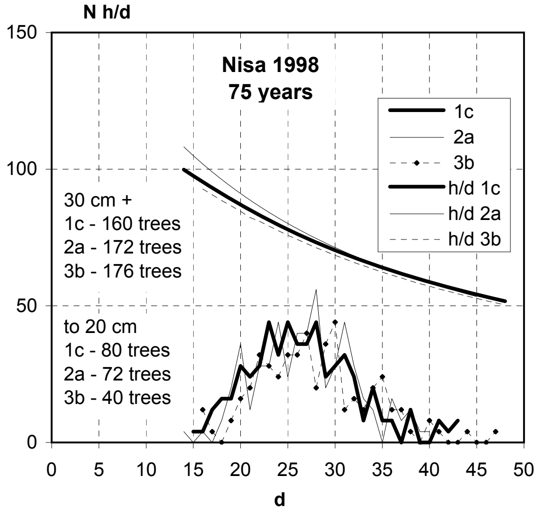


Fig. 28: Diameter structure and h/d ratio for diameter degrees on Nisa experimental series at the age of 75 years - last revision (d – diameter in cm, N – number of trees per hectare)

– 91 at the age of 40 – 45 years (2nd and 3rd revision). Next development of h/d ratio on control plot 1c and plot 2a with high thinning had nearly identical development with decreasing tendency caused mainly by natural mortality of trees with very disadvantageous static attributes (high h/d ratio). At the age of 75 years (last revision), h/d ratio of mean stem on these plots reached the values 74 and 76.

Development of h/d ratio of mean stem on comparative plot 3b with low thinning differed from other two variants. Applied relatively heavy low thinning at the age of 35, 40 and 45 years with removing thin unstable individuals resulted in stepwise decrease of quotient by calculation shifts, its slower increase to the value of 86 at the age of 45 years and relatively quick decrease after culmination to the final value of 71 (age of 75 years).

Evaluating the static stability of dominant trees (in this series 100 thickest trees per hectare, i. e. the same number of individuals on each comparative plot), the initial h_{100}/d_{100} ratio on all comparative plots was nearly equal and differs from 67 on comparative plot 2a to 71 on control plot 3b. Culmination of h_{100}/d_{100} ratio was registered on plots 1c and 2a similarly as on h/d ratio of mean stems at the age of 45 years with value 73 and following decrease of ratio finished with the values of 63 and 65 (differences insignificant). Decreasing tendency since the beginning of observation was found on comparative plot 3b (from initial 71 to significantly different final value of 61 at the age of 75 years).

Although thinning resulted in significantly better h_{100}/d_{100} ratio on the comparative thinned plot 3b at the age 75 years, differences in d_{100} between control plot 1c without thinning and thinned plots 3b and 2a were statistically insignificant (fig. 30).

Conclusions from the Nisa experiment

- During 40 years of observation of experimental Norway spruce stands of Nisa series (age of 35 – 75 years), the stand basal area increased on control plot 1c by 28.3 m^2, but all this increment had to be continuously removed as salvage cut (breaks, dry trees, etc.). At the same time, on comparative plot 2a with high thinning and 3b with low thinning basal area increased by 26.9 m^2 and 27.6 m^2 and salvage cut reached only 7.7 and 7.1 m^2 (i. e. 29 and 26 % of basal area increment). Total periodic basal area increment was on both thinned variants (2a and 3b) by 1.4 and 0.7 m^2 lower than on control plot 1c, but after excluding salvage cut, the differences between thinned and unthinned variants increased to 19.2 and 20.5 m^2 in favour of thinned stands 2a and 3b.
- Effect of thinning by negative selection from below and positive selection from above lasting 40 years resulted in decreased abundance of trees in lower diameter classes (especially on plot 3b with low thinning) and slightly increased abundance of trees in higher diameter classes on both thinned variants (2a and 3b) comparing with control stand 1c without thinning. Number of thin

trees (diameter 20 cm and lesser) was by 10 % lower on plot 2a with high thinning and by 50 % lower on plot 3b with low thinning comparing with control plot 1c (80, 72 and 40 thin trees on plots 1c, 2a and 3b). On the other hand, number of thick trees in higher diameter classes (diameter 30 cm and more) slightly increased on plot 2a by 8 % and on plot 3b by 10 % comparing to control plot 1c (160, 172 and 176 thick trees on plots 1c, 2a and 3b). Low effect of thinning on diameter structure after 40 years (at the age of 75 years) was confirmed, by insignificant differences in frequency distributions of diameter structure on investigated variants.

- Static stability of experimental stands of Nisa experimental series assessed by development of h/d ratio of mean stem was influenced by thinning only on comparative plot 3b with low thinning. Lower h/d ratio of mean stem on this variant finishing with value of 70 at the age of 75 years was caused partly by calculation shifts after removing thin and unstable individuals and partly by better diameter increment of left trees. The volume of h/d ratio of mean stem on control plot 1c and comparative plot 2a with high thinning developed similarly, culminating at the age of 45 years with the value of 90 and decreased to the final value of 75.

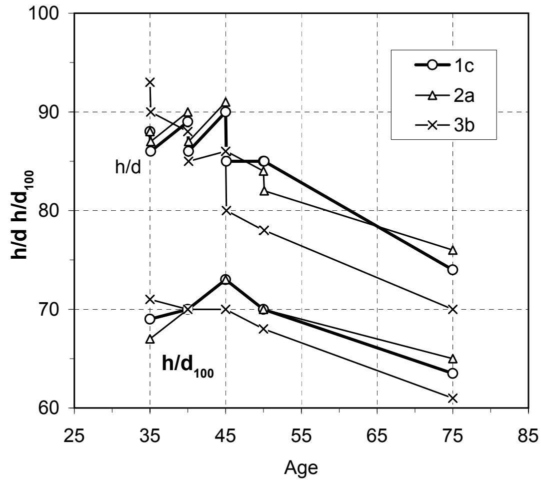


Fig. 29: Development of h/d ratio of mean stem and upper tree story (100 thickest trees per hectare) on Nisa experimental series at the age of 35 – 75 years

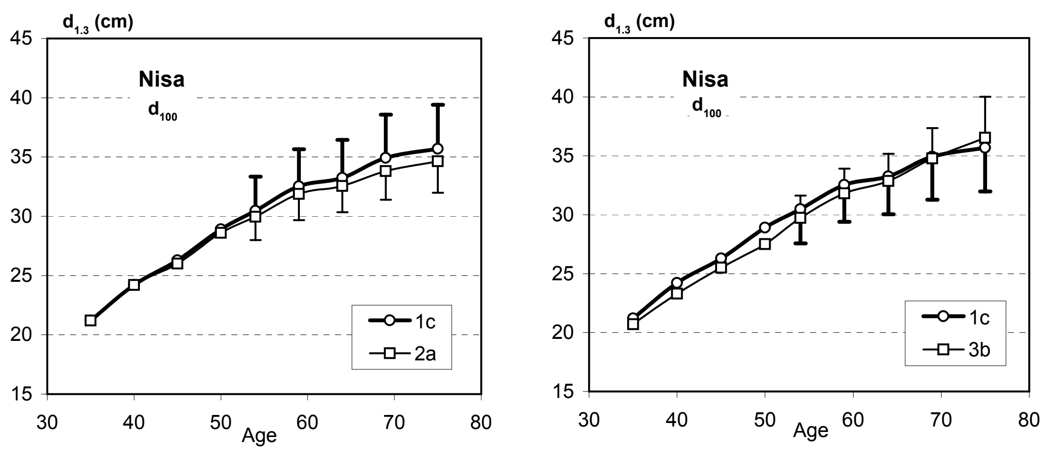


Fig. 30: Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on experimental series (1c/2a – left, 1c/3b – right) Nisa in the period 1958 – 1999 (age of 35 – 75 years). Statistical analysis (t-test) - significant differences on confidence level 0.95 (+) and 0.99 (++)

- Static stability of experimental stands of Nisa experimental series assessed by development of h/d ratio of dominant trees (100 thickest trees per hectare, i. e. the same number of individuals on each comparative plot) developed similarly on control plot 1c and on plot with high thinning 2a with culmination at the age of 45 years with value 73 and following decrease to final values of 63 and 65 (differences insignificant). Development of h/d ratio of dominant trees on comparative plot 3b with low thinning was characterized by decreasing tendency since the beginning of observation from initial 71 to significantly different final value of 61 at the age of 75 years.

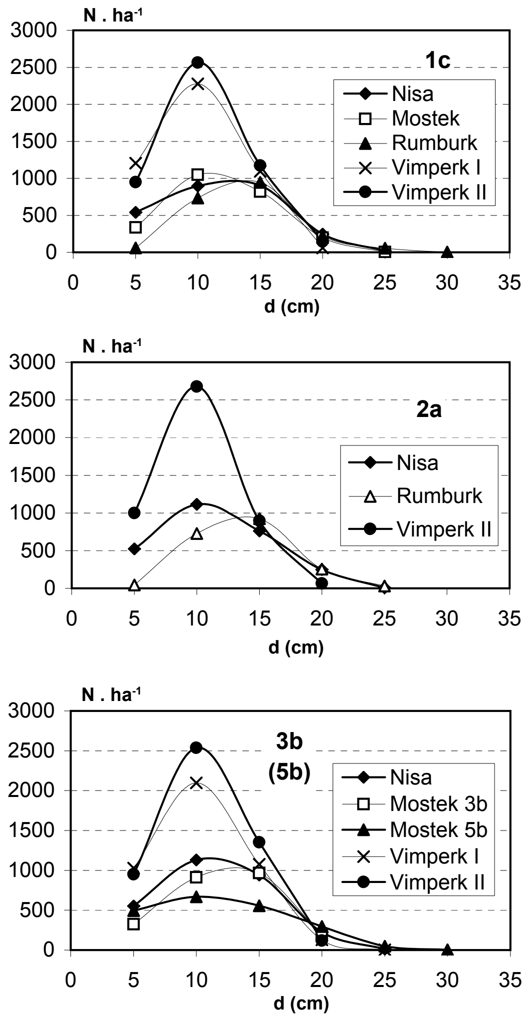


Fig. 31: Initial diameter distribution (in 1958) in particular series of the 1st group of series. 1c – control plots without thinning, 2a – comparative plots with thinning from above, 3b (5b) comparative plots with thinning from below

DISCUSSION AND CONCLUSIONS

The method used in the thinning experiment did not suppose the replication inside the individual series, but using particular variants inside the group of the series as replication was not possible because of high initial differences between series. Especially high differences were found in initial density of experimental stands which varied from 2,016 individuals (control plot 1c on Rumburk series) to 4,828 individuals per hectare (control plot 1c on Vimperk II series). Similar differences appeared in basal area (from 29.1 m^2 on Mostek series to 47.4 m^2 on Vimperk II series). Investigated series can be divided into two groups: series with relatively low initial number of trees (Rumburk, Mostek and Nisa series with initial number of trees from 2,016 to 2,604) and series with relatively high initial number of trees (Vimperk I and Vimperk II series initial number of trees from 4,632 to 4,828). The difference between series is apparent from the initial diameter distribution in particular series (fig. 31). Final evaluation of the 1st group of series established in 1958 therefore concentrated on common phenomena observed on particular series.

Production

Effect of thinning on production of the experimental stands evaluated on the period basal area increment was different (tab. 7).

Positive selection from above (2a) included into series Rumburk, Nisa and Vimperk II resulted in two cases in higher and in one case in lower total period basal area increment (including salvage cut) comparing with control plot without thinning. Higher BA increment was found on series Rumburk (+5.6 m^2, i. e. +20 %) and Vimperk II (+2.8 m^2, i. e. +7 %) and lower increment on series Nisa (-1.4 m^2, i. e. -5 %).

Negative selection from below (plots 3b or 5b) included into series Mostek, Nisa, Vimperk I and Vimperk II resulted in one case in higher and in three cases in lower total period basal area increment (including salvage cut) comparing with control plot without thinning. Higher BA increment was found on series Vimperk II (+3 m^2, i. e. +8 %) and lower increment on series Mostek (-3 m^2, i. e. -8 % on both plots 3b and 5b), Nisa (-0.7 m^2, i. e. -2.5 %) and Vimperk I (+9.6 m^2, i. e. -17 %).

The most pronounced effect of thinning consisted in decreased amount of basal area, which had to be removed as salvage cut (dead, broken and uprooted trees). While on all thinned plots (both from above and from below), the salvage cut in the period of investigation varied from 6 % (plot 5b of Mostek series) to 29 % (plot 2a of Nisa series), the salvage cut on control plots 1c without thinning represented 60 – 107 % of period basal area increment.

When excluding mostly unmarketable salvage cut, the basal area increment of thinned plots was on Vimperk I series by 59 % higher and on Mostek and Vimperk II series more than twice higher comparing with control plots. Special cases are Rumburk and Nisa series stressed by air pollution, where only thinned plots (2a and 3b) brought any marketable production as all basal area increment on control plots of these series had to be removed by salvage cut.

Diameter structure

Applying positive selection from above, it is expected, that diameter distribution will be wider with higher abundance of surviving thin trees. These expectations were not confirmed as effect of thinning by positive selection from above (comparative plots 2a of Rumburk, Nisa and Vimperk II series) lasting in 40-year period of investigation resulted in by 10 – 45 % decreased abundance of trees in lower diameter classes comparing to control plots of particular series (tab. 8). On the other hand, negative selection from below (variants 3b and 5b of Mostek, Nisa, Vimperk I and II) resulted in more pronounced decrease of thin trees abundance (by 50 - 69 % comparing to control plots).

Abundance of thick trees (mostly with diameter of 30 cm and more) increased on all comparative plots with thinning by 5 – 50 %. The special case was very heavy thinning from below applied on

Tab. 7: Total period basal area increment (including salvage cut) and period basal area increment without salvage cut (dead, broken and uprooted trees) in particular series of the 1st group of series in 1958 – 1998(99)

Series	Including salvage cut (m^2)								Excluding salvage cut (m^2)			
	1c	salvage cut	2a	salvage cut	3b	salvage cut	5b	salvage cut	1c	2a	3b	5b
Rumburk	28.3	30.2	33.9	5.1					*-1.9	28.8		
Mostek	37.9	23.1			35.0	4.2	35.3	2.1	14.8		30.8	33.2
Vimperk I	56.6	34.0			47.0	11.0			22.6		36.0	
Vimperk II	38.0	26.2	40.8	10.0	41.0	10.1			11.8	30.8	30.9	
Nisa	28.3	28.3	26.9	7.7	27.2	7.1			*0.0	19.2	20.5	

*Notes: 1c – control plots without thinning, 2a – comparative plots with thinning from above, 3b (5b) comparative plots with thinning from below, * - basal area decreased or did not change*

Tab. 8: Number of thin ($d_{1.3}$< 20 cm) and thick ($d_{1.3}$> 30 cm) trees ($N.ha^{-1}$) in particular series of the 1st group of series in 1998(99) – last revision

Series	Thin trees (< 20 cm) ($N.ha^{-1}$)				Thick trees (> 30 cm) ($N.ha^{-1}$)				Differences in frequencies of diameter distributions		
	1c	2a	3b	5b	1c	2a	3b	5b	1c/2a	1c/3b	1c/5b
Rumburk	72	44			184	264			ns		
Mostek	276		372	136	36*		16*	112*		+	ns
Vimperk I	400		124		280		300			+	
Vimperk II	752	416	248		120	180	140		+	+	
Nisa	80	72	40		160	172	176		ns	ns	

*Notes: 1c – control plots without thinning, 2a – comparative plots with thinning from above, 3b (5b) – comparative plots with thinning from below, * - thin trees with ($d_{1.3}$ < 29 cm) and thick trees with ($d_{1.3}$ > 40 cm) were observed in this series, + - statistically significant, ns – not significant*

comparative plot 5b of series Mostek, where the number of trees with diameter 40 cm and more increased comparing to control by more than 200 %, but this comparative plot showed significant differences in diameter distribution already in the beginning of observation.

Only exception between thinned stands is comparative plot 3b of Mostek series which showed by 35 % higher number of thin and 29 % lower number of thick trees than on control plot (significantly different frequencies of diameter distributions). The reason is probably different site conditions of particular comparative plots of this experimental series.

Static stability

Static stability characterized by h/d ratio of mean stem was influenced by thinning mostly positively, i. e. the final value of h/d ratio found by the last revision was principally lower (by 1 – 10 %) on thinned plots comparing to control plot without thinning (tab. 9). The only exception was

Tab. 9: Values of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) in particular series of the 1st group of series in 1998(99) – last revision

Series	Mean stem h/d				Dominant trees h_{200}/d_{200}				Differences in h_{200}/d_{200}		
	1c	2a	3b	5b	1c	2a	3b	5b	1c/2a	1c/3b	1c/5b
Rumburk	86	81			73	72			ns		
Mostek	94		98	85	85		88	77		+	+
Vimperk I	95		94		82		82			ns	
Vimperk II	104	98	98		86	82	84		+	+	
Nisa	74	76	71		63	65	61		ns	+	

Notes: 1c – control plots without thinning, 2a – comparative plots with thinning from above, 3b (5b) – comparative plots with thinning from below, + - statistically significant, ns – not significant plot 2a with high thinning (Nisa series) and problematic plot 3b with low thinning (Mostek series), where final h/d ratio increased comparing to control by 3 – 4 % respectively.

Similar picture was found evaluating of h/d ratio of dominant trees (200 thickest trees per hectare, i. e. the same number of individuals on each comparative plot). Mostly positive effect (with exception of variant 2a of Nisa and 3b of Mostek series) was statistically confirmed on variants 2a of Vimperk II series and on variants 3b of Vimperk II and Nisa series. The best results were achieved on variant 5b (Mostek series) with very heavy thinning from below, where h/d ratio of dominant trees descended comparing to control plot by 10 % (85 on control plot 1c and 77 on comparative plot 5b).

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VÝSLEDKY EXPERIMENTŮ V POROSTECH SMRKU ZTEPILÉHO VYCHOVÁVANÝCH NEGATIVNÍM A POZITIVNÍM VÝBĚREM PO 40 LETECH SLEDOVÁNÍ – SÉRIE ZALOŽENÉ V ROCE 1958

Souhrn

Rozsah experimentální základny pro výzkum výchovy lesních porostů byl před rokem 1955 malý a nedostatečný, většinou s krátkým obdobím sledování. Získávané výsledky tak nebyly dostatečně reprezentativní a použitelné pro praktické účely. Proto bylo v poválečných letech rozhodnuto vytvořit experimentální základnu pro získání exaktních podkladů pro řešení problematiky porostní výchovy hlavních hospodářských dřevin – smrku ztepilého (*Picea abies* /L./ Karst.) a borovice lesní (*Pinus sylvestris* L.). Tímto úkolem byl pověřen Výzkumný ústav lesního hospodářství a myslivosti Jíloviště-Strnady. V rámci projektu bylo založeno ve smrkových porostech v letech 1956 až 1973 celkem 46 experimentálních sérií ve čtyřech časových skupinách (1. skupina sérií v letech 1956 až 1958, 2. skupina sérií v roce 1960, 4. skupina sérií v letech 1963 až 1964 a 5. skupina sérií v letech 1971 až 1973). Jedna skupina sérií (v pořadí 3.) byla založena v porostech borovice lesní.

Z původních 46 experimentálních sérií se jich doposud dochovalo pouze 24. Ostatní série byly částečně nebo zcela zničeny působením sněhu a větru nebo dalších škodlivých činitelů. Předkládaná práce je orientována na první skupinu sérií (Rumburk, Mostek, Vimperk I, Vimperk II a Nisa), založenou v mladých smrkových porostech v roce 1958.

Pro sledování a vyhodnocování dlouhodobých experimentů s výchovou bylo použito metod založených na běžných postupech používaných v lesnickém výzkumu. Experimentální série byly založeny v souvislých tří až čtyřhektarových stejnověkých a nevychovávaných lesních porostech se shodnou expozicí a půdními a geologickými poměry, s vyloučením porostů okrajových, ohrožených větrem, sněhem a námrazou a rovněž porostů na prudkých svazích. Experimenty byly navrženy tak, aby bylo možné porovnat dva základní způsoby výchovy: úrovňové zásahy s pozitivním výběrem (2a) a podúrovňové zásahy s negativním výběrem (3b). Některé experimentální série byly doplněny variantou s extrémním zásahem do porostu – s prosvětlením (5b). Kontrolním prvkem celého experimentu jsou srovnávací plochy bez zásahu (1c), tj. dílčí plochy, na kterých se sledoval vývoj porostu bez úmyslných zásahů.

Intenzita výchovných zásahů byla stanovena pro první polovinu doby obmýtní na 15 – 10 % a pro druhou polovinu obmýtí na ca 10 – 6 % z počáteční výčetní kruhové základny za předpokladu plného zakmenění experimentálních porostů a pětileté pěstební periody. Při zakmenění nižším než 1,0 (např. 0,8 – 0,9) se doporučovalo snížit intenzitu na 30 – 50 % původní výše. Při dalších opakovaných zásazích se vždy přihlíželo ke stavu porostu. Největší redukce výčetní kruhové základny (30 % a více) byla prováděna na variantách s prosvětlením.

Všechna naměřená data byla vložena do databází. Základní zpracování se skládalo z vyhodnocení počtu stromů (N), výčetní kruhové základny porostu (G) v přepočtu na hektar a střední tloušťky (d),

a to při každém výchovném zásahu pro porost sdružený, hlavní a podružný. Tloušťka d_{200} byla vypočtena jako aritmetický průměr 200 nejsilnějších stromů na hektar. Pro všechny varianty na sériích byla sestavena výšková křivka (podle rovnice Näslunda), a to pro každou periodu sledování. Pomocí údajů o tloušťce a výšce byly vypočteny štíhlostní kvocienty h/d (pro střední kmen) a h/d_{200} (pro dominantní stromy), sloužící jako indikátory statické stability stromů, především odolnosti vůči kmenovým zlomům. V další fázi byla vyhodnocena tloušťková struktura experimentálních porostů.

Použitá metodika experimentů s výchovou nepředpokládala porovnávání individuálních sérií. Zejména rozdílná počáteční hustota porostů jednotlivých sérií zabraňuje použití metod porovnávání dílčích variant výchovy (obr. 31). Počáteční hustota experimentálních porostů se pohybovala od 2 016 jedinců (kontrolní plocha 1c na sérii Rumburk) do 4 828 jedinců na jeden hektar (kontrolní plocha 1c na sérii Vimperk II). Podobné rozdíly vykazovala i výčetní kruhová základna (od 29,1 $m^2 . ha^{-1}$ na sérii Mostek do 47,4 $m^2 . ha^{-1}$ na sérii Vimperk II). Sledované série lze rozdělit do dvou skupin: série s relativně nízkým počtem stromů (Rumburk, Mostek a Nisa – série s počáteční hustotou 2 016 až 2 604 jedinců na hektar) a série s relativně vysokým počtem stromů (Vimperk I a Vimperk II – série s počáteční hustotou 4 632 až 4 828 jedinců na hektar). Konečné vyhodnocení první skupiny sérií založené v roce 1958 je proto zaměřeno na společné jevy zjištěné na jednotlivých sériích.

Produkce experimentálních porostů, hodnocená podle periodického přírůstu výčetní kruhové základny, byla ovlivněna jednotlivými variantami výchovy rozdílně. Uplatňování pozitivního výběru v úrovni (varianta 2a) na sériích Rumburk, Nisa a Vimperk II vedlo ve dvou případech k vyššímu a v jednom případě k nižšímu celkovému přírůstu výčetní kruhové základny (včetně nahodilé těžby) ve srovnání s kontrolní variantou bez výchovy (tab. 7). Vyšší přírůst výčetní kruhové základny byl zjištěn na sériích Rumburk (+20 %) a Vimperk II (+7 %) a nižší na sérii Nisa (-5 %). Negativní výběr v podúrovni (varianta 3b nebo 5b), prováděný na sériích Mostek, Nisa, Vimperk I a Vimperk II, vedl v jednom případě k vyššímu a ve třech případech k nižšímu celkovému přírůstu výčetní kruhové základny (včetně nahodilé těžby) ve srovnání s kontrolní variantou bez výchovy. Vyšší přírůst výčetní kruhové základny byl zjištěn na sérii Vimperk II (+8 %) a nižší na sériích Mostek (-8 % na obou plochách 3b a 5b), Nisa (-2,5 %) a Vimperk I (-17 %).

Nejvýraznější efekt výchovy tak spočíval ve snížení podílu výčetní kruhové základny odstraněné při nahodilých těžbách (souše, zlomy, vývraty). Zatímco na všech plochách s výchovou (obě varianty – úrovňová a podúrovňová) se pohyboval podíl nahodilé těžby za celou dobu sledování v rozmezí 6 % (varianta 5b na sérii Mostek) až 29 % (varianta 2a na sérii Nisa), na kontrolních plochách představovala nahodilá těžba 60 – 107 % periodického přírůstu výčetní kruhové základny. Po odečtení nahodilé těžby (většinou hůře prodejné sortimenty) byl přírůst výčetní kruhové základny na vychovávaných plochách série Vimperk I o 59 % větší a na sériích Mostek a Vimperk II více než dvakrát větší ve srovnání s plochami kontrolními. Zvláštním případem jsou porosty série Rumburk a Nisa, které jsou pod dlouhodobým vlivem imisí. Na těchto sériích poskytovaly pouze vychovávané plochy (2a a 3b) prodejnou produkci, zatímco celý přírůst výčetní kruhové základny na kontrolních plochách těchto sérií byl odstraněn při nahodilých těžbách.

Všeobecně se předpokládá, že uplatňováním pozitivního výběru v úrovni dojde k rozšíření tloušťkové struktury porostu s větším zastoupením životaschopných tenkých stromů. Tento předpoklad nebyl na plochách s pozitivním výběrem v úrovni (srovnávací plochy 2a na sériích Rumburk, Nisa a Vimperk II) potvrzen. Po 40 letech sledování bylo zjištěno na plochách s touto variantou výchovy o 10 až 45 % méně stromů v nižších tloušťkových třídách ve srovnání s kontrolními plochami (tab. 8). Na druhou stranu u ploch s negativním výběrem v podúrovni (varianty 3b a 5b na sériích Mostek, Nisa, Vimperk I a Vimperk II) byl zaznamenán výraznější úbytek tenkých stromů (o 50 – 69 % ve srovnání s kontrolními plochami). Zastoupení silnějších stromů (s výčetní tloušťkou 30 cm a více) bylo na všech vychovávaných plochách o 5 – 50 % vyšší ve srovnání s plochami bez výchovy. Výjimku tvoří vychovávané porosty srovnávací plochy 3b na sérii Mostek, kde byl zjištěn o 35 % vyšší počet tenkých stromů a o 29 % nižší počet silnějších stromů než na ploše kontrolní. To bylo zřejmě způsobeno poněkud méně homogenními stanovištními podmínkami na této experimentální sérii.

Statická stabilita charakterizovaná štíhlostním kvocientem středního kmene a horního stromového patra (200 nejsilnějších stromů na hektar) byla ovlivněna pozitivně, tj. konečná hodnota štíhlostního kvocientu (středního kmene i horního stromového patra) byla principiálně nižší (o 1 – 10 %) na vychovávaných plochách ve srovnání s plochami bez výchovy (tab. 9). Výjimku tvořila pouze plocha 2a (série Nisa) s pozitivním výběrem v úrovni a dříve zmíněná plocha 3b (série Mostek) s negativním výběrem v podúrovni, na kterých byla konečná hodnota štíhlostního kvocientu o 3 – 4 % vyšší ve srovnání s plochami kontrolními.

RESULTS OF THINNING EXPERIMENTS WITH NEGATIVE AND POSITIVE SELECTION IN NORWAY SPRUCE STANDS AFTER 40 YEARS OF INVESTIGATION – SERIES ESTABLISHED IN 1958

Summary

The experimental basis for thinning research before 1955 was small and insufficient, mostly with short-time period of investigation and therefore, the received results were not representative and applicable for practical purposes. For that reason, it was decided to create new experimental basis with the aim of receiving exact experimental data for the thinning strategy in the forest stands of the main forest tree species – Norway spruce (*Picea abies* /L./ Karst.) and Scotch pine (*Pinus sylvestris* L.). This project was delegated to Forestry and Game Management Research Institute Jíloviště–Strnady. In the framework of the project, 46 experimental series were founded in Norway spruce stands in four time groups in the period 1956 – 1973 (1st group in 1956 – 1958, 2nd in 1960, 4th in 1963 – 1964 and 5th in 1971 – 1973). One group (in chronology the 3rd) was founded in Scotch pine stands.

From the original 46 experimental series, only 24 persisted to the present time. Other series were partly or completely destroyed mostly by snow and wind or other harmful factors. Presented contribution is oriented on the first time group of series (Rumburk, Mostek, Vimperk I, Vimperk II and Nisa), established in young Norway spruce stands in 1958.

The methods for founding and evaluation of long-term thinning experiments are based on the common techniques and methods used in forestry research towards easier comparing with similar experiments abroad (Pařez 1958).

Experimental series were located in at last 3 – 4 hectares large even-aged pure and untreated stands on the same exposition, similar soil conditions and parent rock. Border stands or localities endangered by wind, snow and icing were avoided as well as heavy slopes.

The thinning experiment was projected in order to compare two basic ways of thinning: positive selection from above (high thinning – 2a) and negative selection from below (low thinning – 3b). Some of experimental series were completed by the variant with heavy thinning (5 b), i. e. the opening up of a stand canopy. The test element of each experimental series is control plot (1c) without intentional thinning.

The intensity of one thinning treatment was determined to 15 – 10 % of basal area for the first half of rotation and to 10 – 6 % of basal area for the second half of rotation. Full stocking and five-year

thinning period was supposed. In case of stocking below 1.0 (for example 0.8 – 0.9), the thinning intensity decreased to 30 – 50 % of original amount. Thinning always reflected the actual state of a stand. Heavier reduction of basal area for 30 % or more was used on variants with release cuttings.

All measured data are included into databases. Primary calculation consisted in evaluation of number of trees (N), stand basal area (G) on hectare basis, and mean diameter from basal area (d) before and after each treatment and the same data for removed trees. The diameter d_{200} was calculated as an arithmetic mean of 200 thickest trees per hectare. Height curves (by Näslund equation) were calculated for all variants of each series and periods of investigation. The data on diameter and height were used for computation of h/d and h/d_{200} ratios serving as indicators of static stability of trees, especially their resistance to stem breaks. Finally, evaluation of diameter structure of experimental stands was achieved.

The method used in the thinning experiment did not suppose the replication inside the individual series, but using particular variants inside the group of the series as replication was not possible because of high initial differences between series (fig. 31). Especially high differences were found in initial density of experimental stands which varied from 2,016 individuals (control plot 1c on Rumburk series) to 4,828 individuals per hectare (control plot 1c on Vimperk II series). Similar differences appeared in basal area (from 29.1 m^2 on Mostek series to 47.4 m^2 on Vimperk II series). Investigated series can be divided into two groups: series with relatively low initial number of trees (Rumburk, Mostek and Nisa series with initial number of trees from 2,016 to 2,604) and series with relatively high initial number of trees (Vimperk I and Vimperk II series initial number of trees from 4,632 to 4,828). Final evaluation of the 1st group of series established in 1958 therefore concentrated on common phenomena observed on particular series.

Effect of thinning on production of the experimental stands evaluated on the period basal area increment was different. Positive selection from above (2a) included into series Rumburk, Nisa and Vimperk II resulted in two cases in higher and in one case in lower total period basal area increment (including salvage cut) comparing with control plot without thinning (tab. 7). Higher BA increment was found on series Rumburk (+20 %) and Vimperk II (+7 %) and lower increment on series Nisa (-5 %).

Negative selection from below (plots 3b or 5b) included into series Mostek, Nisa, Vimperk I and Vimperk II resulted in one case in higher and in three cases in lower total period basal area increment (including salvage cut) comparing with control plot without thinning. Higher BA increment was found on series Vimperk II (+8 %) and lower increment on series Mostek (-8 % on both plots 3b and 5b), Nisa (-2.5 %) and Vimperk I (-17 %).

The most pronounced effect of thinning consisted in decreased amount of basal area, which had to be removed as salvage cut (dead, broken and uprooted trees). While on all thinned plots (both from above and from below), the salvage cut in the period of investigation varied from 6 % (plot 5b of Mostek series) to 29 % (plot 2a of Nisa series), the salvage cut on control plots 1c without thinning represented 60 – 107 % of period basal area increment.

When excluding mostly unmarketable salvage cut, the basal area increment of thinned plots was on Vimperk I series by 59 % higher and on Mostek and Vimperk II series more than twice higher comparing with control plots. Special cases are Rumburk and Nisa series stressed by air pollution, where only thinned plots (2a and 3b) brought any marketable production as all basal area increment on control plots of these series had to be removed by salvage cut.

Applying positive selection from above, it is expected, that diameter distribution will be wider with higher abundance of surviving thin trees. These expectations were not confirmed as effect of thinning by positive selection from above (comparative plots 2a of Rumburk, Nisa and Vimperk II series) lasting in 40-year period of investigation resulted in by 10 – 45 % decreased abundance of trees in lower diameter classes comparing to control plots of particular series (tab. 8). On the other hand, negative selection from below (variants 3b and 5b of Mostek, Nisa, Vimperk I and II) resulted in more pronounced decrease of thin trees abundance (by 50 - 69 % comparing to control plots). Abundance of thick trees (mostly with diameter of 30 cm and more) increased on all comparative plots with thinning by 5 – 50 %. Only exception between thinned stands is comparative plot 3b of Mostek series which showed by 35 % higher number of thin and 29 % lower number of thick trees than on control plot. The reason is probably different site conditions of particular comparative plots of this experimental series.

Static stability characterized by h/d ratio of mean stem and h/d ratio of dominant trees (200 thickest trees per hectare) was influenced by thinning mostly positively, i. e. the final value of h/d ratio found by the last revision was principally lower (by 1 – 10 %) on thinned plots comparing to control plot without thinning (tab. 9). The only exception was plot 2a with high thinning (Nisa series) and problematic plot 3b with low thinning (Mostek series), where final h/d ratio increased comparing to control by 3 – 4 % respectively.

INTROSKELETAL EROSION OF FOREST SOILS ON ROCKY LOCALITIES

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ABSTRACT

A special type of soil erosion became frequent on some forest rocky localities in the Czech Republic. This type of erosion, called introskeletal erosion, was defined as a mostly vertical movement of soil particles into voids among the rocks. The introskeletal erosion endangers particularly rocky localities in mountain forests afflicted by air-pollution, bark-beetle disasters, and newly by fungi diseases. The introskeletal erosion affects already the soil layer under slowly disintegrating mature spruce stands but namely the soil layer of clear-cut areas. A case study from the Krkonoše Mts., where nearly 30 % of forest lands is exposed to introskeletal erosion, gives a good example of this erosion process. This process is the most frequently initiated by cutting down trees and is usually accelerated by skidding logs. The thin soil layer covering the rocks permanently decreases and the surface stoniness increases.

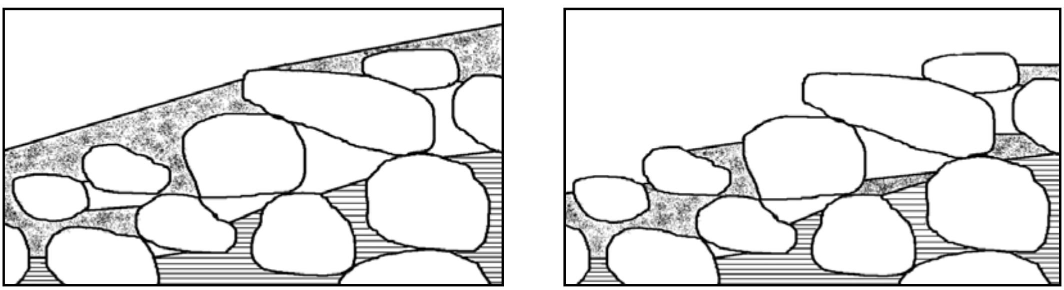

Fig. 1: Schematic sketch of the introskeletal erosion succession on a bouldery locality: the left-hand drawing shows a phase before infliction of introskeletal erosion, right-hand drawing shows a phase after infliction of that type of erosion (a mostly vertical dropping and washing of organic and inorganic soil particles from a surface layer through voids of the rocky skeleton into subsoil horizons of rock mantle – into hollows between rocks at bouldery grounds).

INTRODUCTION

A special type of soil erosion has occurred on some forest rocky localities in the Czech Republic. The type of erosion (fig. 1) was defined as a mostly vertical dropping and washing of organic and mineral soil particles through voids of the rocky skeleton into subsoil horizons of rock mantle – into hollows between rocks at bouldery grounds. We called it introskeletal erosion because we concluded that this erosion belongs neither to erosion forms like suffusion and biological erosion nor to soil mass movement like solifluction and geliflution.

Soil degradation on rocky sites where forest stands were cut down is also studied in other countries. Gorshenin (1974) presented high values of so called ”vnutriposhchvennaya” erosion on clear-cut boulder slopes of the Carpathian Mts. in Sub-Carpathian Russia while Bochter et al. (1981) reported on a great reduction in forest floor on stony clear-cut areas in Berchtesgaden National Park in the Alps. Childs, Flint (1990) studied physical properties of rocky soils connected with their fertility and possibilities of reforestation of those soils. As skeletal soils they defined soils with more than 35 % content of stones by volume. Boyles, Tajchman (1984) determined surface and subsurface stoniness of an entire 271-hectare forest watershed in the Appalachian Mts. Surface stoniness on northern exposures was lower than on the southern ones.

The introskeletal erosion endangers particularly rocky localities in mountain forests afflicted by air-pollution, bark-beetle disasters, and newly by fungi diseases. If these localities are extremely rocky and sunny, the introskeletal erosion can occur already at the progressive stage of forest tree die-back. Nevertheless, in the most cases the process of introskeletal erosion starts on forest soils by cutting down trees, and is usually accelerated by skidding. The mountain forest sites damaged by the introskeletal erosion cannot fulfil either wood-production or non-wood-production functions, especially flood and soil-erosion control (Šach et al. 2000).

The study from the Krkonoše Mts. gives a good example of an introskeletal erosion process. As documented by the results of surveys conducted by the Institute for Forest Management in Hradec Králové and reported in General Survey in 1989, the area of sites with hazard of introskeletal erosion had been roughly estimated at 9,000 ha (28 %) of the Krkonoše Mts. forest land resources.

The results of the General Survey challenged more detailed studies on this problem. The special survey of the area endangered by introskeletal erosion and investigation of its dynamics were carried out in the 1990s as a part of research projects supported by the Czech Ministry of Agriculture, the Czech Ministry of the Environment, and Dutch foundation FACE. The area endangered by introskeletal erosion was more accurately surveyed by Pašek (1991, 1993, 1994) and it was equalled to 6,201 ha (19.2 %) of the Krkonoše Mts. forest land resources. The risk of introskeletal erosion was especially localized on the ridges constituted of granite. Four degrees of introskeletal erosion risk were classified: extreme plots, localities at higher risk of introskeletal erosion, localities at middle risk of introskeletal erosion and localities at lower risk of introskeletal erosion. They occupied respectively 5.4 %, 1.2 %, 7.4 % and 5.2 % of the Krkonoše Mts. forest area (32,251 ha). The further inventory of area jeopardized by introskeletal erosion was made by Mikeska for the Regional plan of forest development elaborated by the Institute for Forest Management at Hradec Králové in 2000. He found 10,388 ha (30.5 %) of the Krkonoše Mts. forest land resources endangered by introskeletal erosion. Five degrees of introskeletal erosion risk were rated: very extreme plots, extreme plots, localities at very high risk of introskeletal erosion, localities at high risk of introskeletal erosion and localities at lower risk of introskeletal erosion. They occupied respectively 0.9 %, 9.4 %, 2.7 %, 5.8 % and 11.7 % of the Krkonoše Mts. forest area (33,965 ha).

Podrázský (1996, 1999) investigated introskeletal erosion with respect to variations in the intensity of mineralization processes. His results confirmed higher mineralization activities on clear-cuttings resulted in accelerated losses of organic matter and nutrients. Vacek et al. (1996a, 1999a) studied that erosion process in view of ground cover development. Their results documented dependence of vegetation dynamics on the introskeletal erosion. The aim of our investigation is to study introskeletal erosion dynamics described by changes in thickness of surface soil layer on rocks, surface stoniness, and microrelief topography.

MATERIALS AND METHODS

Research plots were established at sites exposed to introskeletal erosion in the Western, Central and Eastern Krkonoše Mts. Each research plot was selected to include both a clear-cut induced by air pollution and a control mature spruce stand. The Kamenice locality in the Western Krkonoše Mts., the locality of the Bílé Labe valley in the Central Krkonoše Mts., and the Obří důl locality in the Eastern Krkonoše Mts. were founded. The bedrock consisted of granite at the Kamenice and Bílé Labe localities, and of mica schist at the Obří důl locality. The slope ranged from 18° to 33°. More detailed description of the research plots shows table 1.

Tab. 1: Survey of basic data pertaining to the research plots

Plot	Mature spruce forest	Clear-cutting	Mature spruce forest	Clear-cutting	High-lead track	Mature spruce forest	Clear-cutting
Locality	the Western Krkonoše Mts.		the Central Krkonoše Mts.			the Eastern Krkonoše Mts.	
	Kamenice Jakšín		Bílé Labe Kozí hřbety		Malý Šišák	Obří důl Růžová hora	
Altitude a. s. l. (m)	1,040 – 1,060		980 – 1,050		1	1,000 – 1,080	
Aspect	NW		N		SW	NW	
Slope (°)	24	24	20	23	18	33	33
Forest site type	skeletal *Sorbeto-Piceetum* on bouldery and stony soils		stony *Piceetum* on stony soils of slopes		stony *Fageto–Piceetum* on stony soils of slopes	stony *Piceetum* on stony soils of slopes	
Soil conditions	non-evolved soil		imperfectly evolved humus podzol			imperfectly evolved humus podzol	
	on medium-textured biotitic granite		on transition to ranker or to podzol ranker on medium-textured biotitic granite, stony, bouldery, with loam-sand filling in base			on transition to ranker or to podzol ranker on muscovitic albitic mica schist, stony, bouldery, with loam-sand filling in base	
Year of establishment	1989		1988			1988	
Years after logging at time of establishment		4		2	2		1
Logging system		high-lead system		horse system	high-lead system		horse system

Dynamics of the introskeletal erosion was assessed by repeated examination of thickness of surface-soil layer (measured as a vertical distance from ground surface to rocks), surface stoniness, and microrelief topography on square partial plots 10 x 10 m. Three squares in control mature spruce stands and four squares on clear-cuts (1 - 4 years after logging) were established. One square of those placed on clear-cuts occupied a high-lead track.

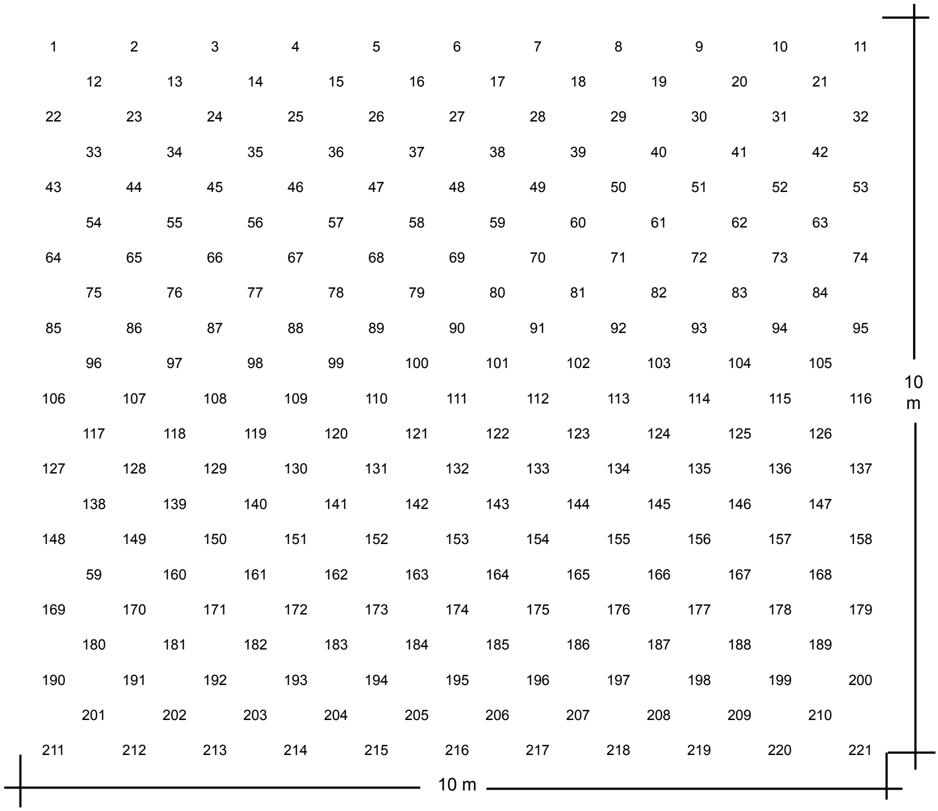

Fig. 2: Arrangement of sampling points on a square partial plot 10 x 10 m

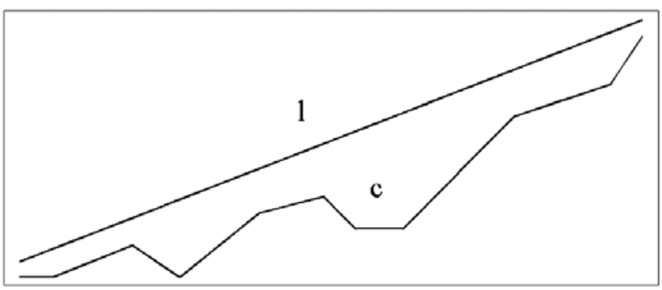

Fig. 3: Assessment of the index of terrain microrelief roughness on partial plots: c – curve following a ground surface, l – oblique line above terrain roughness; index of terrain microrelief roughness = (c / l)*100

Thickness of surface-soil layer (examined by vertical pushing the measuring stick into the ground until it contacted a rock) and portion of denuded stones were determined by a sampling point method. Investigations were carried out at 221 points (vertices and midpoints of the grid 1 x 1 m shown in fig. 2) on each of the seven partial plots.

The microrelief topography was described by a chain method (Saleh 1993). At each third part of a plot, lengths of those partial plots were measured at right angle to the contours. Firstly the chain followed a ground surface (including all mounds and depressions), secondly the chain was stretched along the terrain above its roughness. Percentage ratio of the first length and the second one was computed (fig. 3).

Investigations were conducted in 1988/89, 1992, 1995, and 1998. Experimental data were processed by statistical methods included in the computer program STATGRAPHICS7 Plus.

Tab. 2: Depth of soil on the partial plots in particular years

Locality	Partial plot	Year of measurement							
		1988/89		1992		1995		1998	
		Thickness of surface-soil layer (cm)							
		average	median	average	median	average	median	average	median
the West	stand	a 21.6 r	a 20 r	ab 20.8 r	ab 19 r	ab 19.4 r	b 17.5 r	b 19.6 r	b 17 r
Krkonoše	clear-cut	a 20.8 r	a 18 r	b 18.2 s	b 16 s	b 17.2 s	bc 15 s	c 15.0 s	c 13 s
the	stand	a 24.4 r	a 23 r	b 19.9 r	b 18 r	bc 19.2 r	b 16 r	c 16.4 r	c 14 r
Central	clear-cut	a 13.5 s	a 11 s	b 10.7 s	b 9 s	b 9.8 s	b 8 s	b 9.6 s	b 7 s
Krkonoše	track	a 10.6 t	a 7.5 t	ab 9.6 s	ab 7 s	bc 8.3 s	b 5 t	c 7.3 t	c 4 t
the East	stand	a 16.6 r	a 13 r	b 12.5 r	b 10 r	bc 11.8 r	bc 10 r	c 10.8 r	c 9 r
Krkonoše	clear-cut	a 15.9 r	a 13 r	b 10.8 r	b 8 s	c 11.4 r	b 8 r	bc 11.0 r	b 10 r

The various letters are used for significant differences at 0.05 probability level; a, b, c, … denote differences among years on the same partial plot and r, s, t, … denote differences among partial plots on the same locality.

Tab. 3: Surface stoniness on the partial plots in particular years

Locality	Partial plot	Year of measurement			
		1988/89	1992	1995	1998
		Surface stoniness (percentage of area)			
the West	stand	a 2.3 r	a 1.4 r	a 2.3 r	a 2.7 r
Krkonose	clear-cut	a 9.0 s	a 5.4 s	a 6.3 r	a 6.8 r
the	stand	a 1.4 r	a 0.9 r	a 1.4 r	a 2.3 r
Central	clear-cut	a 12.2 s	a 16.3 s	a 14.0 s	a 15.8 s
Krkonose	track	a 31.2 t	a 26.2 t	a 28.0 t	a 35.7 t
the East	stand	a 12.7 r	a 12.7 r	a 10.9 r	a 15.8 r
Krkonose	clear-cut	a 20.4 r	b 33.5 s	ab 24.4 s	a 19.4 r

The various letters are used for significant differences at 0.05 probability level; a, b, c, … denote differences among years on the same partial plot and r, s, t, … denote differences among partial plots on the same locality.

Tab. 4: Index of terrain microrelief roughness on the partial plots in 1995

Locality	Partial plot	Index of terrain microrelief roughness (%)	
		average	median
the West	stand	110 r	110 r
Krkonose	clear-cut	123 s	123 r
the	stand	113 r	111 r
Central	clear-cut	121 r	123 r
Krkonose	track	119 r	120 r
the East	stand	110 r	111 r
Krkonose	clear-cut	127 s	123 r

The various letters are used for significant differences at 0.05 probability level; r, s, t, … denote differences among partial plots on the same locality.

RESULTS

Depth of soil on rocks, measured to determine a reduction in thickness of surface soil layer, proved as a statistical variable with left-peaked distribution of a type not yet defined (coefficient of variation 85 %, skewness 1, and kurtosis 1). This is the reason why the median can be considered as a more convenient central tendency than the arithmetic mean. Besides parametric tests (especially paired t-test) and analysis of variance, their nonparametric parallels were used to test differences in mean values (tab. 2).

Lower values of surface soil layer thickness on clear-cut areas (including the high-lead track) than under mature spruce stands (2/3 of the differences are statistically significant) document more intensive introskeletal erosion after clear felling and skidding. In general, the thickness of the surface soil layer is reduced by gradual disappearance of ground vegetation and surface soil creeping away from stones, and by vertical sinking of soil particles through voids among boulders into the depths.

Surface stoniness expressed as a percentage of all land that is stony (tab. 3) indicated significant differences between forest stands, clear-cut areas and high-lead track (when a rate test was used). But time variations in surface stoniness (even with a slightly increasing trend) were statistically insignificant.

Microrelief topography (tab. 4) expressed by index, described in chapter Materials and Methods, was usually more variable on clear-cut areas than under forest stands. If the arithmetical mean was used as the mean value, the statistically significant differences were found. The average index of microrelief topography was 111 % under forest stand, 124 % on clear-cut areas, and 119 % on the high-lead track. As the sample size was small (three measurements per square partial plot), the median was also used, but it did not demonstrate any statistically significant differences between clear-cut areas and forest land.

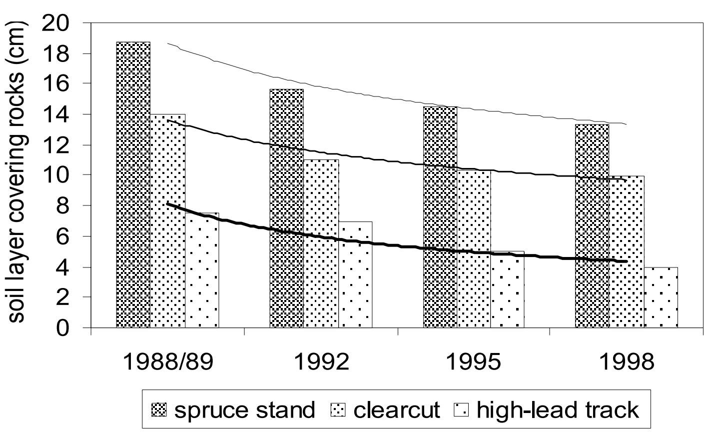

Fig. 4: Dynamics of the introskeletal erosion in the forest region of the Krkonose Mts.

DISCUSSION AND CONCLUSION

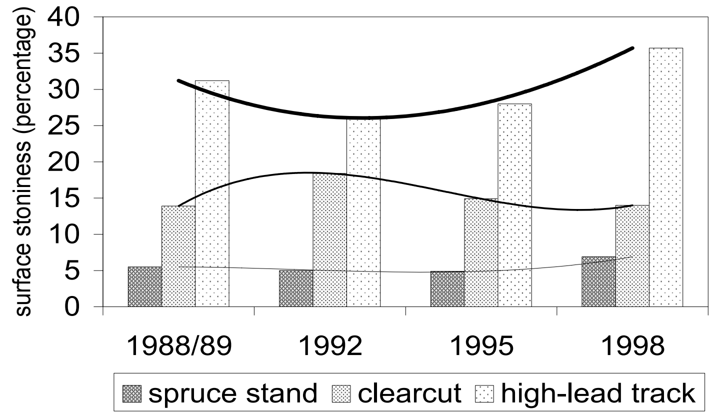

Fig. 5: Dynamics of the surface stoniness in the forest region of the Krkonose Mts.

The time series of four measurements carried out within ten years confirmed that introskeletal erosion had been still in progress at rocky localities. The similar conclusion also ensued from surveying area in risk of introskeletal erosion performed by Institute for Forest Management in Hradec Králové (Pašek found 6,201 ha at the beginning of 1990s and Mikeska found 10,388 ha at the end of 1990s). The soil layer covering stones and boulders is constantly reduced (fig. 4). Surface stoniness (fig. 5) is (if insignificantly) increasing and it is broadcasting also by expansion of originally small rocky islets. Following reduction of thickness of surface soil layer and displacement of soil particles into underlier, the microrelief topography on clear-cut areas gets also more variable (emerging stones and boulders, forming terrain depressions, tab. 4). As shown by figure 4, introskeletal erosion affects not only clear-cut areas but also the ground surface under slowly disintegrating mature spruce stands. From all reasons mentioned above, introskeletal erosion-control measures were proposed and its research was initiated (Vacek et al. 1996b, 1999b – underplantings, Nárovec, Šach 1996 – applications of natural amending materials at outplanting, Kriegel 1996, 1999 – special reforestation technologies).

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INTROSKELETOVÁ EROZE LESNÍCH PŮD NA KAMENITÝCH LOKALITÁCH

Souhrn

Introskeletová eroze je definována pro kamenité lokality jako převážně vertikální transport půdních částic z povrchové vrstvy mezerami mezi balvany do spodin zvětralinového pláště. Do introskeletové eroze se promítá také chřadnutí, usychání a rozpad původní přízemní vegetace a mineralizace nadložního humusu. Výsledkem je obnažování kamenů a balvanů a vystupování sutí (obr. 1).

Horské území vhodné pro studium introskeletové eroze představují Krkonoše, kde je ohroženo zhruba 30 % lesních pozemků. Proces introskeletové eroze je nejčastěji iniciován kácením stromů a umocněn transportem kmenů. Introskeletová eroze atakuje zejména povrch holosečí, ale objevuje se i na půdním povrchu pod chřadnoucími, rozpadajícími se smrčinami.

V devadesátých letech minulého století byl zahájen průzkum rozsahu introskeletové eroze a výzkum její dynamiky. Studie byly podporovány MZe ČR, MŽP ČR a holandskou nadací FACE (Forests Absorbing Carbondioxide Emission).

Průzkum rozsahu introskeletové eroze prováděl Ústav pro hospodářskou úpravu lesů v Hradci Králové. K mapování ploch s nebezpečím introskeletové eroze využíval lesní typy. Šetření rezultovalo v klasifikaci ohroženosti lesních pozemků Krkonoš. Na počátku devadesátých let vylišil PAŠEK 6 201 ha a koncem devadesátých let MIKESKA již 10 388 ha ploch ohrožených introskeletovou erozí.

Šetření dynamiky introskeletové eroze prováděla Výzkumná stanice Opočno na třech výzkumných plochách: jedné v západních, jedné ve středních a jedné ve východních Krkonoších (tab. 1). Hodnocení dynamiky introskeletové eroze se provádělo na základě měření tloušťky půdní vrstvy pokrývající suť (měření vertikální vzdálenosti úrovně suti od povrchu terénu), zjišťování podílu povrchové kamenitosti, měření členitosti mikroreliéfu terénu a pozorování půdního krytu. Šetření se konala na srovnávacích plochách pod dospělými smrkovými porosty a na holosečích.

Časová řada čtyř šetření v průběhu deseti let prokázala, že introskeletová eroze na kamenitých a balvanitých lokalitách pokračuje (podobné závěry vyplývají také z šetření Ústavu pro hospodářskou úpravu lesů v Hradci Králové). Tloušťka půdy pokrývající suť se trvale zmenšuje (tab. 2, obr. 4). Povrchová kamenitost se zvětšuje (tab. 3, obr. 5) a to zejména v důsledku rozšiřování suťových ostrůvků. Ztenčování a mizení půdní vrstvy je indikováno také zvyšováním členitosti mikroreliéfu terénu (vystupováním kamenů a balvanů, vytvářením depresí, tab. 4). Byla navržena ochranná a meliorační opatření, kterými se zabývají vybrané práce uvedené v seznamu publikací.

INTROSKELETAL EROSION OF FOREST SOILS ON ROCKY LOCALITIES

Summary

The introskeletal erosion is defined as a dominantly vertical removement of soil particles into voids among stones on bouldery localities. The introskeletal erosion includes yet further phenomena: declining, drying and decaying of original low vegetation, prompt mineralization of forest floor and emerging stones and boulders (fig. 1).

A case study from the Krkonoše Mts., where roughly 30 % of forest lands is exposed to introskeletal erosion, gives a good example of that erosion process. The introskeletal erosion process is the most often initiated by tree felling and strengthened by timber skidding. The introskeletal erosion affects not only the surface of clear-cuttings but also the soil surface under the slowly disintegrating mature spruce stands.

In the 1990s the special exploration of introskeletal erosion extent and investigation of introskeletal erosion dynamics were performed as a part of research projects subsidized by the Ministry of Agriculture and Ministry of Environment of the Czech Republic and by the Dutch Forests Absorbing Carbondioxide Emission Foundation.

The exploration of introskeletal erosion extent was based on site rating Krkonoše Mts. lands with using of forest typology. The Institute of Forest Management at Hradec Králové performed surveying area in risk of introskeletal erosion. At the beginning of 1990s Pašek found 6,201 ha. The risk of introskeletal erosion was especially localized on the ridges constituted from granite. At the end of 1990s Mikeska found 10,388 ha.

The examination of the introskeletal erosion dynamics was carried out on three research plots in the west, middle and east Krkonoše Mts. (tab. 1). The determination of introskeletal erosion was made by measurement of stone level below soil surface, measurement of surface stoniness, measurement of terrain microrelief roughness and by observation of ground cover. Those measurements were made on comparing plots under mature spruce-stand canopy and on clearcuts.

The time series of four observations during ten years proved that introskeletal erosion had been running on stony and bouldery sites (similar conclusions came also from the Institute for Forest Management at Hradec Králové). The depth of soil, covering the rockfields, has permanently decreased (tab. 2, fig. 4). The surface stoniness has increased due to broadening the primal small stony focus (tab. 3, fig. 5). Diminution and loss of soil layer reflects in increase of terrain microrelief roughness (emergence of stones and boulders, depression arising, tab. 4). The conservation ameliorative measures were proposed and realized, others are searched. These measures were reported in articles mentioned in references.

SILVER FIR (*ABIES ALBA* MILL.) IN LIMITING ECOLOGICAL CONDITIONS

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ABSTRACT

This article presents results from investigation on the experimental plot no. 57 – Forests Jíloviště, Cukrák where 19 silver fir provenances are growing. The plot was established in 1975 with 9 provenances from the Czech Republic, 2 from Slovakia and 2 from Bosnia and Herzegovina and after one from Germany, from Austria, from France, from Romania and from Italy. The plot has been located in for silver fir nearly extreme elevation of 360 m. For synthetic assessment of partial populations three indicators were used on this experimental plot: degree of survival as indicator of viability, height and diameter growths.

INTRODUCTION

In the past silver fir, growing in the original forests of central Europe and in the Czech Republic as well, used to occur very frequently in the highlands and mountainous areas up to subalpine spruce stands. For example SAMEK (1967) mentions this fact in his work that deals with silver fir distribution in the postglacial time. Relatively high representation of silver fir in the CR territory in the past, based on historical survey of forests composition (NOŽIČKA 1957, MRÁZ 1959 et al.), is documented by many authors. The original silver fir distribution in forests of the Czech Republic is estimated for 16 % (ŠINDELÁŘ 1995, VOKOUN 1995). Fir had occurred more or less in mixed stands, only exceptionally like unmixed stands in some forest vegetation zones, ranging mainly from zone 3 – oak-beech to zone 7 – beech-spruce. Optimal distribution for fir was forest vegetation zone 5 – fir-beech, especially sites on heavier loamy to clay soils, gleysoils and partly water-logged soils. Due to historical development of forest husbandry in the Czech Republic, the fir proportion was gradually reduced in favour of Norway spruce and partly Scots pine to a less than 1 % according to plot at present. Health state worsening was another cause of fir retreat from forest stands. Many authors analysed fir decline caused by bad health state, for example KANTOR et VINCENT (1966), POLENO (1977), ZAKOPAL (1978), MÁLEK (1981), BROŽ (1982) and others. Besides indirect consequences of silvicultural technique, mainly of forest stands regeneration systems, fir decline has been caused by unfavourable climatic conditions, browsing of growth advances and cultures, by insect and fungal diseases, etc. Recently other harmful anthropogenic agents have impacted the environment, above all air pollution often accompanied with worsening of forest soils.

Despite the mentioned state silver fir is still taken for important tree species in the Czech Republic both from economical and ecological viewpoint and it is necessary to adequately promote fir in tree species composition of forest stands. Its high volume production of biomass is one of its positive properties in forest ecosystems. At present fir is irreplaceable on heavier packed soils, especially on gleyed sites of medium and higher altitudes. Silver fir, admixed in forest stands, creates demanded forms of humus; its root systems penetrate into the deeper soil layers and stabilize the stands.

In the half of the 1990s a desirable perspective arrangement for forest species composition in the Czech Republic was worked out both by the Forestry and Game Management Research Institute (FGMRI) Jíloviště-Strnady (Šindelář 1995) and Forest Management Institute at Brandýs nad Labem (Vokoun 1995). According to these proposals the fir proportion is planned to increase on 4 or 5 % in future. This conception was approved by the Ministry of Agriculture Decree no. 83/1996 Coll. on regional plans for forest development and specification of management units. This decree has not considered the fir as the basic tree species in any of 24 management units; however, silver fir is proposed as the alternative ameliorative and reinforcement tree species in 22 of the total amount of 24 sets. This tree species can become a part of stand composition even on extraordinary unfavourable sites, on 10 of 22 sets of forest types that are defined for these conditions. Investigation indicates very wide ecological amplitude of this species and great possibilities of its use as admixture in very different site conditions of the Czech Republic forests.

RESEARCH OBJECTIVES

Although the importance and perspectives of silver fir were not precisely formulated until the late 1990s, they were generally known both in forest practice and forest research in the last decades. This fact documents relatively rich literature, mainly periodical within European countries and specifically in the Czech Republic and Slovakia. Many partial problems were solved; attention was given also to problems of silver fir variability from the viewpoint of health state, vitality, production ability with special regard to perspectives of partial and regional populations for forest practice. The oldest known provenance trials were carried out in Switzerland (Engler 1905), then in Italy (Pavari 1951), in Denmark (Løfting 1954). In the Czech Republic territory Vinš established the oldest plantings in 1964 assessing them (Vinš 1966). Investigations of J. Kantor are approximately from the same and following years being focused above all on selection of vital and increment trees and on assessment of their progenies. Kantor (1967, 1974, 1982) dealt with interspecific hybridization, at present Kobliha (1983, 1988), Kobliha, Janeček (2005a, b), Janeček, Kobliha (2007), etc. have continued in this research.

Investigation of Vinš (1966) has become a research base of variability and breeding of silver fir for needs of Czech forestry. In the early 1970s comparative plots with silver fir of various origins and of some other species of *Abies* genus were established in the FGMRI Jíloviště-Strnady. Czech Republic assortment is represented by 69 provenances; material gained from abroad is from 11 countries.

In 1973 – 1977 period 20 experimental plots were established from material planted from seed. Research objectives were defined as following (Šindelář 1974):

- to deepen theoretical knowledge on silver fir variability and get information for further cultivation
- to get some more information on variability of economically significant features and properties of silver fir
- to contribute for *Abies alba* species preservation for CR forestry on base of mass selection
- to propose partial populations (provenances) for preferential use in forestry and define principles of their regionalization
- to find which of other fir species could enrich or replace silver fir under certain conditions

This article presents evaluation of experimental plot no. 57 – Forests Jíloviště, Cukrák, that was established in conditions for silver fir extreme in the sense of average temperature, sum of annual precipitation and soil conditions (soil desiccation). Silver fir is bred on the forest types 1H – loess hornbeam-oak stand, that has such conditions, in which silver fir occurs in species composition very rarely. But regulation of the Decree no. 83/1996 Coll. intends to use silver fir in these conditions like the ameliorative tree species. Foundation of experimental plot with silver fir is aimed at gaining information of limiting ecological conditions for this tree species cultivation.

MATERIALS AND METHODS

Materials

Due to relatively small plot for planting only limited number of provenances is represented on plot no. 57 – Forests Jíloviště, Cukrák. Table 1 presents a survey of 19 partial populations, that are growing on this experimental plot. This set contains 9 provenances from the Czech Republic, of which 8 come from the Hercynian-Sudeten natural forest zones and only one from the Carpathian area, 2 provenances are from Slovakia, after one partial population origins from Austria, Germany,

Tab. 1: Survey of represented provenances

Provenance no.	Country	Name	Region	Natural forest area	Elevation (m)
32	CR	Nýrsko, Dešenice	3.05.4	12	500
71	CR	VLS Plumlov, Ruprechtov	3.14.0	30	450 - 510
74	CR	Milevsko, Klučenice	3.12.0	10	380
81	CR	Vyšší Brod, Vitkův Kámen	3.05.4	13	800 - 900
82	CR	Vizovice, Bratřejov	6.07.0	38	550
83	CR	Kašperské Hory, Rejštejn	3.05.4	13	860
87	CR	VLS Hořovice, Jince	3.07.0	7	520 - 540
93	Austria	Wörschachwald, Steiermark	5.04.3	-	1,100 - 1,200
104	France	Race de l´ Aude	4.05.0	-	800 - 1,040
130	CR	Nasavrky, Podhůra	3.13.0	16	370
132	Bulgaria	Boroveč, Rila	6.26.0	-	1,600
146	FRG	Schwarzwald, Schönmünzach	3.32.0	-	530 - 650
215	Romania	Vilcea	6.19.0	-	800
221	CR	Janovice u Rýmařova, Malá Morávka	3.05.1	27	720 - 730
224	Bosnia	Sokolac	6.22.0	-	1,060
225	Bosnia	Vitez	6.22.0	-	1,200
229	Italy	Campobasso	9.13.0	-	1,100 - 1,300
S_1	Slovakia	Banská Bystrica, Badín	6.07.0	-	800
S_{14}	Slovakia	Svidník, Komárnik	6.06.1	-	480

France, Italy, Romania, Bulgaria and two provenances are from the Republic Bosnia and Herzegovina. European forest regions (Rubner, Reinhold 1953) are represented by 5 units: central European region of beech-oak forests, western European region of deciduous tree species, Alpine region, eastern European and southern European region of oak-beech forest and southern European region of hard-wooded broadleaves and chestnut forests. Within each region one or more forest areas are represented. Provenance from the Czech Republic originate from 7 natural forest zones (Plíva, Žlábek 1986) from the elevations of 370 to 900 m.

Provenances growing on the plot no. 57 – Forests Jíloviště, Cukrák come from very different site conditions. Their parent stands are growing in the elevations ranging from 370 m (Czech provenance no. 130 – Nasavrky, Podhůra) to 1,300 m (Italian provenance no. 229 – Campobasso).

For assessing variability of partial populations with silver fir a classification of origin according to sets of Hercynian-Sudeten and Carpathian natural forest zones is important because of their different historical development (different refugia in the glacial time) (Samek 1967). This assessment cannot be taken for quite reliable because only one population no. 82 – Vizovice, Bratřejov, represents the set of natural forest zones from the Carpathian region.

Plants for the plot no. 57 were grown in the experimental forest nursery Baně. Two-year old seedlings were cultivated in nursery to the age of four years.

Methodology

Research plot no. 57 situated in the former FGMRI Administration of Experimental Forest Objects Jíloviště-Strnady, forest district Jíloviště, locality Cukrák, stand $37H_3$ was outplanted in spring 1975. This plot in the elevation of 360 m lies on very mild northwestern slope with 10° inclination. Geological parent rock is formed by Algonkian shales that are covered by loess of variable thickness. Typologically is the soil classified as typical Cambisol. It is heavier, loamy, with very good supplies of mineral nutrients. From the data of the nearest meteorological station and respecting local conditions estimated average annual temperature is 9.3 °C and annual sum of precipitation 480 mm. Soil is very dry; one of the causes is very low annual precipitation. The set of forest types is classified as 1H – loamy hornbeam-oak stand. Regarding the ecological conditions, mainly soil desiccation and low sum of annual precipitation, this site can be marked like limiting even extreme for silver fir.

Planting was carried out in three stripes 20 m wide in coppice with oak prevalence and low admixture of hornbeam and birch. The stripes in slope direction of length about 200 m were used for planting. The plot was established in three repetitions by method of random block arrangement. So, each progeny has been tested in total number of three lots of size 10 × 10 m, which represents 50 plants per each lot. Total number of experimental lots is 57 with spacing 2 × 1 m. Marginal stripes were not necessary to be established because margins of lots were relatively near to the neighbouring forest stand.

After planting in spring 1975 the plot was fenced and lots were demarcated by wooden stakes. Weed when needed was plucked out. Plot development was satisfactory; losses in the first years after planting were relatively low so that the plot needed no improvement. Self-sowing tree species, mainly birches and oak shoots, were cut down three times until culture closing. Most of higher losses appeared first after the culture was closed.

The first measurement and evaluation on the plot were done at the age of 13 years. Proportion of growing individuals was recorded; height measured and assessed as well as damage degree (Hynek 1985).

In autumn 1998, i. e. at the age of 28 years, another measurement was done; from the total planted amount of 2,850 plants, 1,088 individuals survived until now, i. e. on average 38 % of original number of plants. Due to losses caused by competition and dead trees no tending operation was realized on the plot.

Results of the 1998 measurement are presented in this contribution. Height and diameter growth were measured and health state of firs was assessed. Basic mathematical and statistical characteristics were calculated for heights and d.b.h. Variability was defined by variance analysis based on model for two causes of variability:

$$y_{ij} = \mu + p_i + o_j + e_{ij}$$

where y_{ij} is value of i-progeny in j-repetition, μ represents average of trial, p_i is effect of i-progeny in relationship to average of trial, o_j is effect of j-repetition in relationship to average of trial, e_{ij} represents random derivation from average of trial (experimental error).

Average effects of provenances and repetitions as well as proportions belonging to non-controlled factors were calculated by means of variance analysis and by solving appropriate normal equations (Weber 1961).

Value of repeatability (heritability) as a criterion for accuracy of trial was calculated according to formula:

$$h^2 = \frac{V_p}{V_p + \frac{V_E}{b}}$$

where V_p is variance component calculated from differences among average values of individual progenies, V_E represents variance component responding to experimental error, b is number of repetitions in the trial.

Differences among individual provenances were calculated both for height growth and d.b.h. by Duncan multiple sequential test.

RESULTS AND CONCLUSION

Results of investigation are summarized in tables 2 – 5 and in figures 1 – 3. The plot was outplanted by 2,850 plants of which 1,088 individuals survived until 28 years of age, i. e. 1,909 individuals per ha. Losses in particular provenances are irregular, but total number is quite sufficient for arithmetical evaluation. Investigation showed that survived individuals are vital even despite unfavourable ecological conditions and drought during vegetation period. There are no differences in viability among provenances at the age of 28 years.

Height growth of silver fir provenances on locality 57 – Forests Jíloviště, Cukrák at the age of 28 years was analysed and summarized as follows:

- If the relatively extreme site for silver fir is considered, the height growth is slow and responds, in average of all represented partial populations, to absolute age class 21 for mean heights at the age of 100 years according to growth tables approved by the Ministry of Agriculture Decree no. 84/1996 Coll., on forest management planning. If we consider relative age class (e. g. Schober 1995), then the set could be classified into the 2nd – 3rd bonity degree (site class).
- Proportion of growing silver firs is average on this plot (at the age of 28 years 40 % of the originally planted individuals is viable) and is comparable with the data from other plots of the same project

Tab. 2: Characteristics of height growth at the age of 28 years

Prov. no.	n (pcs)	$\bar{x}$ (m)	sx (m)	$s\bar{x}$ (m)	Vk (%)
32	49	2.18	2.31	0.33	44.70
71	64	6.13	2.31	0.29	37.72
74	61	6.17	2.26	0.29	36.54
81	24	4.25	2.14	0.44	50.33
82	94	6.38	2.48	0.26	38.87
83	63	4.61	2.05	0.26	44.48
87	69	6.20	2.20	0.26	35.46
93	17	3.79	1.76	0.43	46.35
104	38	4.03	1.96	0.32	48.57
130	64	6.00	2.42	0.30	40.36
132	84	5.79	1.93	0.21	33.38
146	78	6.21	2.30	0.26	37.00
215	20	2.73	0.97	0.22	35.52
221	25	3.36	1.57	0.31	46.86
224	45	4.86	1.94	0.29	39.89
225	48	4.66	2.24	0.32	48.17
229	30	4.88	2.07	0.38	42.36
S_1	70	5.43	2.28	0.27	42.02
S_{14}	65	5.37	2.21	0.27	41.22

Tab. 3: Variance analysis for height growth of silver fir (1998)

Cause of variability	N	Sum of squares	Average square	F		Critical F for p = 1 - α	
						α = 0.05	α = 0,01
Provenance	18	72.75	4.04	3.64	++	1.90	2.48
Repetition	2	12.72	6.36	5.73	++	3.26	5.25
Residual	36	39.95	1.11				
Total	56	125.42					

where nearly all trees are growing in conditions for fir ecologically more favourable than those on locality no. 57.

– Values of average heights of provenances on the plot range from interval 2.18 to 6.38 m. Differences among average heights are statistically significant. Value of repeatability (heritability) for heights $h^2 = 0.73$ and proves the demanded reliability of the trial.

According to Rubner, Reinhold (1953) partial populations from all regions are represented on the plot in some cases only by one provenance. Provenances from central European beech-oak forests and eastern European region of beech-oak forests are on average the best growing. Provenances from

Tab. 4: Characteristic of d.b.h. at the age of 28 years

Prov. no.	n (pcs)	$\bar{x}$ (cm)	sx (cm)	$s\bar{x}$ (cm)	Vk (%)
32	49	5.57	3.81	0.54	68.42
71	64	7.06	3.52	0.44	49.80
74	61	7.07	3.48	0.45	49.22
81	24	5.33	4.16	0.85	78.00
82	94	7.26	3.51	0.36	48.43
83	63	5.29	3.31	0.42	62.65
87	69	7.30	3.61	0.43	49.41
93	17	4.18	3.15	0.76	75.38
104	38	4.37	2.89	0.47	66.18
130	64	6.89	3.73	0.47	54.06
132	84	7.13	3.38	0.37	47.45
146	78	7.17	3.42	0.39	47.68
215	20	2.60	1.46	0.33	56.26
221	25	3.72	2.62	0.52	70.31
224	45	6.20	3.35	0.50	54.04
225	48	5.77	3.80	0.55	65.82
229	30	6.23	3.69	0.67	59.26
S_1	70	6.90	3.67	0.44	53.12
S_{14}	65	6.23	3.38	0.42	54.28

Tab. 5: Variance analysis for d.b.h. of silver fir provenances (year 1998)

Cause of variability	N	Sum of squares	Average square	F		Critical F for p = 1 - α	
						α = 0.05	α = 0.01
Provenance	18	124.10	6.89	3.87	++	1.90	2.48
Repetition	2	53.20	26.60	14.95	++	3.26	5.25
Rezidual	36	64.07	1.78				
Total	56	241.37					

the Alpine and western European regions are characteristic by weaker height growth. Experiences both from the Czech Republic plots and from abroad show that growth of provenance from the southern European region (Italy) is average or even above-average.

Of the Czech Republic provenances above all partial populations from natural forest zones 10 – Středočeská Upland, 7 – Brdská Upland, 16 – Českomoravská Highland are characteristic by above-average growth, of the Carpathian provenance those from the White Carpathians and Vizovické Upland. Provenance no. 27 from the central mountainous area of the Hrubý Jeseník Mts. is of lower growth.

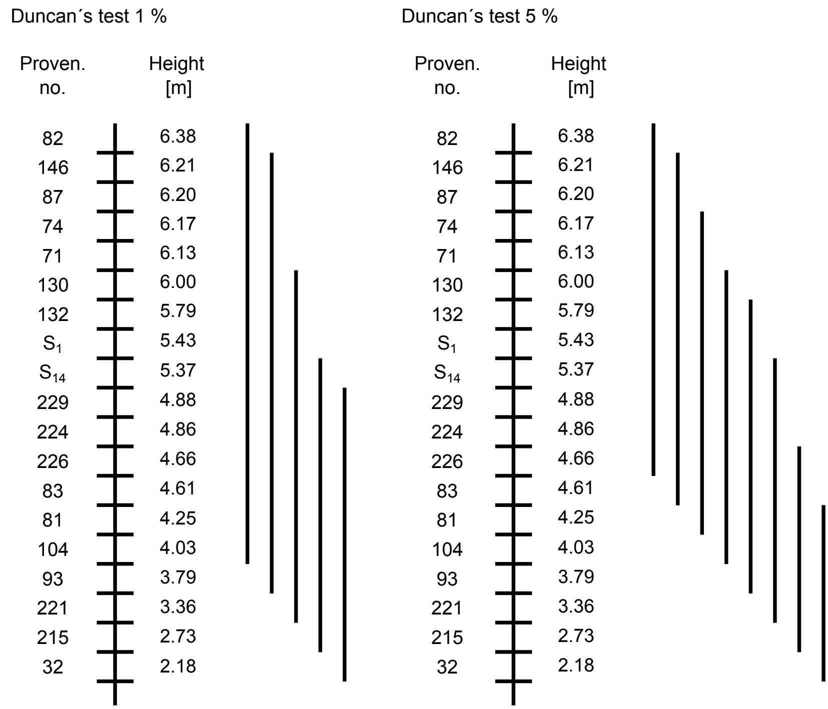

Fig. 1: Results of Duncan test for height growth assessment for silver fir provenances in 1998

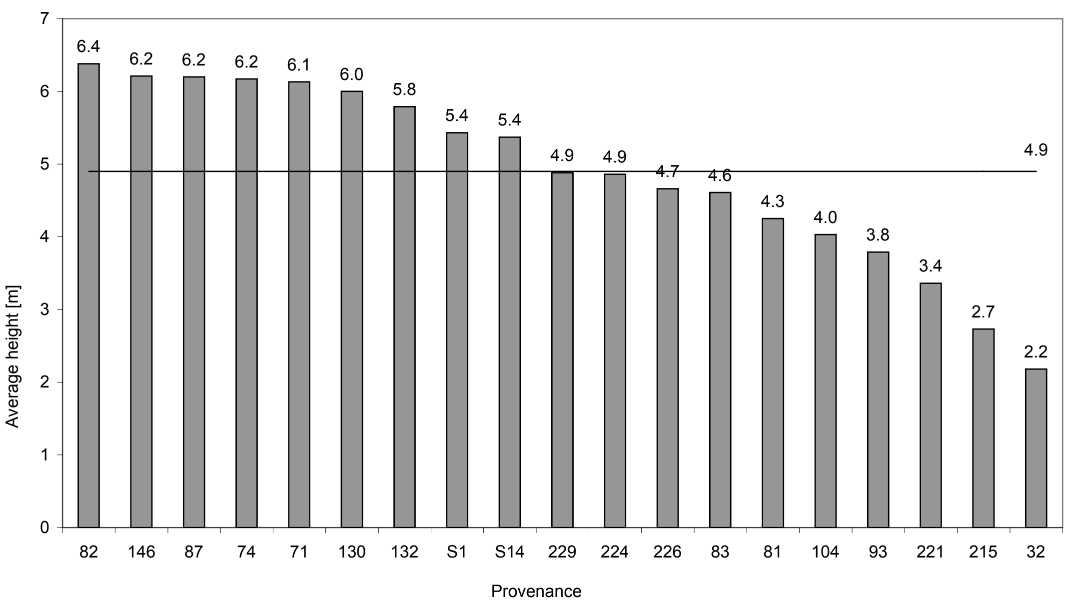

Fig. 2: Graphical course of average heights for silver fir provenances on the plot no. 57

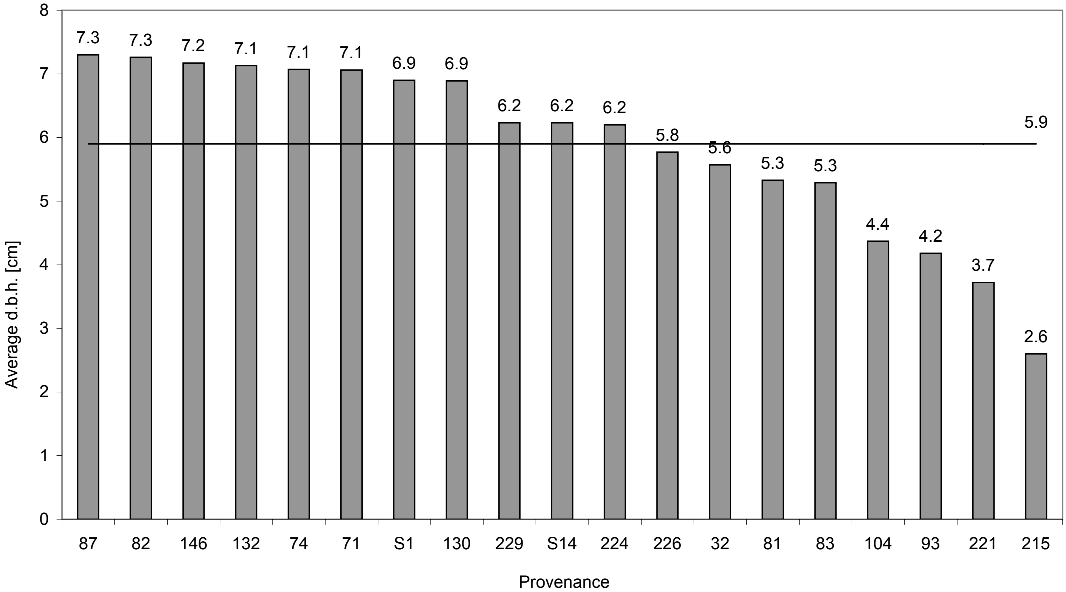

Fig. 3: Average d.b.h. graphical course

Average height values of provenances of different historical origin from the former Czechoslovakia (Hercynian-Sudeten region on one side and the Carpathian one on the other side) do not differ on average.

Influence of elevation of parent stand locality on height growth of progenies can be observed in calculation (negative value) but is not statistically significant.

During growth until 28 years sequence of average heights does not distinctly change and remains the same as found at the age of 15 years. This is proved by the statistically important correlation coefficient with $r^2 = 0.62$.

Five of nine provenances from the Czech Republic, that are growing on the research plot, distinctly differ from the average of the experiment in positive sense of more than 20 % of average value. These differences are not statistically significant and cannot be used for assessing parent stands suitability of these progenies for classification into category of positively certified units. This classification is not confirmed by evaluation of other research plots.

Similar to height growth results of d.b.h. analysis can be summarized to the following statements:

- Average d.b.h. of fir on plot no. 57 is 5.91 cm for all provenances.
- Based on results of variance analysis differences in diameter growth among provenances show to be statistically highly significant and range from 2.60 to 7.30 cm.
- Variance ratios for provenances represented by variability factor and repeatability value prove sufficient reliability of the experiment ($h^2 = 0.74$).

Height growth and above-average diameter growth are characteristic especially for provenances from the Czech Republic as well as for two partial populations from the Slovakian Carpathians and for partial population no. 146 – Schwarzwald, Schönmünzach from Bavaria. Increment of provenances from the Romanian Carpathians, Austrian Alps and France is very weak, of partial populations from the Czech Republic then provenances from mountainous localities of the Hrubý Jeseník Mts. (provenance no. 221) and the Šumava Mts. (no. 83) as well. Analogous variability tendencies of height and diameter growth affirm positive highly significant correlation relationship of these quantities ($r^2 = 0.86$).

Mathematical and statistical analysis also affirms negative correlation relationship between average d.b.h. of silver fir and site elevation of parent stands. However, correlation relationship $r^2 = -0.21$ is statistical insignificant.

Within the whole plot mainly three provenances from the Czech Republic are of markedly above-average value in diameter growth – provenances no. 87 – Hořovice, Jince, no. 82 – Vizovice, Bratřejov and no. 74 – Milevsko, Klučenice that exceed the experimental average of 20 %. This result is comparable with information gained from analogous assessment for average heights.

Using results of observation and evaluation, synthetic assessment of partial populations can be based on three indicators: degree of survival like the indicator of viability, then height and diameter growths. If we suppose that the individual indicators used for synthetic assessment are of the same importance, then the group most suitable for the plot involves provenances no. 82 – Vizovice, Bratřejov, no. 141 – Schwarzwald, Schönmünzach (Germany), no. 87 – Hořovice, Jince, no. S_1 – Banská Bystrica, Badín, and no. 71 – Plumlov, Ruprechtov. The least favourable indicators are characteristic for these units: no. 215 – Vilcea, Romania, no. 221 – Janovice at Rýmařov, Malá Morávka, no. 81 – Vyšší Brod, Vítkův Kámen, no. 104 – Race de l´Aude, France and no. 93 – Wörschachwald, Steiermark, Austria.

Comparison of investigation results with indicators observed on three other research plots of the same experimental series indicates irregular influence of environment on most of the investigated provenances which shows on the significant influence of interaction provenance × planting locality.

Parent stands of provenances from the Czech Republic that proved to be the best on the research plot no. 57, i. e. no. 82 – Vizovice, Bratřejov, no. 87 – Hořovice, Jince and no. 74 – Milevsko, Klučenice, could be theoretically proposed for classification into category of certified planting stock resources. But different characteristics of these partial populations on other comparative localities make this classification debatable.

Research results show that the investigated silver fir provenances grow relatively good even on the research plot of nearly extreme character that is for fir unfavourable in its ecological demands. Forest vegetation zone 1 – oak and set of forest types 1H – loess hornbeam-oak stand is concerned. Ministry of Agriculture Decree no. 83/1996 Coll., on processing of regional plans of forest development and specification of management sets, or amendment to the decree no. 4 enables to use silver fir in these conditions as the ameliorative and enforcement tree species. Despite this proposal it is obvious that silver fir on these sites will be used only sporadically for modifying forest stands species composition in forest practice.

ACKNOWLEDGEMENT

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Photo 1, 2: Research plot with silver fir no. 57 – Forests Jíloviště, Cukrák at the age of 28 years (Photo 1 shows provenance no. 32 – Nýrsko, Děšenice) J. Frýdl

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JEDLE BĚLOKORÁ (*Abies alba* Mill.) V LIMITNÍCH EKOLOGICKÝCH PODMÍNKÁCH

Souhrn

V příspěvku jsou prezentovány výsledky hodnocení potomstev devatenácti proveniencí jedle bělokoré na provenienční ploše č. 57 – Lesy Jíloviště, Cukrák, ve věku 28 let. Na provenienční ploše, která byla založena v roce 1975, je testováno devět proveniencí z České republiky, dvě provenience ze Slovenska, dvě provenience z Bosny a Hercegoviny; další země jsou v experimentu zastoupeny po jedné provenienci (Německo, Rakousko, Francie, Rumunsko a Itálie). Provenienční plocha byla založena v nadmořské výšce 360 m, tj. ve stanovištních podmínkách z hlediska požadavků jedle téměř extrémních.

V rámci hodnocení byly získány výsledky o vitalitě testovaných proveniencí a o jejich výškovém a tloušťkovém růstu. Pokud je jako srovnávací kritérium uvažována průměrná hodnota hodnocených charakteristik, pak lze jako provenience s nejlepšími výsledky uvést č. 82 – Vizovice, Bratřejov, č. 146 – Schwarzwald, Schönmünzach (Německo), č. 87 – Hořovice, Jince, č. S_1 – Banská Bystrica, Badín a č. 71 – Plumlov, Ruprechtov. Mezi provenience s výsledky podprůměrnými lze zařadit č. 215 – Vilcea (Rumunsko), č. 221 – Janovice u Rýmařova, Malá Morávka, č. 81 – Vyšší Brod, Vítkův Kámen, č. 104 – Race de l´Aude (Francie) a č. 93 – Wörschachwald, Steiermark (Rakousko).

SILVER FIR (*Abies alba* Mill.) IN LIMITING ECOLOGICAL CONDITIONS

Summary

There are results of nineteen silver fir provenances measurement and evaluation presented in this paper. Measurements and evaluation have been realized on the research plot no. 57 – Forests Jíloviště, Cukrák, at the age of 28 years. Research plot was established in 1975. There are tested nine provenances from the Czech Republic, two provenances from Slovakia, two provenances from Bosnia and Herzegovina on this research plot. Other countries are represented by one provenance each, Germany, Austria, France, Romania and Italy. Research plot was established in 360 m above sea level, it means in conditions nearly extreme, as for silver fir site demands.

Results of evaluation of vitality, height growth and d.b.h. growth have been obtained. If we suppose that the significance of individual indicators used for synthetic assessment is of equal value, then the provenances no. 82 – Vizovice, Bratřejov, no. 146 – Schwarzwald, Schönmünzach (Germany), no. 87 – Hořovice, Jince, no. S_1 – Banská Bystrica, Badín and no. 71 – Plumlov, Ruprechtov are the best on this plot. The least favourable indicators are characteristic for no. 215 – Vilcea (Romania), no. 221 – Janovice at Rýmařov, Malá Morávka, no. 81 – Vyšší Brod, Vítkův Kámen, no. 104 – Race de l´Aude (France) and no. 93 – Wörschachwald, Steiermark (Austria).

EVALUATION OF NORWAY SPRUCE (*PICEA ABIES* /L./ KARSTEN.) GENETIC VARIABILITY RELATED TO REGIONALIZATION OF REPRODUCTION MATERIAL IN THE CZECH REPUBLIC

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ABSTRACT

Research of Norway spruce (*Picea abies* /L./ Karsten) variability was conducted on progenies of 53 selected stands certified for seed material crop in 20 comparative plantings. Established between 1986 and 1990, these 14-year old stands were evaluated for variations in survival rate and height growth as a function of natural forest regions, seed areas, forest vegetation zones, and elevation of parent stands. We also considered other criteria, including historical origin of populations and characteristics of the local genotypes. Within the entire study, we observed statistically significant phenotypic and genotypic variability. Significant variability between Czech-originated provenances was not observed likely due to the small share of Czech forests within the vast Euroasian Norway spruce areas; another cause may be that the trial involved partial populations of cultural origin. We observed that, in most cases, partial populations of "local" origin were not the most productive. The study results underlined the importance of verifying units (stands) using progeny tests. The most valuable units were proposed for certification as "tested" reproduction material.

BASIC CHARACTERISTICS

Although originally represented by roughly 15 % of the forest area (Šindelář 1995), currently Norway spruce is the most widely distributed and economically the most important tree species, there, in the Czech Republic. During the last two centuries its share has increased reflecting the historical development of forest management that followed the prevailing economical trend oriented above all on coniferous cultures. In order to implement a new concept for forest management, where principles of ecological character, biodiversity enhancement, and forest stability assume increased importance, the current level of 53 % of Norway spruce forest stands would be gradually reduced to a target level of 36.5 % (Zpráva o stavu lesa a lesního hospodářství České republiky 2006/Czech Republic Ministry of Agriculture 2006 Report) and not allowed to ever increase above 40 %. The 15 % or so of Norway spruce stands that are scheduled for conversion should be replaced by silver fir, later supplemented with deciduous tree species with the goal of establishing mixed forest stands of various species and age on a wide variety of sites and densities. In selected locations, biodiversity and production could be enriched by introducing exotic tree species.

Even after these activities are complete, Norway spruce will still remain the most important tree species in the Czech Republic. The reasons behind retaining Norway spruce stands on a large proportion of the forested landscape include: the species' greater productivity, universal utilization of valuable wood and relatively easy breeding. This dominant presence has also given rise to a host of problems that geneticists seek to minimize via tree breeding, including abiotic agents, insect attack, fungal diseases, and anthropogenic factors, particularly air pollution.

VARIABILITY OF NORWAY SPRUCE POPULATIONS, CHARACTERISTIC, METHODS AND RESEARCH GOALS

One of the principal foundations of effective forest management, especially in silviculture, is an understanding of variability within particular forest tree species. Knowledge of morphological, physiological (e. g. leaf flush), growth, production, qualitative and health variability and mutual dependences between the individual features and properties are essential in choosing reproduction material resources (mainly stands for seed crop) and for regionalization. Knowledge of the phenotypic and genetic variability of forest tree populations within all or part of its range is also an important prerequisite for investigations of theoretical and practical problems in forest research, especially in genetics and tree improvement. Scientists in the Czech Republic and throughout Europe have examined variability in Norway spruce for over 100 years (Mezera 1939, Svoboda 1953, Samek 1964, Roudná 1970 etc.).

Variability at the genetic level is systematically investigated on established research plots that are assessed; often using genetic markers. Within the Czech Republic, 20 research plots were established in various natural forest areas between 1986 and 1990 in order to investigate Norway spruce variability, both its genetically-influenced traits and the regional characteristics (fig. 1, tab. 2). The study included progenies of 53 forest stands certified to provide seed material and classified into two phenotype classes: class A and class B (fig. 1, tab. 1). This planted assortment, originating from 24 natural forest zones and 6 former seed areas, is fairly representative of forests within the Czech Republic. The planting arrangement followed standard procedures for such studies, with plantings on 10 × 10 m plots, at quadruple repetition, and with a spacing of 2 × 1m.

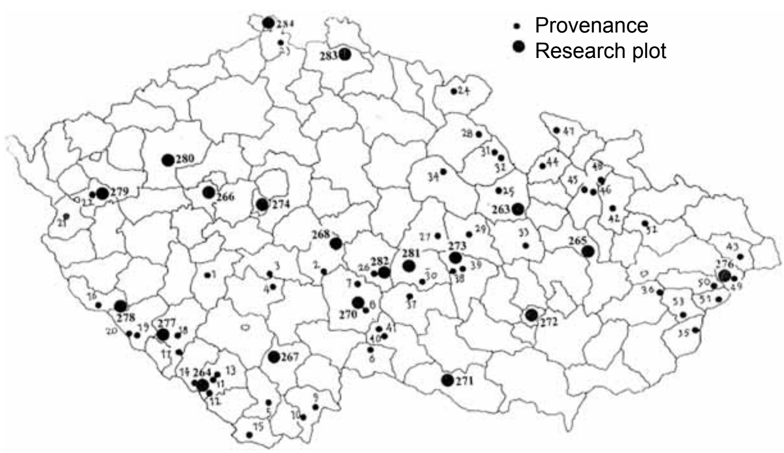

Fig. 1: Localization of certified Norway spruce stands and all research plots

The presented measurement and evaluation was conducted at the age of 14 years. At this point, we focused only on analysis of tree survival and height growth. Therefore, these data are more for informative value and for planning subsequent investigations. Subsequent assessments will include

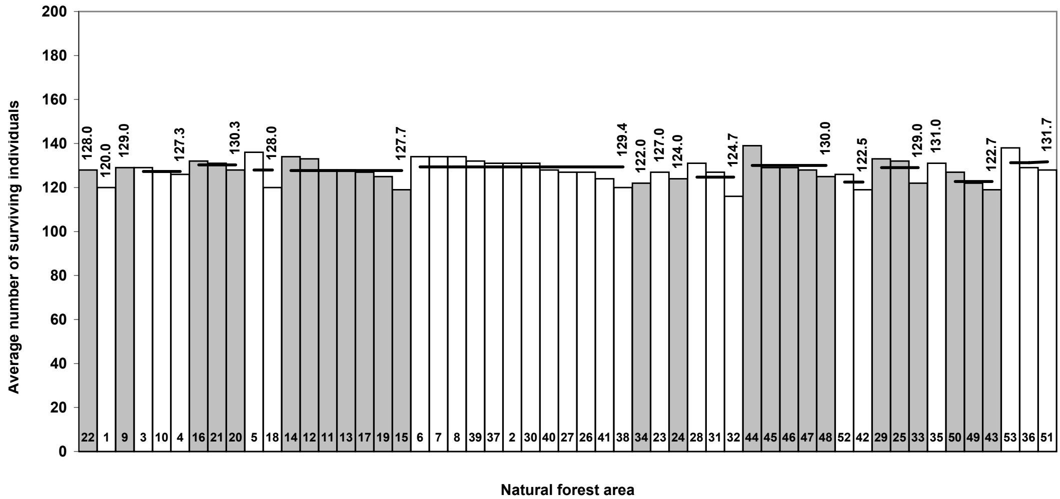

Fig. 2: Diagram of mean number of surviving individuals per plot according to natural forest areas

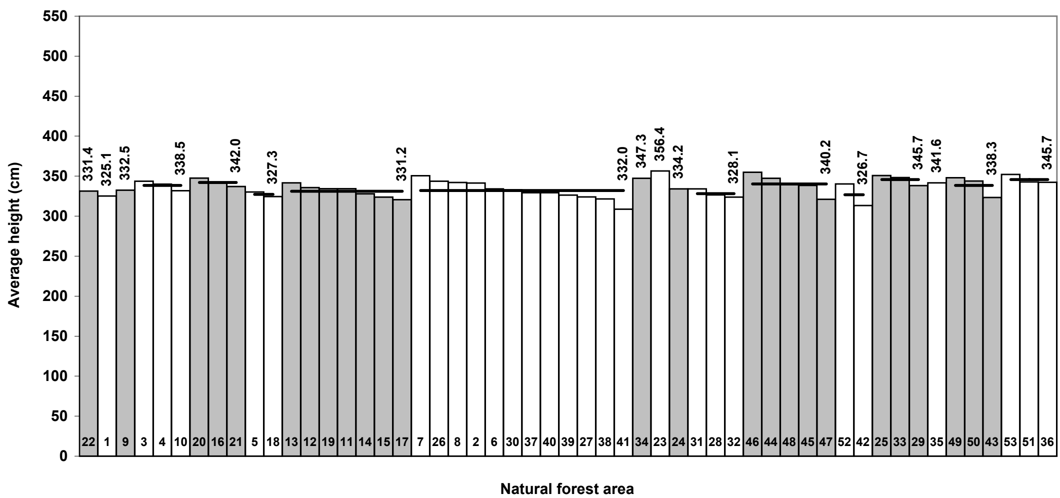

Fig. 3: Diagram of mean heights for each provenance as a function of the natural forest areas' place of origin

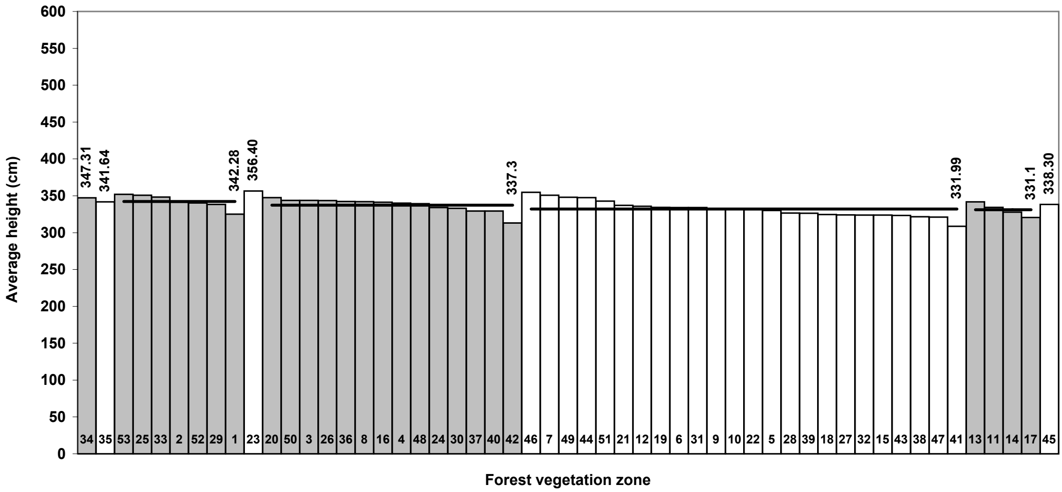

Fig. 4: Diagram of mean heights for each provenance as a function of the forest vegetation zones

other variables; e. g. d.b.h., volume production, etc., as a function of age. For data evaluation, we employed common statistical techniques, such as analyses of variance, correlations, Duncan's test, etc.

We examined our data for differing levels of variability in Norway spruce partial populations (stands) including:

– Variability across the entire set of research plots and the populations they represent
– Variability among genotypes emanating from post-glacial refugia forests
– Genetic and phenotypic variability in populations from the Hercynian-Sudeten and Carpathian areas
– Characteristics of autochthonous populations composed of trees from the other cultural or unknown origin
– Local, within-site, variability, i. e. from planting sites or nearby forests
– Variability among progenies from different natural forest areas
– Variability as a function of former seed zones
– Variability based on forest vegetation zones
– Survival rate and height growth as a function of altitude of parent stands localities

The results of this study will allow us to evaluate current management guidelines for Norway spruce reproduction. Particular areas for potential modification due to the results of this study include the parameters for employing local seed source, as well as influence of forest vegetation zones and elevation on progeny characteristics. Our results will also be used to evaluate changes (defined by the Regulation no. 139/2004) to previous regulations from the 1990s (the Act no. 289/1995, Ministry of Agriculture Regulation no. 82/1996).

Tab. 1: Survey and characteristics of origin of certified units studied in the experiment (coloured units appear on all plots)

Progeny no.	Forest administration (enterprise)	Forest district	Norway spruce certified unit	Natural forest area	Former seed zone	Altitude (m a.s.l.)	Forest vegetation zone	Set of forest types	Research plots, where progeny is not tested
1	Rožmitál pod Třemšínem	Hutě pod Třemšínem	380 / Ib / PB	7	II	460	3		265
2	Vlašim	Mladá Vožice	1 / II / TA	16	IV	460	3	3K5	
3	Vysoký Chlumec	Veletín	336 / II / PB	10	II	660	5	4L5	
4	Milevsko	Milevsko	114 / II / PI	10	II	670	5	5A1	
5	Český Krumlov	Vltava	99 / II / CK	12	III	780	6	6V4	
6	Český Rudolec	Kunžak	40 / Ib / JH	16	IV	720	6	6K6	268
7	Pelhřimov	Častrov	10 / II / PE	16	IV	700	6	5D1	
8	Pelhřimov	Pacov	46 / II / PE	16	IV	600	5	5S1	274
9	Nové Hrady	Černé Údolí	126 / Ib / CB	9	II	850	6	6S1	263
10	Kaplice	Pohorská Ves	29 / Ib / CB	10	II	800	6		276, 280
11	Prachatice	Zátoň	255 / Ib / PR	13	III	900	7	6S1	
12	Prachatice	České Žleby	512 / Ib / PR	13	III	880	6	6V2	
13	Prachatice	Boubín	198 / Ia / PR	13	III	1010	7	6V4	
14	Vimperk	Strážný	140 / Ib / PR	13	III	920	7		274, 279
15	Vyšší Brod	Vítkův Kámen	26 / Ib / CK	13	III	860	6		271 - 273, 281, 282
16	Domažlice	Výhledy	101 / Ib / DO	11	III	600	5		
17	Kašperské Hory	Rejštejn	324 / Ib / KT	13	III	940	7	6B1	263, 271 - 273, 276
18	Kašperské Hory	Svatobor	341 / Ib / KT	12	III	740	6	5Y0	265
19	Nýrsko	Královský Hvozd	260 / Ib / KT	13	III	700	5		
20	Nýrsko	Liščí	264 / II / KT	11	III	600	5		273
21	Planá	Kamenec	158 / Ib / CH	11	III	710	6	6K1	
22	Teplá	Podhora	239 / II / KV	3	II	700	5		
23	Rumburk	Jedlová	623 / Ib / DC	19	IV	550	4	6S4	279
24	Broumov	Adršpach	27 / II / NA	24	V	660	5	0Z1	
25	Lanškroun	Damníkov	6 / II / VO	31	IV	490	3	5S6	283

26	Ledeč nad Sázavou	Orlovy	10 / II / HB	16	IV	600	5	5S1	
27	Nasavrky	Lány, Kameničky	1 / Ib / CR	16	IV	700	6	6S1	263, 264, 266, 267, 270
28	Opočno	Deštné v Orlických horách	185 / Ib / RK	25	VII	850	6		265, 277
29	Polička	Vysoký les	510 / II / SV	31	IV	500	3	5S1	284
30	Přibyslav	Polná	7 / II / HB	16	IV	640	5	5O1	264, 267, 270
31	Rychnov nad Kněžnou	Zdobnice	182 / Ib / RK	25	VII	800	6	6K	
32	Rychnov nad Kněžnou	Říčky	403 / Ib / RK	25	VII	840	6		263, 280 - 282
33	Svitavy	Boršov	203 / IV / SY	31	IV	460	3	4B1	
34	Vysoké Chvojno	Vysoké Chvojno	21 / III / PA	17		320	1	3B5	278
35	Brumov - Bylnice	Valašské Klobouky	11 / IV / CT	38	VIII	380	2	5B1	
36	Bystřice pod Hostýnem	Rajnochovice	01 / IV / KR	41	VIII	660	5		277
37	Jihlava	Štoky	127 / II / JI	16	IV	640	5	5B1	
38	Nové Město na Moravě	Cikháj	6 / Ib / ŽD	16	IV	730	6	6P1	
39	Nové Město na Moravě	Herálec	21 / Ib / ŽD	16	IV	750	6	6P1	
40	Telč	Řásná	112 / Ib / JI	16	IV	670	5	6N3	277
41	Telč	Horní Dubenky	113 / Ib / JI	16	IV	700	5		265, 266, 268, 280 - 282
42	Bruntál	Moravský Beroun	515 / IV / BR	29	VII	680	5		266, 268, 271 - 273
43	Frýdek-Místek	Morávka	185 / VIb / FM	40	VIII	720	6		271 - 273, 277
44	Hanušovice	Františkov	22 / Ib / SV	27	VII	820	6		278, 283, 284
45	Janovice	Karlov pod Pradědem 1	328 / Ia / BR	27	VII	1100	8		264, 267, 270, 274, 280
46	Janovice	Karlov pod Pradědem 2	326 / Ib / BR	27	VII	800	6		266, 274, 281, 282
47	Javorník	Nýznerov	2141 / Ib / SV	27	VII	800	6		264, 267, 270
48	Karlovice	Karlovice	603 / Ib / BR	27	VII	650	5		
49	Ostravice	Staré Hamry	225 / VIb / FM	40	VIII	720	6		283, 284
50	Rožnov pod Radhoštěm	Horní Bečva	6 / VIb / VS	40	VIII	680	5		278, 279
51	Velké Karlovice	Malé Karlovice	4 / VIb / VS	41	VIII	700	5		276, 283
52	Vítkov	Skřipov	100 / IV / OP	29	VII	430	3		278
53	Vsetín	Pozděchov	22 / IV / VS	41	VIII	460	3	5B1	276, 279, 284

Tab. 2: Basic data on localities of evaluated research plots

Research plot no.	Forest administration	Locality	Forest stand	Natural forest area	Altitude (m a.s.l.)	Forest vegetation zone	Average annual temperature (°C)	Annual sum of precipitation (mm)	Set of forest types	Number of repetitions
263	Lanškroun (J. Kašpar)	Damníkov	211 A1y	31	450	3	7.3	600		4
264	Vimperk	Strážný	236 A	13	880	6	5.0	1,354		4
265	Šternberk	Úsov - Bradlo	670 B2a	28 b	510	3	8.0	625		4
266	Křivoklát	Pařeziny	107 C3	8 a	430	3	8.5	520		4
267	Hluboká nad Vltavou	Poněšice	432 C1	10	470	3	7.5	665	4H1	4
268	Kácov	Javorník	336 B1	16	500	3	7.8	650	5K3	4
270	Pelhřimov	Drážďany	108 A	16	660	5	6.2	690	5S1	4
271	Měst. lesy Znojmo	Šumná	42 A1	33	420	3	7.5	650	3C	4
272	ŠLP Křtiny	Jedovnice	276 A1y	30	540	3	6.8	647	4B1	4
273	Nové Město na Moravě	Devět Skal	619 B	16	750	6	4.9	933	6K3	4
274	Lesy Jíloviště	Jíloviště	38 H1z	10	380	2	7.8	564		4
276	Ostravice	Samčanka	413 B3	40	820	6	5.6	1,171		3
277	Železná Ruda	Volšovy	331 C1	12	660	5	6.0	700		4
278	Obecní lesy Pocinovice	Liščí	212 A7	11	500	3	7.0	650		4
279	Teplá	Štenská	94 B5	3	700	6	5.0	839		4
280	Žatec	Žihle	309 C1b	9	580	4	7.2	501		4
281	Městské lesy Havlíčkův Brod	Mírovka	580 C0	16	460	3	6.5	790	5V2	4
282	Ledeč nad Sázavou	Čerňák	606 D1	16	580	4	7.1	665	5S1	4
283	Jablonec nad Nisou	Josefodol	552 E1z	21	810	6	5.8	1,400	6K4	3
284	Rumburk	Šluknov	228 G10	20	390	2	7.0	650	5S6	3

Legend to forest types:

4H1 loamy BEECH oxalic
5K3 acid fir-BEECH woodrush
5S1 fresh fir-BEECH oxalic
3C desiccated oak-BEECH
4B1 rich BEECH malic grass
6K3 acid spruce-BEECH hairgrass
5V2 wet fir-BEECH lady fern
6K4 acid spruce-BEECH reedy
5S6 fresh fir-BEECH impoverished

PRELIMINARY RESULTS

When investigating the total variability of Norway spruce, it must be remembered that the species' extent in the Czech Republic is a very small part of the total Eurasian range. Therefore, one might also assume that the variability within this territory would be relatively low. Survival and height growth results support this assumption even though height and survival were significantly different for all localities (tab. 4). Survival rate ranged between 79 to 108 % (tab. 3). For height growth, the range was between 92 to 106 % (336.1 cm) for particular partial populations (tab. 3). Relatively fast growing partial populations (progenies of certified units) with high survival rate include populations no. 23 – Rumburk, Jedlová, no. 46 – Janovice, Karlov, and no. 53 – Vsetín, Pozděchov. Using preliminary data, we can potentionally classify these units into category of tested sources of reproductive material.

The bulk of Norway spruce populations growing in the Czech Republic today are genetic descendants of a limited number of refugia populations from the glacial era. A portion of the population from the Carpathian and Sudeten natural forest zones including the Bohemian-Moravian Hills originates from the northern Carpathian foothills. A second portion of the population traces its origin to refugia located in the southern margins of the Alps. The first group involves 34 units, the second one 19 partial populations. Survival rate for both groups is identical. The difference in mean height growth is less than 1 %. Similar results were found in case of partial populations of assumed autochthonous origin.

Svoboda (1953) identified two ecotypes of Norway spruce within the Czech Republic territory – Hercynian and Carpathian. Using his categories, we assessed variability and classified the set of partial populations. The mean survival rate was quite equal for these two data groups. Difference in average height growth was less than 2 %, favouring Carpathian partial populations. None of these differences were statistically significant.

A common assumption in forestry is that local, autochthonous populations of forest tree species are optimally adapted in their response to local climate and site conditions. This principal is the base for seed source selection and forest regeneration activities in the Czech Republic. At increasingly larger scales, such as natural forest areas, former seed zones, and forest vegetation zones, the nearest seed sources are always preferred. Analyses of survival rate and height growth of partial populations found that progenies of units selected under this "local" or "nearest origin" criterion showed marked variability in survival rate and height growth. These coefficients lag behind the average values of progeny sets on particular plots in approximately half of the cases suggesting that the progenies of "local" partial populations are not always the optimal genotype for that site. This conclusion is supported by other studies (Schotte 1910, Langlet 1936, Schmidt-Vogt 1977, Geburek 2002). Partial populations, very likely autochthonous, are characterized by quite high variability in the survival rate and height growth compared to overall averages of our dataset. However, average values in these local indexes approximate the mean values of the study as a whole.

While the Czech Republic occupies a relatively small area, it is characterized by pronounced geological, geomorphologic, climatic, and biological variability. Typological investigation enabled us to define typological units and to differentiate areas with similar conditions – natural forest areas. Variation in the ecological conditions characterizing individual natural forest areas could differentially influence forest tree species populations during their evolutionary processes, resulting in measurable differences in genetic composition. Therefore, the natural forest areas were taken as the basis for regionalization of forest tree species reproduction material. The relationship of Norway spruce variability to planting site was evaluated, as well as the influence of natural forest areas regarded as sites of local genotype origin.

Tab. 3: Results of observation (coloured units appear on all plots)

Progeny no.	Forest administration (enterprise)	Forest district	Growing individuals: Average (pcs)	Growing individuals: % average of trial	Growing individuals: % of growing individuals	Growing individuals: % average of trial	Height: Average (cm)	Height: % average of trial
1	Rožmitál pod Třemšínem	Hutě pod Třemšínem	120	94	63	95	325.1	97
2	Vlašim	Mladá Vožice	131	102	68	103	341.3	102
3	Vysoký Chlumec	Veletín	129	101	67	102	343.8	102
4	Milevsko	Milevsko	126	98	65	98	340.1	101
5	Český Krumlov	Vltava	136	106	71	108	330.1	98
6	Český Rudolec	Kunžak	134	105	70	106	334.1	99
7	Pelhřimov	Častrov	134	105	70	106	350.6	104
8	Pelhřimov	Pacov	134	105	70	106	342.1	102
9	Nové Hrady	Černé Údolí	129	101	67	102	332.5	99
10	Kaplice	Pohorská Ves	127	99	64	97	331.7	99
11	Prachatice	Zátoň	128	100	67	102	334.2	99
12	Prachatice	České Žleby	133	104	69	105	335.7	100
13	Prachatice	Boubín	128	100	66	100	341.7	102
14	Vimperk	Strážný	134	105	70	106	327.9	98
15	Vyšší Brod	Vítkův Kámen	119	93	63	95	323.7	96
16	Domažlice	Výhledy	132	103	68	103	341.3	102
17	Kašperské Hory	Rejštejn	127	99	52	79	320.7	95
18	Kašperské Hory	Svatobor	120	94	63	95	324.5	97
19	Nýrsko	Královský Hvozd	125	98	65	98	334.3	99
20	Nýrsko	Liščí	128	100	67	102	347.5	103
21	Planá	Kamenec	131	102	68	103	337.1	100
22	Teplá	Podhora	128	100	66	100	331.4	99
23	Rumburk	Jedlová	127	99	66	100	356.4	106
24	Broumov	Adršpach	124	97	64	97	334.1	99
25	Lanškroun	Damníkov	132	103	68	103	350.7	104
26	Ledeč nad Sázavou	Orlovy	127	99	66	100	343.6	102
27	Nasavrky	Lány, Kameničky	127	99	63	95	324.1	96
28	Opočno	Deštné v Orlických horách	131	102	65	98	326.6	97

29	Polička	Vysoký les	133	104	65	98	338.2	101
30	Přibyslav	Polná	131	102	65	98	332.9	99
31	Rychnov nad Kněžnou	Zdobnice	127	99	63	95	334.0	99
32	Rychnov nad Kněžnou	Říčky	116	91	56	85	323.8	96
33	Svitavy	Boršov	122	95	59	89	348.3	104
34	Vysoké Chvojno	Vysoké Chvojno	122	95	59	89	347.3	103
35	Brumov - Bylnice	Valašské Klobouky	131	102	68	103	341.6	102
36	Bystřice pod Hostýnem	Rajnochovice	129	101	67	102	342.3	102
37	Jihlava	Štoky	131	102	68	103	329.2	98
38	Nové Město na Moravě	Cikháj	120	94	62	94	321.5	96
39	Nové Město na Moravě	Herálec	132	103	68	103	326.3	97
40	Telč	Řásná	128	100	67	102	329.2	98
41	Telč	Horní Dubenky	124	97	65	98	308.6	92
42	Bruntál	Moravský Beroun	119	93	62	94	313.2	93
43	Frýdek-Místek	Morávka	119	93	63	95	323.3	96
44	Hanušovice	Františkov	139	109	71	108	347.4	103
45	Janovice	Karlov pod Pradědem 1	129	101	68	103	338.3	101
46	Janovice	Karlov pod Pradědem 2	129	101	67	102	354.8	106
47	Javorník	Nýznerov	128	100	69	105	321.1	96
48	Karlovice	Karlovice	125	98	65	98	339.2	101
49	Ostravice	Staré Hamry	122	95	62	94	347.9	104
50	Rožnov pod Radhoštěm	Horní Bečva	127	99	66	100	343.8	102
51	Velké Karlovice	Malé Karlovice	128	100	64	97	342.7	102
52	Vítkov	Skřipov	126	98	66	100	340.3	101
53	Vsetín	Pozděchov	138	108	70	106	352.0	105
	Average (pcs)		128		66		336.1	
	Average (%)		100 %		100 %		100 %	

The emphasis of our investigation was on the partial populations originated from natural forest areas and growing on research plots within the same natural forest area. The number or share of surviving plants originated from the particular natural forest areas presented an obvious variability factor. This variability depended upon particular research plots, for example on plot no. 270 – Pelhřimov, Drážďany is significant, on locality no. 264 – Vimperk, Strážný distinctly lower. Within the total set of all plots, variability was balanced and the average survivability values of natural forest areas ranged between 123 and 130 surviving individuals; 56 to 71 % of the original number of planted seedlings. The height growth of the partial populations that originated from the same natural forest

Tab. 4: Analysis of variance of height growth at the level of particular plots

Plot no.	Cause of variability	Sum of squares	Degrees of freedom	Average square	Statistic F	Statistical significance
263	progeny	11,036,469.767	48	229,926.453	14.899	++
	repetition	3,025,674.292	3	1,008,558.097	65.353	++
264	progeny	4,266,719.069	48	88,889.981	7.448	++
	repetition	3,597,189.972	3	1,199,063.324	100.465	++
265	progeny	3,273,917.8	48	68,206.621	7.64	++
	repetition	1,633,375.178	3	544,458.393	60.985	++
266	progeny	4,047,287.166	48	84,318.483	4.93	++
	repetition	2,491,078.652	3	830,359.551	48.546	++
267	progeny	3,244,243.3	48	67,588.402	5.787	++
	repetition	461,361.269	3	153,787.09	13.167	++
268	progeny	8,492,637.142	49	173,319.125	11.996	++
	repetition	8,246,705.604	3	2,748,901.868	190.26	++
270	progeny	3,925,799.047	48	81,787.48	7.391	++
	repetition	4,590,152.695	3	1,530,050.898	138.273	++
271	progeny	6,355,124.873	48	132,398.435	14.103	++
	repetition	789,138.961	3	263,046.32	28.019	++
272	progeny	2,322,657.706	48	48,388.702	3.293	++
	repetition	3,029,156.463	3	1,009.718.821	131.311	++
273	progeny	3,584,370.902	48	74,674.394	6.058	++
	repetition	764,074.974	3	254,691.658	20.662	++
274	progeny	2,069,240.902	48	43,109.185	6.382	++
	repetition	2,178,274.524	3	726,091.508	107.496	++
276	progeny	1,744,830.916	48	36,350.644	4.197	++
	repetition	810,379.142	2	405,189.571	46.786	++
277	progeny	3,592,524.343	48	74,844.257	8.74	++
	repetition	926,122.7	3	308,707.567	36.048	++
278	progeny	4,308,551.16	48	89,761.483	9.596	++
	repetition	1,073,751.069	3	357,919.023	38.263	++
279	progeny	3,151,634.195	48	65,659.046	11.666	++
	repetition	3,609,659.058	3	1,203,219.686	213.784	++
280	progeny	4,530,437.715	48	94,384.119	11.374	++
	repetition	371,868.304	3	123,956.101	14.937	++

281	progeny	3,594,914.673	48	74,894.056	8.004	++
	repetition	1,568,171.435	3	522,723.812	55.863	++
282	progeny	3,992,277.496	48	83,172.448	8.394	++
	repetition	8,316,361.788	3	2,772,120.596	279.782	++
283	progeny	995,572.195	48	20,741.087	5.687	++
	repetition	463,583.659	2	231,791.829	63.557	++
284	progeny	1,571,139.667	48	32,732.076	5.501	++
	repetition	2,167,682.072	2	1,083,841.036	182.165	++

++ Significant differences on level of probabillity error 1 %
+ Significant differences on level of probabillity error 5 %
- Differences statistically non-significant

Tab. 5: Analysis of variance of height growth across the entire dataset

Source of variability	Sum of squares	Degree of freedom	Average square	Stat. F
PLOT	436,206,121.188	19	22,958,216.905	2,197.047++
PROVENANCE	2,625,776.500	20	131,288.825	12.530++
PLOT x PROVENANCE	29,269,303.414	380	77,024.483	7.351++
Residual (error)	560,415,670.371	53.484	10,478.193	
Totally	1,028,516,871.473	53.903	19,080.884	

area where the planting was established is above-average on two research plots (population set from natural forest area 46 – Bohemian-Moravian Hills on the research plot no. 273 – Nové Město na Moravě, Devět Skal and progeny set from natural forest area 13 – the Šumava Mts. on locality no. 277 – Železná Ruda, Volšovy). On the majority of the other plots, growth of provenances from the same natural forest area was average. In accordance with results from analysis of individual variability of "local" populations we found that provenances from the same natural forest area in which the planting was established were not always the most productive in terms of height growth and survival.

The investigation of survival and height growth revealed that provenances from the same former seed zone in which the planting was established rarely exhibited results that were above-average. These local populations do not belong to the fastest growing on the most of plots and survival rate was average as well. Results of this analysis were comparable with those acquired from analysis of parameters from natural forest areas.

The local forest environment is conditioned by vegetation zonation. This zonation, which includes elevation, average annual temperature, length of vegetation period, sum of annual precipitation, and their annual distribution, influences the amount and direction of adaptability

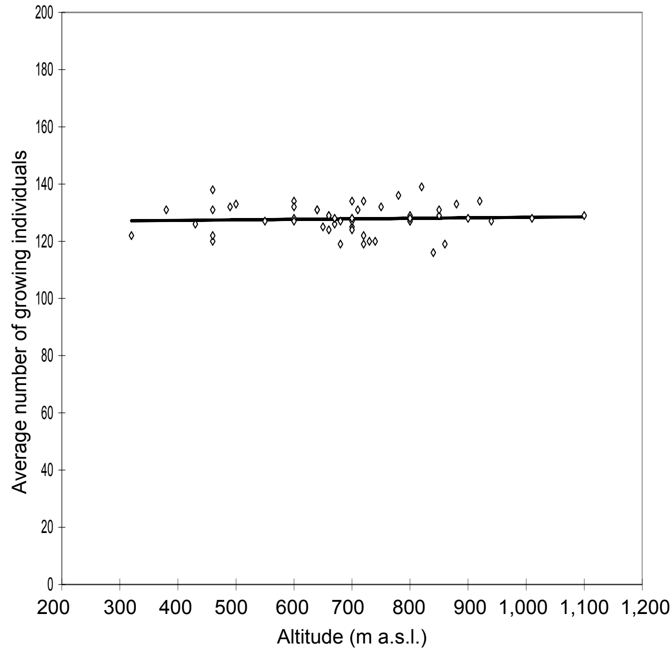

Fig. 5: Relationship between the mean number of surviving individuals within investigated partial populations of the whole set of plots on site elevation of their parent stands

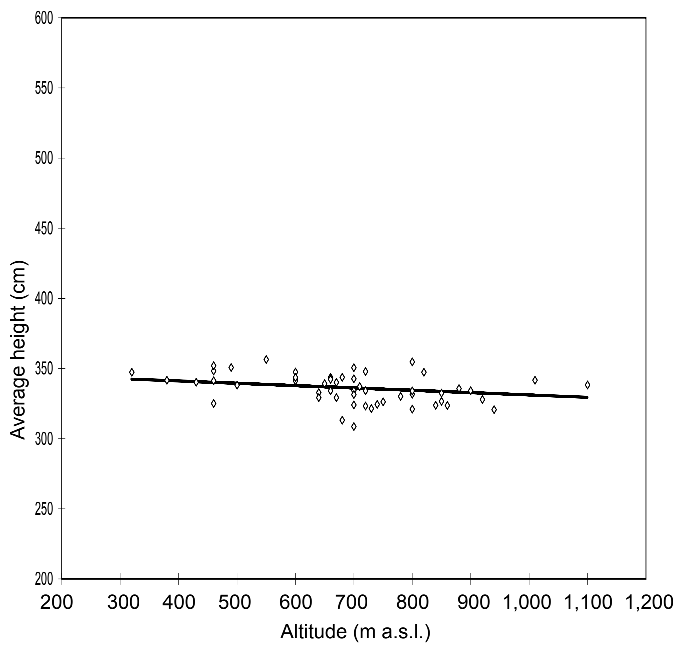

Fig. 6: Dependence of average heights within investigated partial populations of the whole set of plots on site elevation of their parent stands

Tab. 6: Partitioning of variance due to specific causes

Plot no.	Variance share (%) for particular causes of variability			Repeatability (heritability)
	progeny	repetition	residual	
263	60	23	17	0.91
264	35	44	21	0.77
265	44	31	26	0.84
266	33	33	34	0.80
267	49	10	41	0.95
268	36	51	13	0.74
270	30	52	18	0.70
271	68	11	21	0.96
272	27	53	20	0.67
273	47	15	38	0.93
274	29	47	24	0.71
276	29	34	37	0.77
277	53	20	27	0.91
278	56	19	26	0.92
279	33	54	13	0.71
280	67	7	26	0.97
281	45	29	26	0.86
282	22	66	12	0.57
283	34	37	29	0.79
284	24	59	17	0.61

to environmental conditions of forest tree species. Understanding this influence was the purpose of our analysis of survival and height growth of progeny of Norway spruce partial population. We found that the influence of vegetation zones and elevations of locality origin is significant both for survival and height growth. Evidence of this influence was observed more at the individual plot level than at the study level as a whole. Variability, though pronounced, was not a significant influence on survival rate. A dramatic decline in variability was observed for height growth both within the whole set of plantings and on the majority of progenies of certified stands and their sets. This effect was related to shifts from lower to higher forest vegetation zones. These tendencies of variability are documented by calculation of correlation coefficients related to elevations of the parent stands. The values of correlation coefficients were negative, but at all levels statistically non-significant. The correlation coefficient for the mean number of surviving individuals, either at the level of individual plots or for whole set of plots and for individual localities was not statistically significant, too.

CONCLUSION

Despite analysing a rather wide assortment of 53 Norway spruce certified units on 20 certified plots, our results are only preliminary because we examined only two variables at the relatively young age of 14 years. Given the limited analysis, at this point our evaluation is only informative in that it shows the potential for more in-depth analyses with stands at a greater age and with more data.

It can be stated that variability in observed quantities is quite high, but unambiguously oriented tendencies of variability were not confirmed. One of the reasons can be that the natural Norway spruce area of the Czech Republic, from which the experimental material originated is very small compared to the full extent of the species in the Eurasia. Another reason might be that the relative similarity of the ecological conditions of many natural forest and seed areas that in some cases, shapes phenotypic response much more than genetic heritage. Results of analysis are also based on evaluation of progenies that are from artificially-regenerated stands also likely influenced expressions of natural variability.

Tab. 7: Correlation coefficients and regression of mean heights for each progenies of certified units vs. site elevations of the parent stands

Plot no.	Locality	Correlation coefficient		Regression equation
263	Damníkov	0.046	-	y = 4.17 + 0.013x
264	Strážný	0.061	-	y = 3.84 + 0.013x
265	Úsov - Bradlo	-0.398	++	y = 5.39 - 0.051x
266	Pařeziny	-0.286	+	y = 3.28 - 0.049x
267	Poněšice	-0.327	+	y = 3.41 - 0.054x
268	Javorník	0.075	-	y = 4.41 + 0.002x
270	Drážďany	-0.352	+	y = 4.36 - 0.055x
271	Šumná	0.085	-	y = 2.77 + 0.015x
272	Jedovnice	-0.107	-	y = 4.68 - 0.012x
273	Devět Skal	-0.161	-	y = 3.83 - 0.022x
274	Jíloviště	-0.342	+	y = 3.37 - 0.050x
276	Samčanka	-0.182	-	y = 2.74 - 0.028x
277	Volšovy	0.029	-	y = 3.95 + 0.004x
278	Liščí	0.092	-	y = 2.26 + 0.015x
279	Štenská	-0.003	-	y = 1.66 - 0.001x
280	Žihle	0.024	-	y = 3.31 + 0.008x
281	Mírovka	-0.325	+	y = 2.95 - 0.047x
282	Čerňák	-0.196	-	y = 3.94 - 0.029x
283	Josefodol	0.089	-	y = 1.84 + 0.010x
284	Šluknov	-0.074	-	y = 3.24 - 0.010x
263 - 284		-0.233	-	y = 3.48 - 0.017x

y .... average height of progeny (m)
x .... site elevation of parent stand
- Correlation coefficient statistically non-significant
+ Correlation coefficient statistically significant on level of probability error p = 0.05
++ Correlation coefficient statistically significant on level of probability error p = 0.01

Critical values of correlation coefficients:
$r_{47}(0.05) = 0.276$
$r_{47}(0.01) = 0.358$

Our results did not support the hypothesis that populations of “local“ origin are always the most productive in terms of survival and height growth. Similar experiences were found in other experiments and for other tree species, not only in this country but also abroad. Nevertheless, natural forest areas, former seed areas and forest vegetation zones are of great importance as factors influencing total variability of Norway spruce populations within the Czech Republic. These investigations, although preliminary, do not contradict established guidelines of regionalization of reproductive material, especially Norway spruce, developed by the Ministry of Agriculture. However, our results do not support eventual changes in the guidelines expressed by the new Ministry of Agriculture regulation no. 139/2004.

Research results, primarily the high degree of individual variability, indicate the importance of testing of certified reproductive units by progeny tests and the need for further systematic investigation and evaluation of plantings along EU and OECD recommendations. Conditions can be created for enhancement of forest stands production that will become the foundation for further tree improvement activities, including seed orchards established from positively certified populations, individual selection connected with autovegetative reproduction of positively verified variants, and other practices.

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HODNOCENÍ GENETICKÉ VARIABILITY SMRKU ZTEPILÉHO (*PICEA ABIES* /L./ KARSTEN) SE ZVLÁŠTNÍM ZŘETELEM K RAJONIZACI REPRODUKČNÍHO MATERIÁLU V ČESKÉ REPUBLICE

Souhrn

Předmětem příspěvku je hodnocení série provenienčních ploch se smrkem ztepilým (*Picea abies* /L./ Karsten) založených v období 1986 – 1990 s potomstvy vybraných porostů uznaných ke sklizni osiva. Tyto výzkumné plochy jsou v prvé řadě využívány a také hodnoceny především se zřetelem na možnou selekci jednotek, jejichž potomstva se nejlépe osvědčila. Vybrané jednotky budou navrženy k zařazení do specifické kategorie reprodukčních zdrojů ověřených. Soubor výsadeb byl dále využit k posouzení proměnlivosti dílčích populací smrku ztepilého **Karst.**mí ČR se zvláštním zřetelem k rajonizaci reprodukčního materiálu. Jako kritérium hodnocení bylo využito stupně přežívání potomstev na plochách a výškový růst ve věku 14 let.

EVALUATION OF NORWAY SPRUCE (*PICEA ABIES* /L./ KARSTEN) GENETIC VARIABILITY RELATED TO REGIONALIZATION OF REPRODUCTION MATERIAL IN THE CZECH REPUBLIC

Summary

Evaluation of provenance research plots with Norway spruce (*Picea abies* /L./ Karsten) established during 1986 – 1990 with the aim to test selected forest stands certified to seed collection, this is a subject of presented paper. Both use and evaluation of these research plots, are aimed to possible selection of positively verified units. These positively verified units would be proposed to be enlisted to specific category of tested sources of reproductive material. Results of Norway spruce provenance research plots evaluation have also been used to review of Norway spruce partial populations variability in the area of the Czech Republic with especial regards to zoning of reproductive material. As the criterion of evaluation, it has been used degree of progeny survival on research plots, together with height growth evaluation at the age of 14 years.

COMPARISON OF SOME EXOTIC SPECIES OF *ABIES* GENUS WITH CHOSEN SILVER FIR PROVENANCES ON THE PLOTS OF TOWN PÍSEK

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ABSTRACT

This article presents evaluation of three research plots no. 64, 65, 66 situated in the localities of the town Písek. The plots evaluated at the age of 24 years were established in the sets of beech-oak stands and oak-beech stands and were planted out by 27 experimental variants of 9 taxonomical units. Of the exotic firs only grand fir (*A. grandis*) showed to be perspective for the Czech forestry. This species, although characteristic by rather high mortality in the first years after planting, grows very quickly, shows good volume production and relatively satisfying health state of survived individuals. Also white fir and balsam fir are growing relatively good at this age but these species are generally known to be short-lived; balsam fir is characteristic by low volume production. Other species like *A. cilicica, A. pinsapo,* are unusable due to their high mortality and slow growth of survived individuals. Disputable is also use of *A. cephalonica* and *A. borisii-regis* the importance of which can be in the field of breeding, especially in hybridization processes.

INTRODUCTION

Investigation of silver fir decline was based both on experiences and on results from partial branches of forest science and research, including mainly proper breeding technique and improved natural regeneration, then ways of establishment and tending of stands, suitable species and space compositions of forest stands with fir participation.

In the sense of genetics and forest tree species breeding some results of evaluated research provenance plots established in many European countries indicate ways of selection. Certain often significant differences were observed on these plots not only in height growth but also in decline and vitality (e. g. Larsen 1986, Šindelář 2000).

Possible selection of vital individuals usable in forestry was investigated in the first provenance planting in the Czech Republic established by Vinš (1963). In 1973 – 1976 research plots (20 in total) were established where partial silver fir populations from the entire fir area were used, and 153 silver fir provenances were ready for planting (Šindelář 1975).

Except selection within *Abies alba* species possibilities to replace silver fir by other suitable relatively resistant tree species were tested. Douglas fir is widely used in European forestry as well as in the Czech Republic and is considered as the suitable silver fir substituent in certain conditions.

Silver fir can be substituted by some exotic species of *Abies* genus. Some species and provenances of exotic firs together with some progenies of spontaneous hybrids from years 1973 – 1976 were included into the series of research plots. In total 72 items (provenances) of 21 species and spontaneous hybrids were acquired from many countries (Spain, Greece, Lebanon, Syria, Turkey, Caucasian republics of the former USSR, USA, Canada, etc.). Some seed samples were represented in small amount, some other samples were of decreased vitality, low germination and germination energy of seeds. Thus in some cases there were not bred enough plants for inclusion into assortment

Tab. 1: Species and provenances of *Abies* genus on research plots no. 64, 65, 66

Provenance no.	**Species**		**Origin name**	**Elevation (m)**	**Geographic**		**Representation on plots**		
					eastern longitude	**northern latitude**	**64**	**65**	**66**
74	*Abies alba*	CR	Milevsko, Klučenice	410	14° 14‘	49° 34‘	100/33	100/19	65/59
81	*Abies alba*	CR	Vyšší Brod, Vítkův Kámen	900	14° 15‘	48° 37’	85/23	76/19	78/21
89	*Abies cilicica*	Lebanon	Kammouha	1.1	36° 00‘	34° 00‘	-/ O	100/3	
93	*Abies alba*	Austria	Wörschachwald, Ennstal	1.15	14° 08‘	47° 34‘			69/34
108	*Abies cephalonica*	Greece	Mnt. Parmon, Sparta	1.15	23° 08‘	37° 00‘			100/2
109	*Abies cephalonica*	Greece	Central Peloponessos, Vytina	1.25	22° 06‘	37° 35‘	100/43	98/33	
110	*Abies hybridis*	Greece	Tymphristos Mnt., Karpenisi	1.2					88/11
112	*Abies hybridis*	Greece	Mnt. Olympos, Katarine	950	22° 00‘	40° 00‘			93/9
113	*Abies hybridis*	Greece	Mnt. Smolicas, Konitsa	1.3	21° 00‘	40° 05‘			89/13
115	*Abies hybridis*	Greece	Mnt. Rodopi, Stavropolis	1.45	25° 00‘	41° 30‘			85/9
120	*Abies grandis*	USA	Washington, Snoqualmie	335	121° 45‘ w.l.	47° 38‘		100/10	
121	*Abies cilicica*	Syria	Djebel el Chouk, Lattakia	1.3	36° 00‘	35° 48‘	67/1		
122	*Abies balsamea*	Canada	Marlow, Frontenac	420	72° 32‘ w.l.	45° 48‘		93/27	
123	*Abies balsamea*	Canada	Carin, Bonaventure	365	65° 27’ w.l.	48° 15‘		100/24	
124	*Abies balsamea*	Canada	Duboisson, Abitibi - Est	320	77° 56‘ w.l.	48° 04‘		98/27	
130	*Abies alba*	CR	Nasavrky, Podhůra	370	15° 48‘	49° 48‘	100/55		
132	*Abies alba*	Bulgaria	Rilskije gory, Borovec	1.2	23° 36‘	42° 14‘	100/49		89/55
135	*Abies pinsapo*	Spain	Malaga, La Yunquerre				78/6		
136	*Abies cephalonica*	Greece	Peloponessos, Vytina	1.01	22° 10‘	37° 40‘	100/61		
137	*Abies borisii - regis*	Greece	Mnt. Pindos, Pertuli	1.2	21° 15‘	39° 50‘	99/59	96/31	
146	*Abies alba*	Germany	Schwarzwald, Schönmüzach	590	7° 59‘	48° 35‘			81/47

223	*Abies alba*	Bosna and H.	Bosna, Sanski Most	1.05	16° 35‘	44° 35‘	98/41	93/31	83/47
226	*Abies alba*	Italy	Abetone e Cul., Abetone	1.36	10° 50‘	44° 00‘		76/23	85/22
228	*Abies alba*	Italy	Regello, Vallombrosa	1.01	11° 30‘	43° 44‘	100/47		84/37
409	*Abies concolor*	USA	California, Mendocino	1.67	123° 48‘ w.l.	39° 15‘		100/12	
S2	*Abies alba*	Slovakia	Banská Bystrica, Radvaň	780	19° 02‘	49° 23‘	98/44		
S14	*Abies alba*	Slovakia	Bardejov, Kružlov	480	21° 42‘	49° 23‘		98/35	92/58

ready for planting onto plots. Of total amount of 20 research plots, greater or smaller assortment of exotic firs grows only on 6 plots. Some partial silver fir populations were planted for comparison.

This contribution brings a brief survey of results from observations on three research plots no. 64, 65, 66 established in 1976 in the Písecké Mts. area (former forest enterprise Protivín, nowadays again Forests of town Písek).

MATERIAL AND METHODOLOGY

Totally 9 taxa of *Abies* genus represented by 27 provenances were planted on research plots no. 64 - Písek "U Nového", no. 65 – Písek "U Sosny" and no. 66 - Písek "Karvašiny". Partial populations of silver fir were represented in greatest amount, *A. cilicica* was represented by two provenances, *A. cephalonica* by three provenances, *A. grandis, A. pinsapo, A. concolor* were represented by one partial population each. This assortment was completed by a partial population marked as *A. borisii-regis* and by four items from Greece marked as *Abies hybrids*, i. e. hybrids of silver and Greek firs. This taxonomical unit can be involved into category *A. borisii-regis* and so on research plots this taxon was represented totally by 5 items from Greece of various origin.

Table 1 presents material used. Seed from *A. cilicica* was gained in one sample from Lebanon and Syria, Greek fir and *A. borisii-regis* including seed indicated as hybrid fir come from Greece, balsam fir is from Canada, white fir from the USA and *A. pinsapo* from Spain. Assortment of silver fir partial populations was of different geographical origin: three provenances were from the Czech Republic, two from Slovakia and after one from Bulgaria, Germany, Bosnia, and two populations were from Italy. Except geographical coordinates also altitudinal variability of material is evident from the table; it ranges from 350 m for item 123 – *A. balsamea* up to maximal height 1,670 m for *A. concolor* from California (USA).

Characteristics of seed material both of exotic fir species and of silver fir provenances from the Czech and Slovak Republics were very incomplete because information from the former forest management plans or documents accompanying delivered seed were difficult to get, and sometimes impossible.

Localities with plantings are briefly characterized in table 2. Localities lies on flat terrain or on very mild slopes, plots surrounded by stands of various age are established along ways that ensure easy access. Taking in account elevations and other characteristics of localities, the plots can be classified into the 2nd and 3rd forest vegetation zones. Typologically the sets represent fresh beech-oak stands and oak-beech stands.

Tab. 2: Description and ecological characteristics of research plots

Plot no.	Forest district	Forest area	No. of stand	Characte-ristics	Natural forest zone	Vegetation forest zone	Elevation (m)	Exposition	Set of forest types
64	Písek	Údraž, U Nového	9 B 2	abolished forest nursery	10	2	390	north-west	2S
65	Písek	Údraž, U Sosny	46 C 1	abolished forest nursery	10	3	470	north-west	3S
66	Písek	Údraž, Karvašiny	27 A 5	abolished forest nursery	10	3	430	north-west	3S

The plots of 0.39 to 0.42 ha are outplanted by 13 to 14 experimental variants by methods of random block in 3 repetitions on lots of size 10 x 10 m. Planting space was 2 x 1 m and each lot was outplanted by 50 plants so that after establishment each experimental variant was represented by 150 individuals. Planting of 5-year old plants was realized by bare-rooted plants into holes during spring. Marginal stripes need not be planted because these plots were surrounded by forest stands. Plots were staked out by wooden bars in lots corners and fenced in order to prevent game damage. Future improvement was not realized because no other plants were at disposal for all the experimental variants.

Plots were measured and evaluated in autumn 1999. Height measured by a bar or altimeter for all individuals and d.b.h. were determined, mortality was recorded or rate of surviving individuals; vitality was classified using three-degree simple scale: 1 – healthy vital tree, 2 - less vital tree without decline signs, 3 – declining tree. Category 2 - less vital individuals involves those with shorter and lesser number of needles. Trees with limited height increment, crown thinning, or sporadic or more frequent occurrence of dry branches were classified as declining.

Species of *Abies* genus are mostly characteristic by straight stem, exceptions are caused by external impacts as damage of annual shoots mainly terminal ones, game browsing and frost damage followed by frequent drying of some branches or whole crowns. Due to physiological weakening in dry period drying of annual shoots could occur in some cases. For all plots and all individuals stem "shapeness" were classified according to scale 1 – stem quite straight, 2 - partly curved or with bayonet top or forked tree, 3 – markedly curved or of brush growth without distinct terminal annual shoots.

Results were processed on base of mathematical and statistical characteristics, differences among average values were investigated by variance analysis (model for two causes of variability).

BRIEF SURVEY OF RESULTS

Plants at the age of 5 years were planted in spacing 2 x 1 m, i. e. 50 plants per a lot or 150 individuals for a provenance. Natural regeneration, mainly birch, when preventing fir from growing was removed. Fir was growing spontaneously on the research plots, only dead or dying individuals were eliminated. Considering these facts we can take, at least approximately, share of growing individuals for one of the criteria for vitality. Very fast growing provenances of grand and white firs with their intensive interspecies competition and mutual suppression on lots caused that number of individuals of these species surviving until the age of 34 years was very low.

Total assessment is based on material gained from 3 research plots; some populations were growing on all the plots, other only on two or one localities. Species *A. alba, A. cephalonica* (except for provenance 168), *A. borisii-regis* and *A. balsamea* were surviving satisfactory. Great losses occurred at species *A. concolor, A. grandis* and at sets marked by contractor like *A. hybrids*. Partial populations of *A. cilicica* and *A. pinsapo* nearly died.

As mentioned in chapter Methodology, health state was assessed ocularly for all individuals according to three-grade scale. Individuals fully vital (100% share) were white and Greek firs, also *A. borisii-regis* and *A. balsamea*. Health state of silver fir and hybrid firs is mildly worse, of species *A. cilicica* and *A. pinsapo* distinctly worse.

Total evaluation of adaptation abilities of individual species and provenances to local conditions must be based not only on health state of growing individuals but also on survival rate. Combining these two criteria completed with growth characteristic could be a perspective for further use of material in local conditions as well as in other CR localities. The following table presents a survey of possible total synthetic assessment.

Species	Average share of surviving individuals		Average share of individuals of category 1	
	%	sequence	%	sequence
Abies alba	37	2	90	6
A. cilicica	2	9	84	8
A. cephalonica	35	3	99	3
A. pinsapo	6	8	78	9
A. borisii-regis	45	1	98	4
A. grandis	10	7	100	1
A. balsamea	26	4	97	5
A. concolor	12	5	100	2
A. hybrids	11	6	89	7

As expected, relatively high number of silver fir individuals survived and a great deal of them can be classified into category 1 – vital according to their health state. *Abies cilicica* is typical by high or total mortality, Greece fir by relatively high degree of survival rate and good health state of growing individuals. For *A. pinsapo* is characteristic quite a high mortality and marked worsened health state of growing individuals. *A. borisii-regis* survives in high number and its progenies are of good health state. Mortality of *A. grandis* is very high but health state of growing individuals is very good; the same is characteristic for *A. concolor*. *A. balsamea* is surviving satisfactory and survived individuals are in very good health state.

Tables 3 – 5 present height growth variability of firs on research plots no. 64, 65, 66. Arithmetical averages of particular species and provenances range from 2.32 m (*A. cilicica* on plot no. 64) to 11.82 m (*A. grandis* on locality 65). This is caused by species spectrum within *Abies* genus, by provenances variability within particular taxa as well as by individual variability within populations. Differentiation in height growth is also caused by some factors of non-genetic nature as site differences of individual localities, competition among species and partial populations at forest margins. Height growth, mainly diameter growth, can be influenced by very variable number of individuals on lots.

Results of variance analysis prove the height differences of particular partial populations. Differences among average heights were statistically significant on all plots. The followed survey shows shares of individual indicators of variability:

Plot	Partial population	Repetition	Residual	Heritability
64	74	3	23	0.91
65	42	9	49	0.72
66	54	1	45	0.78

Tab. 3: Heights and d.b.h. on plot no. 64

Number	Species (Taxon)	n	Height (cm)		D.b.h. (mm)	
			x	Vk (%)	x	Vk (%)
74	*Abies alba*	50	700.20	25.35	80.12	38.25
81	*Abies alba*	34	515.88	35.25	53.85	59.75
89	*Abies cilicica*	0				
109	*Abies cephalonica*	64	700.31	27.2	94.67	41.02
121	*Abies cilicica*	3	231.67	34.19	38.50	91169
130	*Abies alba*	83	705.42	25.58	81.40	39.39
132	*Abies alba*	74	675.41	26.72	81.85	41.12
135	*Abies pinsapo*	9	521.67	34.10	74.33	49.06
136	*Abies cephalonica*	92	659.57	20.83	90.03	35.34
137	*Abies borisii-regis*	80	657.75	28.72	88.04	40.11
223	*Abies alba*	62	711.05	30.5	84.77	47.04
228	*Abies alba*	70	673.79	24.96	65.00	39.61
82	*Abies alba*	66	615.53	27.17	70.67	47.16

This survey documents very small variance proportion for repetition which is the evidence of relative site homogeneity on plots and relative reliability of the trial. This is also proved by high values of repeatability (heritability) that overcome the usual limit value of 0.70 in all cases. Evaluation of height growth of species and partial populations can be summarized:

- Two North American species, *A. grandis* and *A. concolor* show to be of above-average height growth, followed by partial populations of *A. balsamea* and *A. borisii-regis*.
- Partial populations of silver and Greece firs are of average height growth despite their considerable degree of variability.
- Provenance of *A. cilicica* and *A. pinsapo* mostly died on the research plots. Survived individuals are growing slowly and their average heights are around 5 m.

Figures 3 – 5 present characteristics of d.b.h. and variability coefficients of this quantity. Results of variance analysis show statistically significant differences for average values of particular provenances on plots no. 64 and 65, for locality no. 66 significance was not proved. Similarly as for height, growth differences among repetitions on all plots are statistically non-significant.

Plot	Variance shares in %			Heritability sequence
	provenance	repetition	residual	
64	66	3	31	0.87
65	37	5	58	0.66
66	20	1	77	0.44

This survey shows that variance share for repetition is small but rather high variability share is characteristics for residual variance, i. e. for non-control or non-controllable factors. Value of repetition (heritability) is high only for plot no. 64, while these values for the other two plots are lower than values characterizing sufficient reliability of trial.

Differences of d.b.h. for particular species and provenances are also distinct and range from 2.32 cm (*A. cilicica* on plot no. 64) to 11.82 cm (*A. grandis* on plot no. 65). Results of d.b.h. analysis can be summarized:

– Partial populations of *A. grandis* as well as of *A. concolor* are excellent, followed by *A. balsamea* and *A. borisii-regis*.
– Average d.b.h. growth is characteristic for partial populations of hybrid firs and silver fir.
– *A. cilicica* and *A. pinsapo* partial populations are of the worst growth as well as partial populations of Greece fir whilst their height growth was average.

Volume production of ideal average stem was found for *A. grandis* that with its value 0.19 m^3 had specific position followed by another fast growing provenance *A. concolor* with biomass of 0.15 m^3. Then in a greater interval there are partial populations of *A. balsamea* with weight of ideal average stem 0.04 to 0.05 m^3. Values of other species including silver fir are in limits 0.01 to 0.06 m^3. Minimal values are characteristic for *A. pinsapo*. Of silver fir provenances the highest values are reached by Slovak provenance S-14 Bardejov, whilst partial population 81-Vyšší Brod is of the worst growth within all outplanted plots. *A. borisii-regis* and hybrid fir are characterized by intermediate quantities.

Species of *Abies* genus have continuous direct stem with pyramidal or cylindrical crown in youth and middle age, under favourable conditions also in maturity. Exceptionally occurring smaller or bigger curving is caused by extrinsic factors. The individuals can be damaged by game browsing in juvenile stage, then during thicket stage until middle or older age by snow pressure, icing and glace. Top breaks occurring in younger and middle age can result in bayonet tops, sometimes even in forks. Breaks in middle or upper part of stem caused by wind are occurring rarely. Firs in areas with deer population are very often damaged by peeling that does not usually cause shape disturbance (straightness) of stem.

Based on these results it is evident that share of individuals with worse stem shape cannot be bound to particular species of *Abies* genus. Besides some partial populations with silver fir higher share of trees with worse stem shape can be found also in some partial populations of species *A. pinsapo, A. cephalonica* and in hybrids. All partial populations of species *A. grandis* and *A. concolor* were of continuous stem, nearly 100% share of trees of category 1 is found for all three partial *A. balsamea* populations. Research results indicate that worsened stem shape, or a certain higher share of stems with smaller or bigger stem deformation is occurring in partial populations with temporary lower increment.

SYNTHETIC EVALUATION OF RESULTS, DISCUSSION AND CONCLUSION

Results of particular characteristics were analysed in the preceding chapters and are the base for synthetic evaluation of species of *Abies* genus and for comparison of silver fir represented on research plots by higher number of partial populations. Assessment was done using arithmetical averages of quantities calculated for the whole set of material planted on research plots. Conclusions based on results of summarized assessment are related to local site conditions and are restricted by criteria gained for plantings at the age of 34 years. It must be reminded that particular criteria are of various importance for forest practice. This assessment involves some other experiences gained in CR and abroad as well as information from literature.

Silver fir is represented by 11 provenances on the research plots, of which three come from the Czech Republic, two from Slovakia and Italy, after one is from Austria, Germany, Bosnia and

Tab. 4: Heights and d.b.h. on plot no. 65

Provenance no.	Species		Origin name	Elevation (m)	Geographic eastern longitude	Geographic northern latitude	Representation on plots 64	65	66
74	*Abies alba*	CR	Milevsko, Klučenice	410	14° 14‘	49° 34‘	100/33	100/19	65/59
81	*Abies alba*	CR	Vyšší Brod, Vítkův Kámen	900	14° 15‘	48° 37’	85/23	76/19	78/21
89	*Abies cilicica*	Lebanon	Kammouha	1.1	36° 00‘	34° 00‘	-/ O	100/3	
93	*Abies alba*	Austria	Wörschachwald, Ennstal	1.15	14° 08‘	47° 34‘			69/34
108	*Abies cephalonica*	Greece	Mnt. Parmon, Sparta	1.15	23° 08‘	37° 00‘			100/2
109	*Abies cephalonica*	Greece	Central Peloponessos, Vytina	1.25	22° 06‘	37° 35‘	100/43	98/33	
110	*Abies hybridis*	Greece	Tymphristos Mnt., Karpenisi	1.2					88/11
112	*Abies hybridis*	Greece	Mnt. Olympos, Katarine	950	22° 00‘	40° 00‘			93/9
113	*Abies hybridis*	Greece	Mnt. Smolicas, Konitsa	1.3	21° 00‘	40° 05‘			89/13
115	*Abies hybridis*	Greece	Mnt. Rodopi, Stavropolis	1.45	25° 00‘	41° 30‘			85/9
120	*Abies grandis*	USA	Washington, Snoqualmie	335	121° 45‘ w.l.	47° 38‘		100/10	
121	*Abies cilicica*	Syria	Djebel el Chouk, Lattakia	1.3	36° 00‘	35° 48‘	67/1		
122	*Abies balsamea*	Canada	Marlow, Frontenac	420	72° 32‘ w.l.	45° 48‘		93/27	
123	*Abies balsamea*	Canada	Carin, Bonaventure	365	65° 27’ w.l.	48° 15‘		100/24	
124	*Abies balsamea*	Canada	Duboisson, Abitibi - Est	320	77° 56‘ w.l.	48° 04‘		98/27	
130	*Abies alba*	CR	Nasavrky, Podhůra	370	15° 48‘	49° 48‘	100/55		
132	*Abies alba*	Bulgaria	Rilskije gory, Borovec	1.2	23° 36‘	42° 14‘	100/49		89/55
135	*Abies pinsapo*	Spain	Malaga, La Yunquerre				78/6		
136	*Abies cephalonica*	Greece	Peloponessos, Vytina	1.01	22° 10‘	37° 40‘	100/61		
137	*Abies borisii - regis*	Greece	Mnt. Pindos, Pertuli	1.2	21° 15‘	39° 50‘	99/59	96/31	
146	*Abies alba*	Germany	Schwarzwald, Schönmüzach	590	7° 59‘	48° 35‘			81/47
223	*Abies alba*	Bosna and H.	Bosna, Sanski Most	1.05	16° 35‘	44° 35‘	98/41	93/31	83/47

226	*Abies alba*	Italy	Abetone e Cul., Abetone	1.36	10° 50‘	44° 00‘		76/23	85/22
228	*Abies alba*	Italy	Regello, Vallombrosa	1.01	11° 30‘	43° 44‘	100/47		84/37
409	*Abies concolor*	USA	California, Mendocino	1.67	123° 48‘ w.l.	39° 15‘		100/12	
S2	*Abies alba*	Slovakia	Banská Bystrica, Radvaň	780	19° 02‘	49° 23‘	98/44		
S14	*Abies alba*	Slovakia	Bardejov, Kružlov	480	21° 42‘	49° 23‘		98/35	92/58

Tab. 5: Heights and d.b.h. on plot no. 66

Number	Species (Taxon)	n	Height (cm)		D.b.h. (mm)	
			x	Vk (%)	x	Vk (%)
74	*Abies alba*	88	702.84	28.19	91.38	45.08
81	*Abies alba*	32	619.06	37.29	78.74	50.47
93	*Abies alba*	51	511.57	44.51	61.17	68.07
108	*Abies cephalonica*	3	493.33	44.43	63.00	57.27
110	*Abies hybrids*	16	465.31	47.01	72.00	53.23
112	*Abies hybrids*	14	629.29	32.32	102.43	51.90
113	*Abies hybrids*	19	620.79	38.61	94.53	57.83
115	*Abies hybrids*	13	665.00	43.64	102.69	70.04
132	*Abies alba*	83	734.82	23.53	102.17	44.28
146	*Abies alba*	70	726.93	22.30	94.83	42.53
223	*Abies alba*	71	683.10	36.28	93.75	58.03
226	*Abies alba*	33	553.52	38.93	70.79	63.22
228	*Abies alba*	56	738.30	27.79	100.56	51.45
814	*Abies alba*	87	784.02	22-May	105.99	37.20

Bulgaria. Due to this varied origin silver fir provenance set is characteristic by quite a high variability in some features. Silver fir compared with the other species of *Abies* genus growing on the plots is characteristic by high survival rate, relatively good health state, average height growth and good stem shape. However, diameter growth and volume production is low and below-average when compared with other fir species. Despite this, perspectives of this native species are indisputable; both this species was the important part in species composition in our forests and today it is irreplaceable because of its production and other useful properties. D.b.h. growth and biomass volume are relatively low in youth as it is typical for this species in conditions of central Europe. Positive and especially important criterion is high survival rate and good health state. Of silver fir provenances represented on plots are of above-average volume production provenances S 14 – Bardejov, Slovakia, 74 – Milevsko and Bulgarian partial population 132 – Rilskie gory. Below-average survival rate, production and partly stem shape occur in provenances 81 – Vyšší Brod, 93 from Austria and in partial Italian populations. In case of selection based on these results of investigation, then two

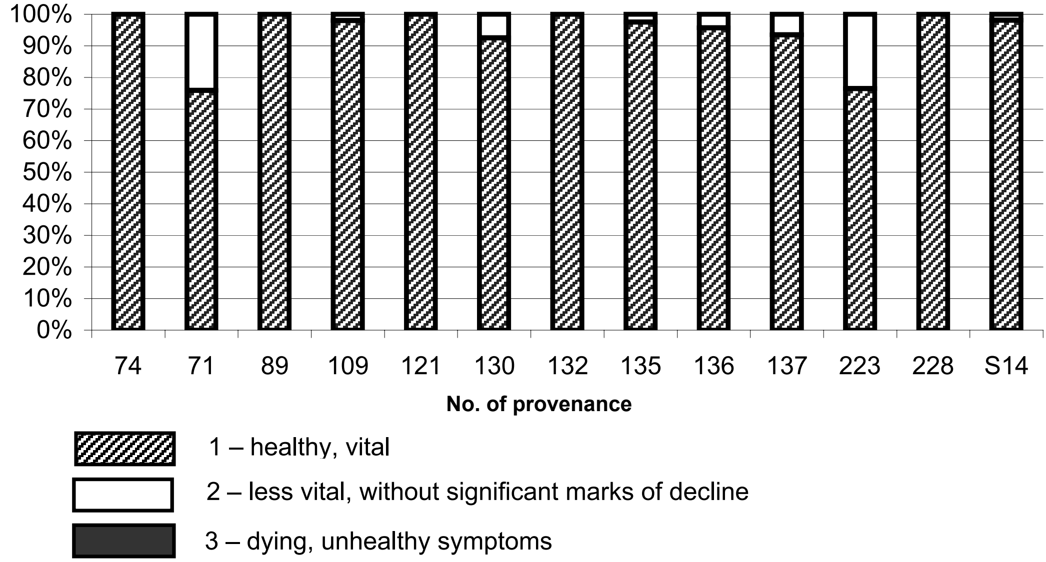

Fig. 1: Characteristic of health state of fir on plot no. 65

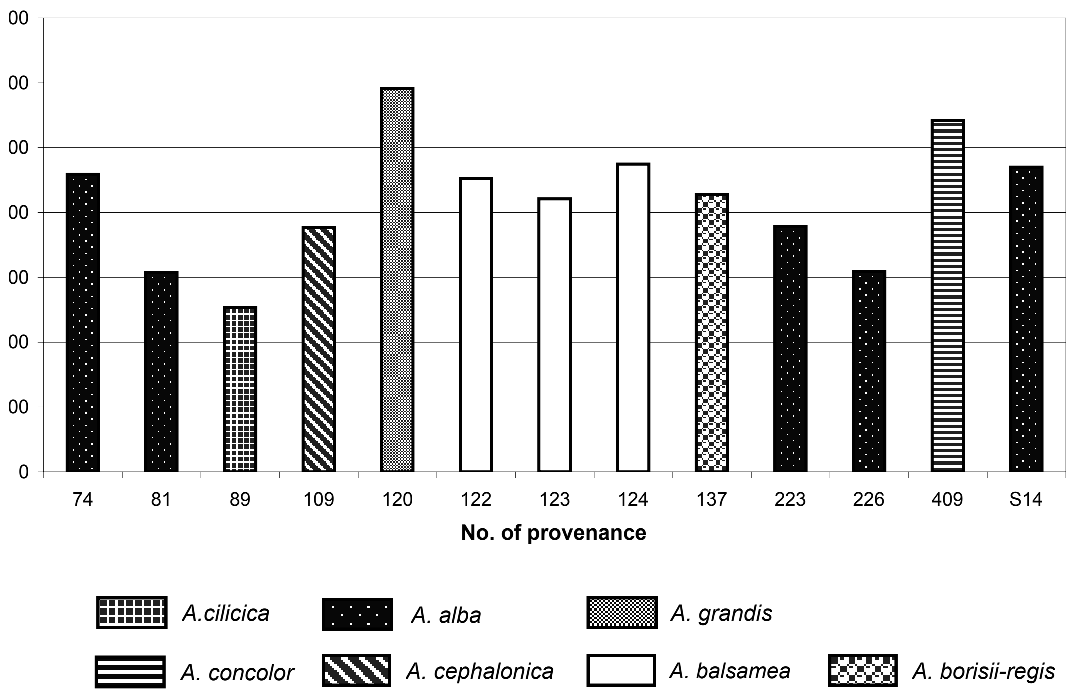

Fig. 2: Average heights on plot no. 65

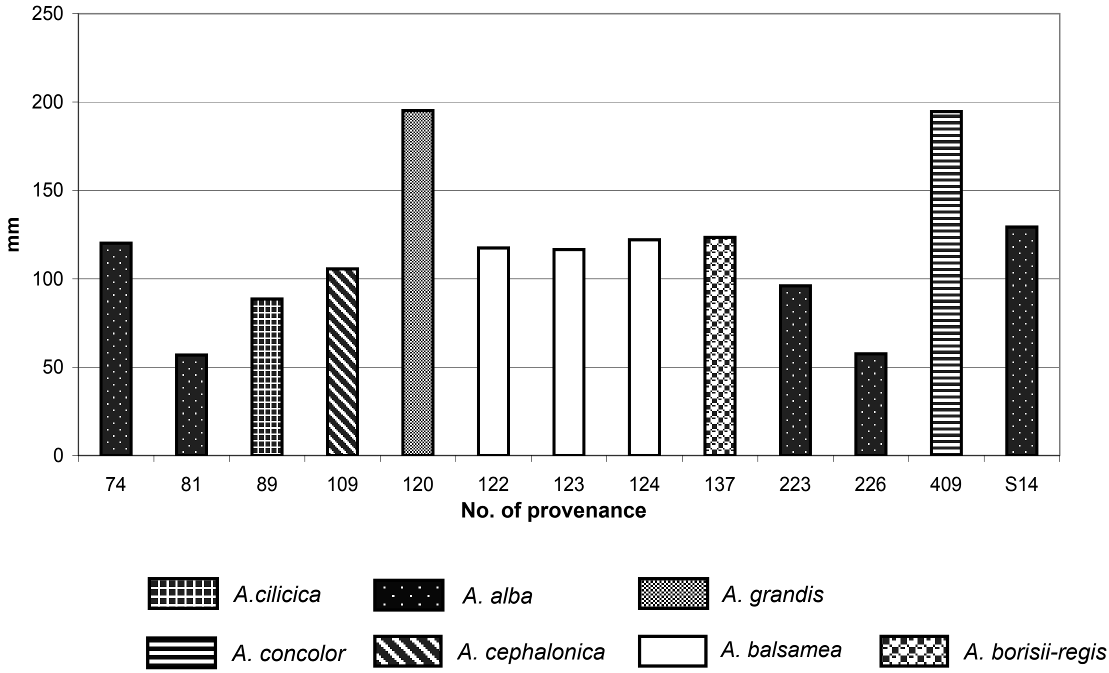

Fig. 3: Average d.b.h. on plot no. 65

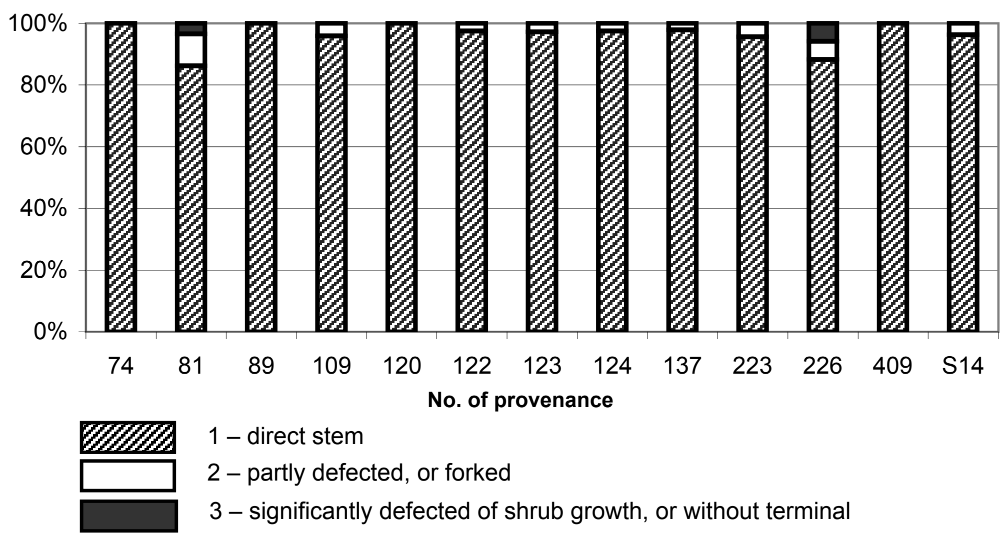

Fig. 4: Characteristics of stem shape on plot no. 65

partial populations – S 14 Bardejov and 74 – Milevsko are suitable. The latter one could be classified into category of unit certified for seed crop.

Species *A. cilicica*, represented by two provenances from Syria and Lebanon, was growing in ecological conditions quite different from those in central Europe. It was characteristic by nearly total decline; there are only a few individuals on the plots (in total 8 trees). Decline might be caused by winter and spring late frosts and partly by weed competition enabled by very slow growth after planting. Damages by late frosts were to a certain degree a consequence of early flushing. Regarding these experiences perspectives of using this species in CR forestry are quite negative.

Greece fir, represented by two provenances originated from island Peloponnesos, was characteristic by quite a high survival rate and relatively good health. Increment mainly of volume was average to below-average; investigations from other localities in CR (Šindelář 1986) revealed early flushing of this species. Use in CR forestry is limited because of problems with importing higher amount of seed so that only relatively small plot of stands could be suitable for seed crop. This species can be worthy for breeding, especially for hybridization.

Only one provenance of *A. pinsapo* species grows on the plot, on locality no. 64. Its mortality is also nearly total like at species *A. cilicica*. Of 150 plants only 9 remained that grow very slowly, their stems are very often deformed and flushing time intermediary. This species cannot be used in forest management; it was proved on locality no. 58 as well as by experiences from arboreta and plantings in parks. Its possible use is in suitable mild ecological conditions in decorative horticulture.

Fir *A. borisii-regis* from the Pindos Mts. in Greece grew on plots no. 64 and 65 in great number until the age of 29 years. Its health state was good as well as average height and diameter increment, without any stem deformation. It does not occur on other research plots of the Institute and so its use in forestry is restricted or even unreal.

Four fir partial populations imported from Greece are marked as *Abies* hybrids. These provenances came from the middle or higher mountainous areas from elevation of 950 to – 1,450 m. All four provenances on research plot no. 66 – Karvašiny show very low survival rate (on average only about 10 % of individuals remained), they grow very slowly having a high proportion of stem deformations. As for *A. borisii-regis* the use of this species is minimal.

A. grandis is successfully introduced tree species mainly in western Europe. In the Czech Republic this species together with Douglas fir are planned to contribute to increment of volume production. Six localities in CR within research plots of IUFRO series were evaluated positively. There were 30 provenances from the USA and Canada represented on the plots. Also some older plantings of *A. grandis*, above all from the former forest administrations Rožmitál pod Třemšínem, and Hořice in the Krkonoše Foothills as well as in forest of Rokycany town were growing fast and had rather high volume production. Observation results on research plot no. 65 are not inconsistent with present experiences. Quite a high decline on the plot was a consequence of gradual expel of suppressed trees which was caused by very intensive growth of trees surviving on the plot. Mortality not only on research plots but also in forestry practice is, to a certain degree, caused by honey fungus infection of root systems. *A. grandis* is growing fast, its volume production is high, is much better in growth coefficient than both the other species and fir provenances on the plot. Based on investigations and experiences from CR and abroad this species can be classified as perspective, on some localities can substitute silver fir. Decisive data for use in practice should be gained from the international 1976 provenance plot.

A. balsamea is represented on one of the research plots by three partial populations from southeastern regions of areas Quebec, Canada, and Maine, USA. All three provenances are vital, in comparison with the other species survival rate was average, growth of height, d.b.h. and volume were above-average with rarely occurring stem deformation. This species grows well over weed and is resistant to frost, and according to experiences from literature it does not suffer from waterlogging. Variability among the three populations on the plot is low. Older plantings mainly in abroad are observed to be short-lived and of rather small volume production. Based on this knowledge possible use of this species in forestry is viewed sceptically and as very limited, both in Europe and CR.

A. concolor (provenance 409 from locality Mendocina, California, USA) from elevation of 1,760 m had the same behaviour on plot no. 65 like *A. grandis*. Survival rate was extremely low, of 150 plantings only 8 individuals survived. The remained trees were growing well and production coefficients differed only a little from *A. grandis* planting. Causes of quite a high mortality were, according to observation, analogous like for *A. grandis* – honey fungus and partly also physiological desiccation in pre-spring period. Due to very late flushing *A. concolor* was not damaged by late frosts. It is known that this species is short-living in conditions of central Europe.

Due to higher volume production on some localities (in CR for example in arboretum Bukovina at Hrubá Skála in north Bohemia) some authors define *A. concolor lowiana* like the hybrid of *A. concolor* and *A. grandis*. Based on investigations and information from literature perspectives of using this species in forestry of CR are unclear at present. This opinion is supported by the fact that in other European countries both forest research and forest practice are not interested in breeding this species.

Characteristics of particular fir species on plots in municipal forest of Písek town will be necessary to compare with results from other research plots of the same series, i. e. 58 – Jíloviště, 68 – Pelhřimov, Černovice, 62 – Nýrsko, Dešenice. As mentioned, comparable results from observation of *A. grandis* on fir research plots from 1976 are at disposal. Assessment was carried out at the age when results and conclusions for some fir species can be taken for informative both from viewpoint of research and forest practice. Of concern are mainly limited or even unreal possibilities of using *A. cilicica, A. pinsapo*, disputable are perspectives of Greece fir, *A. balsamea*, hybrid populations of *A. cephalonica* x *A. alba* as well as of *A. concolor*. These conclusions will be specified during further investigations that should be done in intervals of 5 to 10 years.

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NĚKTERÉ CIZOKRAJNÉ DRUHY RODU *ABIES* VE SROVNÁNÍ S VYBRANÝMI PROVENIENCEMI JEDLE BĚLOKORÉ NA PLOCHÁCH V LESÍCH MĚSTA PÍSKU

Souhrn

V letech 1975 – 1976 bylo založeno 6 provenienčních ploch s jedlí bělokorou s cílem zachování tohoto druhu a posouzení možné náhrady původního druhu jinými nepůvodními druhy jedle. Plochy byly založeny v různých ekologických podmínkách středních a jižních Čech a zahrnují 16 druhů, včetně poddruhů a hybridů (celkem 56 populací). V práci jsou uvedeny výsledky z hodnocení třech výzkumných ploch č. 64, 65 a 66 na Písecku. Plochy byly hodnoceny ve věku 24 let. Plochy jsou založeny na stanovištích společenstva bukovo-dubovém a dubovo-bukovém a je zde vysazeno 27 variant 9 taxonů. Pro české lesnictví je z introdukovaných jedlí perspektivní jedle obrovská. Jedle obrovská, přes počáteční vyšší mortalitu po výsadbě, roste velmi rychle, vykazuje značnou objemovou produkci a je relativně odolná. Také jedle ojíněná a jedle balzámová rostou relativně dobře v tomto věku, ale nevýhodou je obecně známá krátkověkost těchto dřevin a navíc jedle balzámová má nízkou objemovou produkci. Proto tyto druhy nejsou perspektivní v podmínkách střední Evropy. Další druhy jako *A. cilicica, A. pinsapo* jsou nevhodné z důvodu vysoké mortality a pomalého růstu přežívajících jedinců. Diskutabilní je i využití druhů *A. cephalonica* a *A. borisii-regis*, jejichž význam je především ve šlechtitelských programech a zejména v hybridizačních projektech především z důvodu vysoké odolnosti.

COMPARISON OF SOME EXOTIC SPECIES OF *ABIES* GENUS WITH CHOSEN SILVER FIR PROVENANCES ON THE PLOTS OF TOWN PÍSEK

Summary

In years 1975 and 1976 six research plots with silver fir provenances were established within activities focused on preservation of silver fir (*Abies alba* Mill.) and its possible substitution by some exotic *Abies* species. Plots were established in various ecological conditions in the central and southern Bohemia including 16 taxa with subspecies and hybrids (totally 56 partial populations). This article presents evaluation of three research plots no. 64, 65, 66 situated in the localities of the town Písek. The plots evaluated at the age of 24 years were established in the sets of beech-oak stands and oak-beech stands and were planted out by 27 experimental variants of 9 taxonomical units. Of the exotic firs only grand fir *(A. grandis)* showed to be perspective for the Czech forestry. This species, although characteristic by rather high mortality in the first years after planting, grows very quickly, shows good volume production and relatively satisfying health state of survived individuals. Also white fir and balsam fir are growing relatively good at this age but these species are generally known to be short-lived; balsam fir is characteristic by low volume production. Therefore these species cannot be used in conditions of central Europe. Other species like *A. cilicica, A. pinsapo*, are unusable due to their high mortality and slow growth of survived individuals. Disputable is also use of *A. cephalonica* and *A. borisii-regis* the importance of which can be in the field of breeding, especially in hybridization processes.

EXOTIC SPECIES OF FIR (*ABIES* SPEC. DIV.) AT THE AGE OF 30 YEARS IN THE NATURE FOREST REGION NO. 10 – STŘEDOČESKÁ PAHORKATINA (CENTRAL BOHEMIAN UPLAND)

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ABSTRACT

Results of provenance plot no. 58 with various species of genus *Abies* evaluation are presented in this partial final report. Provenance plot no. 58 was established in 1975 in locality Jíloviště (forest ownership Zbraslav, Bartoň from Dobenin). A great deal of genus *Abies* species and its provenances were represented in this provenance plot. Portion of growing individuals was investigated regularly and height growth measurement with evaluation of phenology was realized at the age of 9 years. Evaluation of phenology used to be very important from that point of view, that level of phenology presents a conditioning factor of species and provenances resistance against late frosts. In case of provenance plot no. 58, individual species of genus *Abies* and their partial populations were compared each other and results of evaluation were confronted with results of evaluation of silver fir provenances planted here, too. Within the framework of presented partial final report, results of the second evaluation from provenance plot no. 58 at the age of 30 years are summarized. Results of evaluation prove perspectives of future use of domestic species – silver fir, namely in the more or less extreme ecological conditions for this species. Considerable variability of partial populations within the framework of this species was also proved as well as convenience of provenances from both Hercynian-Sudeten and Carpathian regions for the Central European conditions.

INTRODUCTION, AIM OF WORK

Problem of silver fir and especially its perspective enhancement up to 4 and 6 % can be solved by many branches of forest science and development, as genetics, breeding and introduction of exotic forest tree species. Some possibilities of selection are based on evaluation results of research provenance plots established in many European countries, for example in Swiss (Engler 1906), in Italy (Pavari 1951), in Denmark (Löfting 1954) etc. This research of partial populations often showed very significant differences in decline, vitality, height growth and some other indicators. In the Czech Republic (CR) selection possibilities of vital partial populations for forestry are observed on the provenance planting established by Vinš (1962), in Slovakia the plantings were realized by many authors (Laffers 1978, Kočiová 1976, Korpeľ, Paule 1981).

In CR in total 20 research plots were established in 1973 – 1976 where the partial populations from the whole species area were used with the aim to get more information on possibility of mass selection within this species. Altogether 157 provenances of various species of *Abies* genus (Šindelář 1975, Hynek 1985) were tested.

Besides selection carried out within *Abies alba* Mill. species another trend is substitution of silver fir by some suitable relatively more resistant tree species. Except Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) which perspective of use is very high in Europe and CR and which can be suitable for replacement of silver fir, the investigations have been ongoing with some exotic species of *Abies* genus.

Tab. 1: Survey of species and provenances of *Abies* genus – plot no. 58

Prov. no.	Species	Country	Origin - determination	Elevation (m)	Geographic e. longitude	n. latitude
87	*Abies alba*	CR	Hořovice, JINCE	530	13° 58´	49° 46´
89	*A. cilicica*	Lebanon	KAMMOUHA	1,100	36° 00´	34° 00´
97	*A. alba*	Austria	Liesing, DRAUTAL	1,280	12° 49´	46° 41´
111	*A. hybridis*	Greece	Mnt. Pindos, KALAMBAKA	1,300	21° 10´	39° 30´
117	*A. alba*	France	La Joux III	750	6° 03´	46° 51´
120	*A. grandis*	USA	Washington, SNOQUALMIE	335	121° 45´ w.l.	47° 38´
122	*A. balsamea*	Canada	Frontenac, MARLOW	427	70° 32´ w.l.	45° 48´
124	*A. balsamea*	Canada	Val Dor, DUBUISSON	320	77° 56´ w.l.	48° 04´
129	*A. lasiocarpa*	Canada	Alberta, ROCKY MOUNT.	1,524	115° 00´ w.l.	51° 00´
134	*A. alba*	Spain	Anso, HUESCA		0° 52´	42° 45´
135	*A. pinsapo*	Spain	Malaga, LA YUNQUERA			
136	*A. cephalonica*	Greece	Peloponnesus, VYTINA	1,010	22° 10´	37° 40´
141	*A. balsamea*	USA	N. Hampshire, FRANCONIA N.	533	71° 41´ w.l.	44° 08´
143	*A. alba*	Austria	Laterns, VORARLBERG	1,000	9° 42´	47° 16´
154	*A. fraseri*	USA	North Carolina, WOLF CREEK	1,372	81° 00´ w.l.	36° 10´
155	*A. bornmülleriana*	Turkey	Bolu, KÖKEZ	1,225	31° 36´	40° 33´
160	*A. concolor*	USA	Colorado, MONTROSE	1,500	107° 00´	41° 00´
165	*A. alba*	France	Saint Evroult II	275	2° 48´	45° 54´
169	*A. nordmanniana*	Turkey	Sebinkarahishar, MERKEZ	1,600		
170	*A. cilicica*	Turkey	Maras, YENICE KALE	1,400	34° 34´	37° 34´
180	*A. nordmanniana*	Turkey	Sebinkarahishar, MERKEZ	1,600		
181	*A. cilicica*	Turkey	Maras - Hartlap, YENICE KALE	1,410	34° 34´	37° 34´
218	*A. alba*	Romania	SUCEAVA	600	25° 50´	47° 40´
226	*A. alba*	Italy	Abetone e Cutigliaro	1,360	10° 50´	44° 00´
406	*A. concolor*	USA	California, SISKIYOU	1,828		
407	*A. concolor*	USA	California, TUOLUME	1,674	120° 15´ w.l.	37° 55´
409	*A. concolor*	USA	California, MENDOCINO	1,670	123° 15´ w.l.	37° 55´
410	*A. magnifica*	USA	California, CALVERAS	1,674	121° 15´ w.l.	39° 40´
411	*A. magnifica*	USA	California, GLENN	1,800	120° 50´ w.l.	41° 00´
418	*A. balsamea*	USA	Maine, BANGOR	91	68° 40´ w.l.	44° 50´
424	*A. lowiana*	USA	California, MEYERS	2,070	120° 00´ w.l.	38° 51´
425	*A. grandis*	USA	Idaho, SAINT POINT	975	116° 18´ w.l.	48° 18´
427	*A. magnifica*	USA	California, HIGHWAY	2,345	120° 10´ w.l.	38° 38´
428	*A. magnifica v. shastensis*	USA	Oregon, NATIONAL FOREST	1,615	122° 21´ w.l.	43° 22´
500	*A. nordmanniana*	Georgia	Georgia			
S14	*A. alba*	Slovakia	Svidník, KOMÁRNÍK	480	21° 42´	49° 23´

The series of research plots had therefore included some species and provenances of exotic firs that were acquired from scientific institutions from various countries of Europe, Africa, Asia, also from the USA and Canada. Some plots were planted mainly or totally with exotic fir species with one or more silver fir provenances for comparison. In total exotic species of *Abies* genus were on 6 plots.

This article presents observation results from one of these plots – plot no. 58 on locality Jíloviště (forest owner Bartoň from Dobenin, Zbraslav). On this plot established in 1975 with quite a high assortment of fir species and provenances their decline was observed at the age of 9 years as well as height growth and flushing course. Flushing time is very important for firs because of influencing sensitivity of species and provenances to late frosts. The particular species and their partial populations were compared one with another and confronted with results from observation of silver fir provenances that were also planted on the plot. This contribution summarizes results of the second evaluation at the age of 30 years.

MATERIAL AND METHODOLOGY

On the plot no. 58 – locality Jíloviště fir assortment was planted on three adjacent partial plots with the same site conditions. Assortment was composed of 15 *Abies* genus species including spontaneous interspecific hybrid *Abies alba* x *A. cephalonica*, the species were represented by 38 provenances. Silver fir was the most numerous assortment of partial populations, *A. balsamea* and *A. concolor* were represented by four provenances. On the plot there were growing after three provenances of *A. cilicica*, *A. magnifica* and *A. nordmanniana*. The other species (tab. 1) were represented by one or two provenances.

Documentation of exotic fir species from abroad was very concise, mostly only geographical coordinates and elevations were known. In some cases there were no data known. Provenances of silver fir were characterized by data presented in documentation about its origin, and sometimes more detailed data from forest management plans could be used.

Research plot was established within the forest district Zbraslav nad Vltavou (after restitution in ownership of Bartoň from Dobenin) in the stand 31 L a. The locality is in the natural forest zone 10 – Středočeská pahorkatina (Central Bohemian Upland) in elevation of 330 m a. s. l. Average annual temperature on the locality is 8.3 °C, average annual sum of precipitation 480 mm. Typologically it is classified into the set 1 H – loess horn-oak stand. The locality can be, due to low annual sum of precipitation, taken for extreme up to limiting for silver fir.

The planting was arranged into blocks; a part of provenances was planted in three repetitions, nearly a half of provenances was only in one repetition because of a small available amount of seed and plants. Plants were planted on lots of size 10 x 10 m in spacing 2 x 1 m. Plot of 0.65 ha consisted of 65 lots with 50 plants on each of them. Some provenances were therefore represented by 150 individuals, some only by 50. In spring 1975, 1,350 four-year plants were planted.

In 1981 and 1983 phenological observation of flushing time was carried out by ocular estimation according to seven-member scale. The investigation was based on principals used for the similar evaluation on the provenance research plots with Norway spruce series IUFRO (1964 – 1968). Information is in the contribution from 1986 (Šindelář 1986).

The second investigation was done at the age of 30 years (spring 2001) and included measurement of heights and d.b.h of all individuals still growing on the plot. Results of this measurement including mortality were assessed by common methods for quantitative evaluation, above all by calculation of basic mathematical and statistical characteristics. Difference of average values for particular experimental variants was tested by variance analysis. Sequence of average values for particular partial populations was assessed by Duncan multiple sequence test.

Tab. 2: Variance analysis for a part of plot with three repetitions – heights and d.b.h.

No. of proven.	Fir species	n	Height (cm)		x (cm)	sx (cm)	sx (cm)	Vk %
			min.	max.				
87	*A. alba*	77	330	1,400	843.83	257.11	29.30	30.47
89	*A. cilicica*	2	630	900	765.00	135,00	95.46	17.65
111	*A. hybridis*	60	175	1,150	685.58	251.32	32.45	36.66
120	*A. grandis*	47	800	1,800	1,272.34	293.51	42.81	23.07
122	*A. balsamea*	38	110	1,400	779.87	295.28	47.9	37.86
124	*A. balsamea*	68	420	1,250	875.15	169.95	20.61	19.42
135	*A. pinsapo*	13	190	950	521.54	220.10	61.04	42.20
136	*A. cephalonica*	48	135	1,200	750.31	236.34	34.11	31.50
141	*A. balsamea*	35	450	1,150	744.00	166.46	28.14	22.37
143	*A. alba*	72	320	1,150	719.10	205.65	24.24	28.60
165	*A. alba*	69	315	1,300	830.72	243.23	29.28	29.28
226	*A. alba*	4	370	1,050	625.00	278.97	139.49	44.64
406	*A. concolor*	1	1,350		1,350.00			
409	*A. concolor*	6	540	1,150	898.33	202.93	82.85	22.59
S 14	*A. alba*	79	200	1,500	868.04	303.52	34.15	34.97
97	*A. alba*	22	150	950	463.64	189.77	40.46	40.93
117	*A. alba*	18	190	950	590.00	210.34	49.58	35.65
129	*A. lasiocarpa*	4	360	680	512.20	128.33	64.17	25.04
134	*A. alba*	19	160	1,300	781.05	255.34	58.58	32.69
154	*A. fraserii*	14	410	1,000	735.00	149.56	39.97	20.35
160	*A. concolor*	11	150	1,200	808.18	262.08	79.02	32.43
169	*A. nordmanniana*	5	190	950	608.00	296.67	132.68	48.80
180	*A. nordmanniana*	1	720		720.00			
218	*A. alba*	3	170	850	478.33	281.20	162.35	58.79
418	*A. balsamea*	14	700	1,250	991.43	187.12	50.01	18.87
424	*A. lowiana*	4	360	1,300	820.00	346.91	173.60	42.31
425	*A. grandis*	30	850	1,700	1,286.67	200.39	36.59	15.57
428	*A. magnifica*	3	680	800	733.33	49.89	28.80	6.80
500	*A. nordmanniana*	10	900	1,500	1,265.00	198.81	62.87	15.72

RESULTS

Of 29 provenances 15 partial populations were planted on three lots, the other 14 were only on one lot due to shortage of plants (see tab. 2, 3). Tending on this plot was directed mainly on removing of natural seedings and sprouts preventing firs from growing. Growth of the stands was spontaneous, and only dead and declining fir individuals were removed so that proportion of growing plants could be taken for one of the criteria for adaptability to local environment and thus for criterion of vitality. A certain exception can represent very fast growing partial populations with low mortality where more intensive interspecific competition and mutual suppression can appear during growing. For our case it was grand fir with its very fast growth and relatively low mortality, partly also some

Tab. 3: Results of d.b.h. evaluation for fir provenance on plot no. 58, basic characteristic (spring 2001)

No. of proven.	Fir species	n	D.b.h. (mm)		x (mm)	sx (mm)	sx (mm)	Vk %
			min.	max.				
87	*A. alba*	77	15	230	107.99	50.49	5.75	46.76
89	*A. cilicica*	2	135	185	160.00	25.00	17.68	15.63
111	*A. hybridis*	60	10	195	90.42	45.10	5.82	47.27
120	*A. grandis*	47	90	380	193.30	69.16	10.09	35.78
122	*A. balsamea*	38	15	195	121.05	41.71	6.77	34.46
124	*A. balsamea*	68	30	175	105.81	32.73	3.97	30.93
135	*A. pinsapo*	13	10	180	88.85	57.05	15.82	64.21
136	*A. cephalonica*	48	5	245	120.63	52.65	7.60	43.65
141	*A. balsamea*	35	60	205	115.86	35.53	6.01	30.66
143	*A. alba*	72	15	230	88.75	47.71	5.62	53.76
165	*A. alba*	69	20	280	103.62	50.52	6.08	48.75
226	*A. alba*	4	30	125	66.25	38.14	19.07	57.57
406	*A. concolor*	1	320		320.00			
409	*A. concolor*	6	70	370	244.17	91.94	37.54	37.66
S 14	*A. alba*	79	10	235	103.73	52.14	5.87	50.26
97	*A. alba*	22	5	140	53.18	36.79	7.84	69.18
117	*A. alba*	18	10	200	81.11	49.49	11.66	61.01
129	*A. lasiocarpa*	4	30	90	58.75	24.59	12.30	41.86
134	*A. alba*	19	5	180	96.84	48.32	11.09	49.90
154	*A. fraserii*	14	45	185	103.93	39.47	10.55	37.98
160	*A. concolor*	11	10	225	114.09	58.03	17.50	50.86
169	*A. nordmanniana*	5	10	160	88.00	60.79	27.19	69.08
180	*A. nordmanniana*	1	85		85.00			
218	*A. alba*	3	5	105	46.67	42.49	24.53	91.05
418	*A. balsamea*	14	60	200	114.64	38.33	10.25	33.44
424	*A. lowiana*	4	40	290	145.00	93.94	46.97	64.79
425	*A. grandis*	30	70	290	168.67	57.20	10.44	33.91
428	*A. magnifica*	3	115	175	138.33	26.25	15.15	18.97
500	*A. nordmanniana*	10	110	295	220.50	56.23	17.78	25.50

provenances of silver fir similarly relatively fast growing with high number of surviving individuals on lots.

Based on survival analysis or mortality of investigated species and partial populations, with special regard to species or taxa, we can summarize results as followed.

Relatively high survival rate is characteristic for *A. alba*, *A. hybridis* (*A. alba* x *A. cephalonica*), *A. cephalonica*, *A. grandis*, *A. balsamea*, *A. fraseri*. Quite high losses showed the species *A. lasiocarpa*, *A. pinsapo*, *A. concolor*, *A. concolor lowiana*, *A. magnifica* var. *shastensis*. Species *A. cilicica*, *A. bornmülleriana*, *A. magnifica* completely or nearly completely died on the plot.

Briefly summarized results from height growth evaluation of species and partial populations are: when mortality degree is not regarded, then *A. grandis* and *A. alba* are of markedly above-average

Tab. 4: Variance analysis for a part of plot with three repetitions

Cause of variability	N	Sum of squares	Average square	F	Critical F for p = 1 - α	
					α = 0.05	α = 0.01
Provenance	14	2,616,432.8	186,888.06	2.87	2.06	2.79
Repetition	2	259,862.17	129,931.09	2.00	3.34	5.45
Residual	28	1,821,627.44	65,058.12			
Total	44	4,697,922.41				

Variance analysis for height growth of fir provenances on plot 58

Cause of variability	N	Sum of squares	Average square	F	Critical F for p = 1 - α	
					α = 0.05	α = 0.01
Provenance	14	97,307.62	695,054.00	2.13	2.06	2.79
Repetition	2	13,876.59	6,938.30	2.13	3.34	5.45
Residual	28	91,404.67	3,264.45			
Total	44	202,588.88				

Variance analysis for d.b.h. of fir provenances on plot 58

growth, followed by partial populations of *Abies nordmanniana*, *Abies balsamea* and *A. concolor lowiana*. Partial populations of *A. pinsapo* and *A. lasiocarpa* were growing very slowly. The other species and their partial populations represented relatively quite a wide intermediary spectrum with high variability of partial populations and species represented in more variants. Partial populations with silver fir showed significant variability in height growth that reflected relatively wide spectrum of provenances that originated from parent stands of various geographical sites and elevation. Relatively the fastest growth occurred at two provenances from the central Hercynian-Sudeten region (87 CR, natural forest zone 7 – Brdská vrchovina Mts.) and from the Carpathian region (S_{14} – eastern Slovakia).

Above all *A. grandis* partial populations were of excellent above-average height and diameter growths, followed by *A. cilicica*, *A. concolor lowiana* and *A. magnifoca shastensis*, but these results were markedly influenced by small number of individuals of these species or their partial populations growing more or less like solitaires. *A. cephalonica*, *Abies balsamea* and *A. fraseri* diameter increments were average, while growth of silver fir presented like a set of provenances was below-average. The lowest diameter increment was characteristic for *A. lasiocarpa*. Volume biomass production presented by the data of silver fir 87 – Hořovice, ČR was 103 m^3/ha and of grand fir (425 – Idaho) – 440 m^3/ha. Preliminary results showed certain positive perspectives for introduction of some exotic tree species based on breeding selection.

SYNTHETIC EVALUATION

Evaluation at the age of 30 years was focused on survival rate, and height and diameter growth. These criteria were the object for synthetic evaluation of investigated partial populations and taxa of *Abies* genus. Indicators characteristic for particular partial populations were compared with indicators of on the plot represented silver fir species. The aim was to investigate to what extent

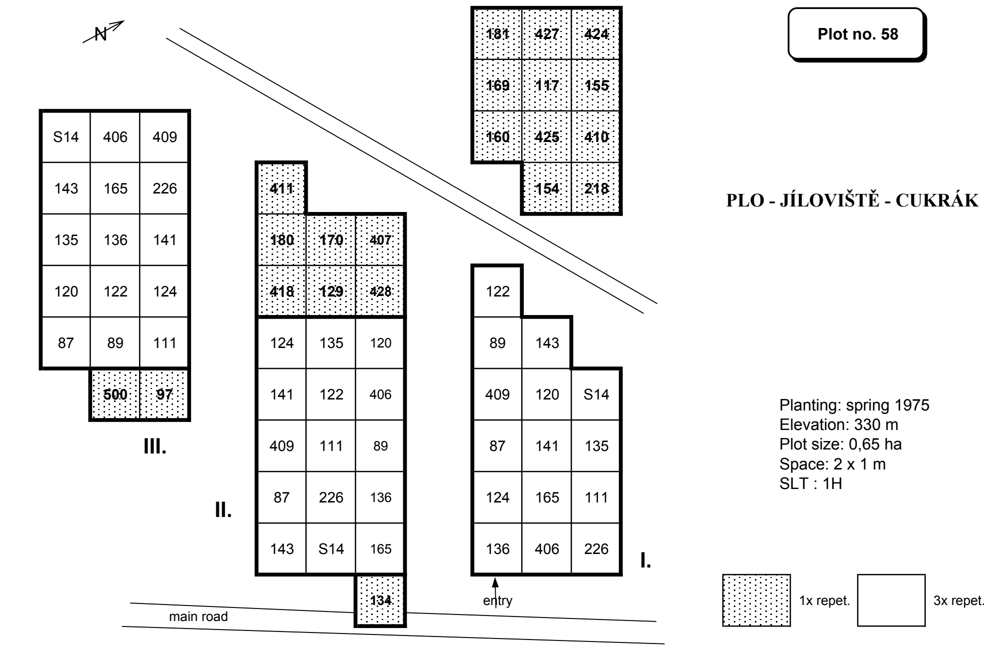

Fig. 1: Research plot no. 58 – sketchmap – locality Jíloviště

exotic fir species can participate in production enhancement in forestry, or to what extent they can substitute native tree species in forest communities. Actual this is especially in cases of some native tree species that being in bad health conditions cannot fulfil their original functions in forest communities. Additionally synthetic evaluation involved also results of phenological observations from flushing time processed during evaluation of research plot at the age of 9 years.

For better survey of evaluation results we repeat the indicators of partial population ”standard“ 87 – silver fir, Hořovice, Jince, CR: number of growing individuals is 150 per plot planted at the age of 30 years – 77, average height 8.44 m, average d.b.h. 10.8 cm. This partial population flushes early and is, in dependence on conditions, more threatened mainly by autumnal frosts.

Abies alba Mill.

This fir was represented on the plot by 9 provenances, of which one came from the Czech Republic, two were from the Austrian Alps, France, and after one partial population originated from Spain, Romania, Italy and Slovakia. Due to different origin (geographical location and altitude) this provenance set was characteristic by quite a high variability of survival as well as height and diameter growth. Provenance 218 – from locality Suceava, Romania and partial population 26 – Abetone, Italy from elevation of 1,360 m quite failed in adaptability to local conditions. Mortality of these partial populations was extraordinary high and their height and diameter growths were distinctly below-average. Slovak partial population S-14 – Komárník - Svidník, was comparable with ”standard“ or indicator of Czech partial population 87 – Hořovice in all three investigated indicators, mildly surpassing comparative provenances in surviving rate and height growth, in diameter growth being

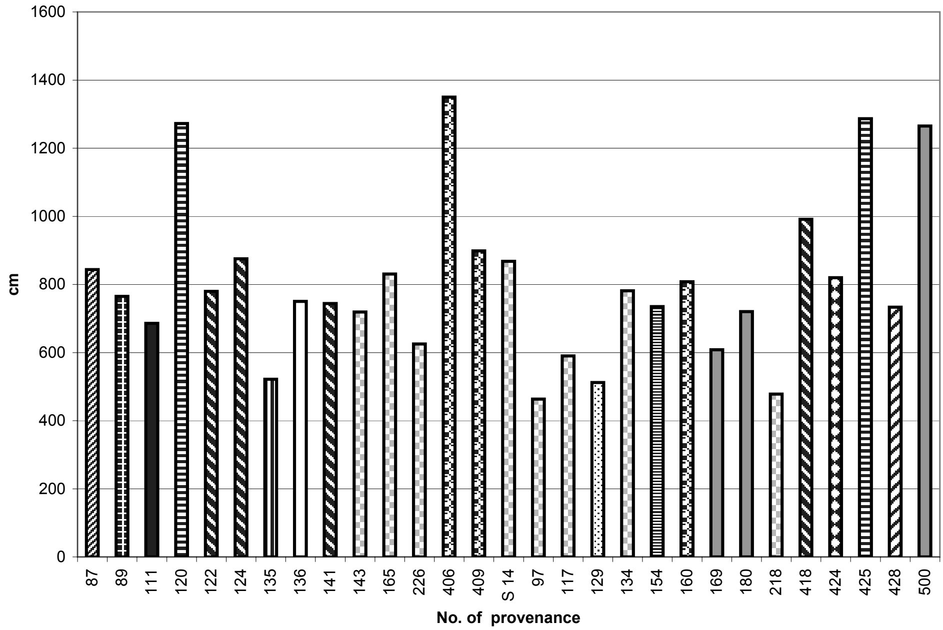

Fig. 2: Average heights, plot no. 58

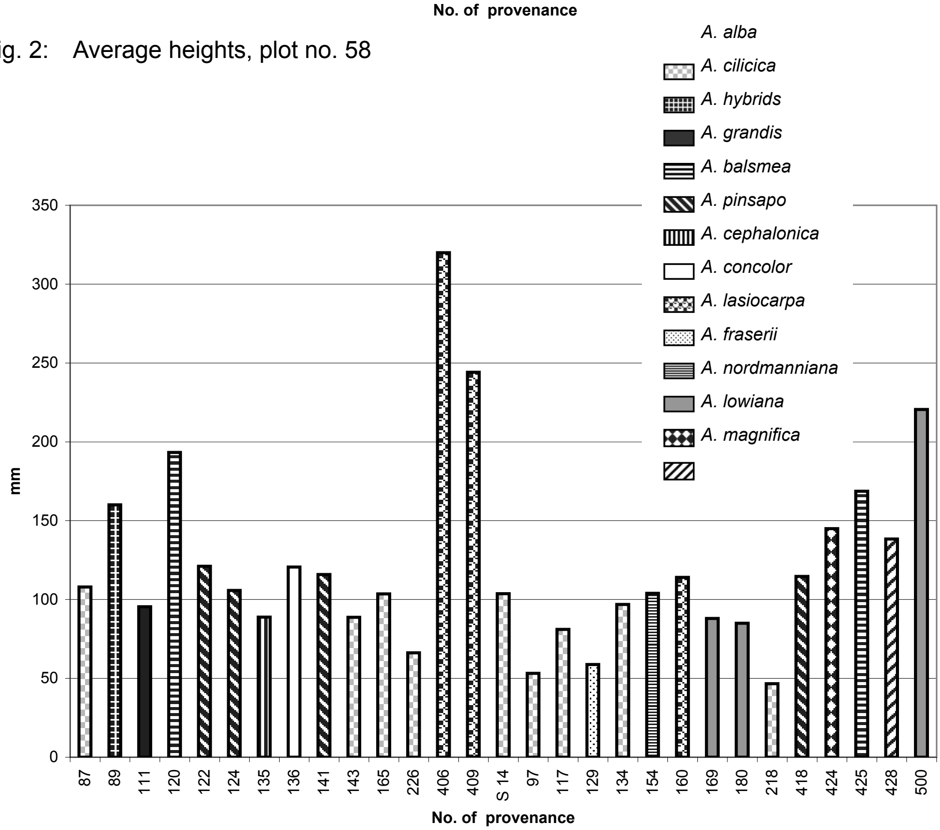

Fig. 3: Average d.b.h., plot no. 58

a little behind. Partial population from the Austrian Alps from elevations 1,000 to 1,200 m a. s. l. was mildly worse in comparable criterion "survival", but markedly below-average both in height and diameter. Of French provenances partial population 117 La Joux from elevation of 750 m a. s. l. was markedly below-average in all indicators while partial population 165 – Saint Evroult II was quite tightly approaching to "standard" in all indicators. Provenance 134 from the Spanish Pyrenees was markedly behind the criterion in survival rate, and mildly behind in other indicators. Evaluation at the age of 9 years showed (Šindelář 1986) that the set of silver fir partial populations could be classified into category of early flushing when compared with other represented species of *Abies* genus. Regarding variability of partial populations, evaluation results confirmed the importance of selection of suitable silver fir provenances for further breeding in the Czech Republic. This investigation brought also information on above-average vitality and growth of partial populations of fir from the Hercynian-Sudeten and Carpathian regions (e. g. Šindelář 2000, Šindelář, Beran 2001 etc.). Based on experiences and research results including also the experimental plot no. 58 – Jíloviště, these regional and partial populations are planned for further use in the Czech Republic due to intended enhancement of fir in species forest composition.

Abies cilicica **Ant. Kizchy, Carr**

This fir grows in Asia Minor and Near East, especially in the Taurus and Antitaurus Mts., and in Lebanon in elevations of 1,300 – 2,000 m a. s. l. on some localities together with Lebanonese cedar and some oak and other species. All three partial populations planted on the plot (89 – Kammouha from Lebanon and other two 170 – Maras and 181 – Maras, Hartlap from Turkey) completely died at the age of 30 years, except for 2 individuals from partial population 89 – Kammouha. The first measurement was carried out at the age of 9 years; within the first and third of the mentioned partial provenances ca two tens of individuals remained whereas provenance 170 – Maras from Turkey showed 100% mortality. Two remained individuals were growing as solitaires; their height did not reach the standard coefficient, their d.b.h. was distinctly above-average undoubtedly due to solitaire position. Observations at the age of 9 years classified *Abies cilicica* into a set of early flushing species. Its losses are probably caused by winter and spring frosts the effect of which could be intensified just by early flushing of this species. Losses and complete failure could be also caused by autumnal frosts as well as by character of environment, i. e. low sum of precipitation, soil desiccation etc. Regarding this experience, breeding perspectives of *Abies cilicica* are quite negative for CR forest management.

Abies cephalonica **Loud.**

This species is occurring in Greece from Peloponnesian to Ochrid lake and adjacent islands in the Aegean sea (Thasos, Euboia, etc.). Continuous stands are up to elevations of 1,700 a. s. l., and their state, assessed from economical viewpoint, is very variable. Partial populations on our research plot originated from the Peloponnesian island from the mountainous elevation of 1,010 m a. s. l. In 2004, on three lots 48 individuals of 150 plants survived, i. e. 67 % compared to standard population. Compared to standard, height growth was of about 10 % lower (average height 7.00 m), d.b.h. was higher of 10 %. Similarly as *A. alba* and *Abies cilicica* this species belongs to the set of early flushing ones. Observations on other localities, for example on research plots in municipal forest of Písek town (Šindelář 2000), showed the limited possibilities for using in the CR forestry. There would be, among others, problems in supply with a greater amount of seed from abroad (relatively small plot with stands suitable for seed crop). *A. cephalonica* is usually used for breeding, mainly for hybridization (e. g. Greguss 1982, Kormuťák 1979 etc.).

Hybrid fir

This fir seed was imported under this designation from Greece, from locality Mt. Pindos, Kalambaka, from the elevation of 1,300 m a. s. l., situated into the northwestern Greece. Occurrence of spontaneous hybrid *A. borisii-regis* (Mattf.) (*A. alba* x *A. cephalonica*) is known in other mountain ranges as the Rhodope, Olympus and Thasos Mts. as well. Documentation for this seed sample did not involve information whether this was hybrid population of silver fir as mother partner and Greece fir as father one or whether it was reciprocal variant of hybridization. Partial population represented on research plot was flushing early. Many interspecific hybrids in vegetable kingdom as well as forest tree species show luxuriant growth or some morphological changes. Manifestations of these natures, heterogeneous growth, were not observed. Compared to the "standard" partial populations with silver fir, spontaneous hybrid was characteristic by below-average survival rate and below-average growth characteristics both of height and d.b.h. Hybrid fir showed to have negative features also on other plots, for example on research plots in municipal forest of Písek town. Not a small number of individuals had a curved stem. That is why possibilities to use this species in forestry of central Europe are unreal.

Abies grandis Lindl.

Two partial populations on the plot represented this species. One of the provenances came from the area of state Washington (USA) from elevation of 335 m a. s. l., the second one from the continental area of state Idaho (USA) from elevation of 775 m a. s. l. Especially in western Europe *Abies grandis* has been time-tested tree species with good perspectives for practice. In CR, IUFRO research plots were positively evaluated on 6 localities with more than 30 species provenances from the USA and Canada. In CR some older plantings had been registered, for example on locality Rožmitál pod Třemšínem, Hořice at the Podkrkonoší Foothills and in forest of Rokycany town. These stands were characteristic by fast growth and notable volume production. Results from observation for two partial populations on the research plot were not contradictive to the gained experiences. Survival rate of provenance Washington was distinctly lower in comparison to the "standard" silver fir population. This phenomenon was conditioned by much more intensive height and d.b.h. growths which were related to more spontaneous reduction of individuals on the plot. Provenance 425 from locality Idaho preceded the comparing criterion in all indicators including survival rate. In general, both partial populations were over the "standard" in height growth of more than 50 %, in diameter growth then nearly of three fourths. In volume production the lead to "standard" was nearly quadruple. In accordance with observations and experiences from CR and abroad as well as from research plots of IUFRO provenance series *Abies grandis* can be taken for perspective species for forestry in central Europe and thus for CR. *Abies grandis* can substitute silver fir on some localities. Regarding experiences with *Abies grandis* sensitivity to infection of root systems by honey fungus, some carefulness is needed. For this species flushing time begins a little later than for silver fir.

Abies balsamea Miller

Four partial populations were on the plot, three were planted in three repetitions and the fourth one was growing only on one lot. Two partial populations came from Canada, from eastern part of province Quebec large area (surrounding of town Montreal) and province Ontario from elevations of 320 to 427 m a. s. l. Other two partial populations were from the USA; 131 – N. Hampshire grows also in the eastern region from elevation of 553 m a. s. l., while partial population 418 from elevation of 98 m a. s. l. represents lake area of state Maine. Mortality of these species provenances was high, on average value of control partial population was overrun of ca 40 %. However, height and diameter growths of this species were approaching to characteristics of the fastest growing partial populations of silver fir, in some cases they were even mildly ahead. Variability within the set of investigated partial species populations was low. Experiences also from other plantings and knowledge from literature confirmed that *Abies balsamea* grew well, did not suffer from frosts and tolerated waterlogging. Observations mainly abroad showed that volume production of this species is rather low and its life is relatively short. Results and conclusions based on observations on research plots established within research series in municipal forests of town Písek were similar to those from assessed research plot no. 58. Despite the initial positive results of plantings, for European forest management possibilities for wider use of *Abies balsamea* are limited.

A. pinsapo Boissier

This fir represented on the research plot by one provenance from Malaga region was of very high mortality. Only 13 individuals of 150 plants lived until the age of 30 years, i. e. 17 % of comparable standard. Both height and diameter growths were weak. Heights of growing individuals were around 5 m, d.b.h. around 8 cm. Stem deformations were frequent and flushing time was intermediar. The similar results were proved on other research plots, above all in municipal forests of town Písek. This species is not suitable for using in forest management. Experiences from arboreta and parks document that *A. pinsapo* can be used as the decorative species in horticulture under suitable ecological conditions.

A. concolor Lindl. et Gord.

This species was initially represented by four partial populations on the research plot, three of them being from California (USA) from elevations of 1,670 to 1,828 m a. s. l. Another provenance originated from the state Colorado from the site in elevation of 1,500 m a. s. l. One variant 407 from locality Tuolume, California, quite died out even when at the age of 9 years still 12 individuals of total number of 150 individuals planted were registered on the lots. Mortality of the other three partial populations was high. Of 350 plants only 18 individuals grew on the research plots at the age of 30 years, i. e. 13 % of number of ”standard“ silver fir provenance. *A. concolor* was growing on lots in several small groups and like solitaire individuals. Height growth of two remained provenances (409 – Mendocino, 160 – Montrose, Colorado) was average, approximately on the level of comparative silver fir provenance, while a solitaire individual of provenance 406 – Siskiyou, California, reached height of 13.50 m at the age of 30 years. D.b.h. of growing individuals for this species was significantly higher than ”standard“. One of the firs reached the remarkable d.b.h. of 37 cm. Intensive diameter growth was to a certain degree conditioned by more or less solitaire growth of preserved individuals. Rather high mortality might be caused, analogically to *Abies grandis*, by physiological desiccation of tissues, mainly needles, in the pre-spring period and infection of root systems by fungal diseases, especially by honey fungus. *A. concolor* is often used in horticulture because of its very decorative appearance and many morphological forms (e. g. *f. fastigiata* with columnar crown, *f. pendula* with overhanging branches, *f. brevifolia* with short blunt and wide needles, *f. argentea* with silvery rimed needles, etc.). For forestry practice perspectives of this species are limited, nearly unreal, which is also documented both by information from literature, and then by the fact that *A. concolor* was not classified into the assortment of *Abies* genus tested for possible introduction into European forests within the IUFRO projects.

***Abies concolor lowiana* (Mars.) Matt.**

For some authors this subspecies of *A. concolor* is a hybrid of *A. concolor* and *Abies grandis*. Its occurrence is registered on many localities in Arizona (USA). This taxon was represented on the research plot by partial population 424 – Meyers from California (USA) from locality in elevation of 2,070 m a. s. l. There were planted 50 individuals on the plot and only 4 exemplars remained until the age of 30 years. Height growth of individuals approached standard (average height 8.20 m), d.b.h. was markedly higher than the standard due to higher occurrence of solitaire individuals on the plot. This species is experienced as excellent in volume production on some localities in Europe, in CR for example in arboretum Bukovina at Hrubá Skála in northern Bohemia. This experience cannot be either confirmed or refuted because of small number of individuals that remained on the research plot.

***Abies nordmanniana* (Stav.) Spach**

This species grows in the western part of Carpathians, then on the southern and south-eastern coast of Black Sea where it is occurring in forest stands together with *Picea orientalis* in the elevation up to 2,000 m a. s. l. There were three partial populations on the plot. Two partial populations 169, 180 Sebinkarahishar came from Turkey from locality in elevation of 1,600 m a. s. l., the third one 500 was from Georgia. For the latter one no data on origin had been at disposal. As mentioned in the chapter dealing with survival rate of investigated material on the research plot, mortality was quite high, even extreme (within provenances 218 only one exemplar remained of 50 plants). Height and diameter growths of partial populations or individuals from Turkish localities were below-average, whereas 10 individuals of partial population 500 from Georgia were characteristic by above-average growth in comparison with standard silver fir provenances. Due to insufficient amount of seed samples only very small number of plants was successfully bred; therefore this species was not parallely planted on the other research plots. This fir seems to be less threatened by late frosts because it flushes a rather later than silver fir. Being successful in some plantings in Europe *Abies nordmanniana* has become a subject of attention. Some works (e. g. Löfting, Mekic 1981) remind quite high species variability and possibility to select perspective, relatively fast growing and resistant partial populations. Quite a high variability is also based on observation results on the research plot. Future establishment of one or several provenance research plots with larger assortment of this tree species partial population is justifiable. It must be also mentioned that *Abies nordmanniana* is used for decorative purposes, for Christmas trees breeding, especially in Denmark and Germany.

***A. lasiocarpa* (Hook.) Nutt.**

To have the full survey *A. lasiocarpa* must be mentioned. This species was represented on the research plot by one provenance from province Alberta (Canada). Only 4 exemplars of 50 plants remained on the plots with distinctly below-average height and diameter growths. Therefore its use in European forestry is unreal.

***Abies fraseri* (Pursch.) Poir.**

Partial populations of *Abies fraseri* are from northern Carolina, USA. They are characteristic by below-average viability as well as height and diameter growths. On the research plot there were growing 14 individuals of 50 planted that flushed late. Little information is at disposal because plantings of this species, morphologically similar to *Abies balsamea*, are very rare in central Europe.

Possibilities to use it are, as for *Abies balsamea*, very limited. This mountainous species is growing in relatively small Atlantic area of the USA. Import of a greater amount of seed will have been quite uneasy. Even in the USA *Abies balsamea* has negligible economical importance.

Abies magnifica **Murray**

This species was planted on the research plot in 4 partial populations, mostly originated from California, USA. One of them belonged to regional population *A. magnifoca shastensis* from the Shasta Mts. in southern Oregon. As mentioned above, mortality of three populations from California was 100% until the age of 30 years on the research plot. In 2004 there were three individuals of 50 planted on the locality with below-average height and markedly above-average diameter growth. This species is useless for forestry in Europe, some perspectives are in decorative horticulture especially for its forms with blue or silvery coloured needles.

Abies bornmülleriana **Mattfeld.**

Until the age of 30 years provenance with species *A. bornmülleriana* Mattfeld., growing in the northwestern Asia Minor, completely died out in the planting on the plot Jíloviště. By its appearance similar to *A. nordmanniana*, *A. bornmülleriana* Mattfeld is in a certain way related to *A. cephalonica* (Klika et al. 1953). Already 19 individuals of 50 planted were growing on the plot at the age of 9 years being all of very weak increment.

DISCUSSION

Characteristics of individual species and partial populations of fir represented on the plot Jíloviště, at least some of them, can be confronted with results that will be acquired on other research plots (64, 65, 66 – Písek, 68 – Pelhřimov, Černovice, 62 – Nýrsko, Dešenice). As mentioned above, for *Abies grandis* comparable results are at disposal from investigations on research plots of series IUFRO from years 1980 to 1983. Nevertheless, after comparison with available information from the other plots, results and conclusions especially for exotic fir species summarized in stands of this age can be taken for informative enough and usable both from viewpoint of research and practice. Results from research plot Jíloviště with silver fir can be used as a base for confrontation with information from numerous series of plots with provenances representing more or less the whole area of *Abies alba* Mill. genus.

CONCLUSION

Results from observations on the research plot no. 58 – Jíloviště document perspectives of further use of the native species – silver fir even in limited ecological conditions. Within this species quite a high variability of partial populations was confirmed as well as suitability of provenances from the Hercynian-Sudeten and Carpathian areas for conditions in central Europe.

Despite location of the research plot on the site with very low annual sum of precipitation and many spring and summer short-term droughts, both represented *Abies grandis* partial populations proved to be of good growths. Mortality of plantings was only average and increment of height, d.b.h. and final biomass remarkable which was surprising in such for grand fir extreme conditions. Volume production of this species at the age of 30 years was nearly of four times higher than of silver fir. This experience shows good possibilities for using this species in forestry of central Europe; also observations on other research plots (64, 65, 66 – Písek, 62 – Nýrsko, 68 – Pelhřimov) had proved it. This conclusion is based above all on investigation results from the IUFRO international plots established in many European countries and CR as well as on a lot of experiences from practice.

In CR conditions all four partial populations of *Abies balsamea* are of quite a high vitality and relatively fast growth in youth. But their observed relative short life and low volume production are the reason for doubts about using this species in forest practice. This is also documented by negligible interest in using this species in the other European countries.

A certain attention should be paid to *A. concolor*, especially to variety *A. concolor lowiana*, that is, like the *Abies grandis*, of fast growth and quite a high volume production. Possibility to use it in forestry is low due to its, on some localities, total mortality after planting. Investigation indicates that this phenomenon is caused by root rot invoked by honey fungus. And besides it, relative short life of this species is mentioned in references. This species will be probably used above all in decorative horticulture because of its many aesthetically impressive forms.

Based on experiences from abroad, among others from Germany and Slovakia, there are promising perspectives for *Abies nordmanniana*. However, mortality of all three provenances, of which two originated in Turkish part and one in the Carpathian area, was very high. Growth rate of this partial population was very variable. While one population from the Carpathian area was growing very fast and its individual trees were of marked volume production, the others were deeply below the indicators of comparative "standard" provenance. Research results in conditions of central Europe show quite a high variability within this species so that selection of suitable provenances for using in forest practice would be of principal importance. Perspectives to use this species in practice are conditioned by further research with numerous assortment of partial populations.

Perspectives of *A. cephalonica* and hybrids of *A. alba* x *A. cephalonica (A. borisii regis)* are limited. Growth of partial populations represented on the research plot was below-average, even when their mortality was average and health state satisfactory. More reliable information can be gained from methodical observations in further stages of development.

A. pinsapo, *Abies cilicica* and *A. bornmülleriana* cannot be used in forestry of central Europe because of their high sensitivity to local conditions. These species were damaged mainly by winter and spring late frosts, and their mortality was very high already in the first years after planting. Of species from North America *A. magnifica* including variety *A. m. shastensis* have no perspectives due to their high, in some partial populations total mortality in the first years after planting.

Results from *Abies grandis* observation in 1975/76 show positive perspectives on the plot 58 and other localities. Another perspective species for European forestry shows to be *A. procera*, which was not growing on this evaluated plot but observations on research plots, established within participation of CR in IUFRO project, had proved it.

The final conclusions were defined on base of measurement and assessment of research plot on locality Jíloviště. They are in accordance both with experiences from the other plots founded in CR and with those available in European literature. Future systematic evaluation of research plot as well as other parallel plantings is planned in intervals of 5 to 10 years.

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CIZOKRAJNÉ DRUHY JEDLÍ (*ABIES* SPEC. DIV.) VE VĚKU 30 LET V PŘÍRODNÍ LESNÍ OBLASTI 10 – STŘEDOČESKÁ PAHORKATINA

Souhrn

V předkládané zprávě jsou uvedeny výsledky z testování různých druhů jedle rostoucích na provenienční ploše č. 58. Provenienční plocha č. 58 byla založena v roce 1975 na lokalitě Jíloviště (vlastník Bartoň z Dobenína). Na ploše roste značná část druhů rodu *Abies*. Část rostoucích jedinců byla poprvé hodnocena ve věku 9 let z hlediska přírůstů a fenologie a porovnány byly různé druhy jedlí s jedlí bělokorou. Komparativní fenologická studie byla významná z hlediska odolnosti k časným mrazům. Další hodnocení proběhlo ve věku 30 let a výsledky byly porovnány a sumarizovány. Výsledky hodnocení potvrdily perspektivu uvažovaného využití domácího druhu jedle bělokoré i pro více či méně extrémní podmínky v ČR. Na základě výsledků hodnocení provenienčního pokusu byla prokázána vhodnost testovaných proveniencí pro výsadbu v hercynsko-sudetské i karpatské oblasti střední Evropy.

EXOTIC SPECIES OF FIR (*ABIES* SPEC. DIV.) AT THE AGE OF 30 YEARS IN THE NATURE FOREST REGION NO. 10 – STŘEDOČESKÁ PAHORKATINA (CENTRAL BOHEMIAN UPLAND)

Summary

This partial final report presents evaluation results from provenance plot no. 58 with various species of genus *Abies*. Provenance plot no. 58 was established in locality Jiloviště (forest ownership Zbraslav, Bartoň from Dobenin) in 1975. There is numerous number of genus *Abies* species and provenances represented in this provenance plot. Portion of growing individuals was investigated regularly and height growth measurement with evaluation of phenology was realized at the age of 9 years. Evaluation of phenology used to be very important because its level presents a conditioning factor of species and provenances resistance against late frosts. In case of provenance plot no. 58, individual species of genus *Abies* and their partial populations were compared each other and results of evaluation were confronted with evaluation results of silver fir provenances planted here, too. The presented partial final report summarizes results from the second evaluation of provenance plot no. 58 at the age of 30 years. Results of evaluation prove perspectives of another use of domestic species – silver fir, namely in the more or less extreme ecological conditions for this species. Also considerable variability of partial populations within the framework of this species and convenience of provenances from both Hercynian-Sudeten and Carpathian regions for the Central Europe conditions were proved.

CHEMISTRY OF WATER IN FORESTS IN RELATION TO CHANGES OF AIR POLLUTION LOAD

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ABSTRACT

Deposition of air pollutants and chemistry of water surface resources in forested catchments distributed in various areas of the Czech Republic were investigated in years 1992 (1991) to 2001 (2002). Clear trend of decrease was observed for deposition of S/SO_4^{2-} and basic cations (Ca, Mg, K, Na) and Al. Decrease of N(NO_3^- + NH_4^+) deposition did not occur in all the catchments. In water streams SO_4^{2-} concentrations change ranging from increment to visible fall. Increase of sulphates was caused by their release from supplies accumulated during the period of maximal deposition. Concentrations of NO_3^- decreased on majority of catchments, mild increase occurred in water in the catchments where their relatively low values in mature spruce stands had been found before. Water contamination is also impacted by deviation of weather, temperature and precipitation.

INTRODUCTION

The 20th century, and especially its second half is the period of massive increment of harmful agents, above all products arisen by combustion of fossil fuels. Emissions of SO_2 are the principal source of acidification in industrial areas, including central Europe, culminating in countries of the European Union (EU/15) between 1980 to 1985 and in the other European countries about year 1985 (Ferrier et al. 2001). Development of SO_2 emissions responded to development of SO_x deposition reaching in central Europe, and in the Czech Republic (CR) as well, maxims in year 1985. Oxides of nitrogen (NO_x) are another important part of acidic deposition. Their highest fallout occurred in central Europe in years 1980 to 1990 and their drop was less distinct in next years when compared to sulphur compounds. Also NH_3 deposition developed similarly like NO_x deposition but it mildly fell down and then mildly increased on the turn of the millennium (Wright et al. 2001).

Decrease of sulphur compounds deposition in Europe was conditioned by an obligation of the European countries to reduce sulphur emissions of 30 % in relation to state in year 1980 (First Protocol, 1985) till 1993. Until 2010 further emission of sulphur compounds should be reduced of 80 % related to state in year 1980 which is based on 1994 obligation of governments of European countries (Second S Protocol). In 1988, emission decrease of nitrogen compounds in Europe was settled by governments (First N Protocol) that obliged signatories to stabilize emission of N (NO_x) oxides onto 1987 level until 1994. In 1999 representatives of European governments signed the settlement in Gothenburg on decrease of acidification, eutrophization and threshold levels of ozone in environment. This settlement also deals with interactions of four key atmospheric pollutants: S, NO_x, volatile organic substances and ammonium (NH_3), and defines the upper limit of these emissions for year 2010. Fulfilment of these targets should reduce European emissions of S of 63 %, NO_x of 41 % and NH_3 of 17 % when compared with 1990.

For observation of depositions development and definition of critical load of ecosystems as well as for control of keeping the settlement on emissions, results of long-term measurement are needed. For this purpose data from long-term observation of trends of water quality are gathered in the

Tab. 1: Geographic data and runoffs from catchments

Catchment	Forest area	Coord. Gauss-Krieger X	Coord. Gauss-Krieger Y	Elevation m min.	Elevation m max.	$l.sec^{-1} km^{-2}$	Year	$l.sec^{-1}/km^{-2}$	Year	Plot km^2
Červík	Beskydy	431145	548350	640	960	21.26 24.72	1992-1996 1997-2001			Červík A 0.88 Červík B 0.84
Malá Ráztoka	Beskydy	430130	548960	602	1.084	25.86	1992-1996	21.8	1997-2001	2.08
U Vodárny	Jeseníky	365930	556445	560	934	14.64	1992-1996	12.56	1997-2001	1.45
U Lizu	Šumava	340380	543790	828	1.074	9.6 *				0.99
Želivka	Středočes. pahorkatina	351715	550410	360	470	2.9 4.1 *	1996-2000			1.19
Moldava	Krušné hory	340795	562105	790	864	17.1 *				
Strouha	Středočes. pahorkatina	345660	544720	430	500	2.9 * 4.1 *				
Šerlich	Orlické hory	359780	557860	860	1026	25.37 ** 19.40 *	1982-1993			
Vojířov	Čes. vrchovina	349850	543345	530	607	6.2 *				

* Atlas ČSSR, 1966
** Kantor 1994

Tab. 2: Geologic and soil conditions in catchments

Catchment	Geologic conditions	Prevailing soil types
Červík	godul sandstone with insets of Istebňany shales	Podzols, dystric Cambisols, partly gleyed
Malá Ráztoka	godul sandstone, partly finely rytmic flysch	Podzols, dystric Cambisols
U Vodárny	biastomylonit and metagranitoid	Podzols and Cambisols
U Lizu	biotitic and sillimanit-biotitic plagioclase paragneiss	Podzols, dystric Cambisols, partly gleyed
Želivka	biotitic and sillimanit-biotitic, double-mica paragneiss	dystric Cambisols, Stagnosols, Luvisols
Moldava	muscovite-biotitic paragneiss	Podzols
Strouha	biotitic to sillimanit-biotitic paragneiss	dystric Cambisols
Šerlich	double-mica schist	Podzols, dystric Cambisols
Vojířov	double-mica and adamelic granite, finely to medium textured with overlapping of eolic sand	Podzols, dystric Cambisols

ICP Waters network. This program contains data from a larger part of Europe and North America (Stoddard et al. 1999). The subjects in Europe were divided into areas of Scandinavia, Great Britain and central Europe. Assessment of developmental trends of water chemistry from 64 surface sources shows improvement of preceding acidification on many catchments between years 1988 and 1989 but these trends are rather differing within regions (Skjelkvåle et al. 2000). The present program RECOVER: 2010 is based on results of preceding work and involves observation of 56 lakes and streams in 8 European countries including the Šumava Mts. lakes.

Since the late 1980s till the first years of this century emission of air pollutants was reduced also in CR. Based on data from the Czech Hydrometeorological Institute (Air pollution on territory of the Czech Republic in years 1999, 2002) emissions of solid substances (dust and ash) reached 840 kt, SO_2 2,066 kt and NO_x 858 kt in year 1988 and 59 kt of solid substances, 236 kt SO_2 and 318 kt NO_x in year 2002. In year 1990 NH_3 emissions were 156 kt and 77 kt in 2002. This decrease of emissions resulted in various level of reduction in deposition of observed substances on the FGMRI plots.

This contribution brings assessment of development of water chemistry in surface sources on forested catchments and evaluates depositions of substances with throughfall in the 1990s. The observed plots are in the areas with different immission load in different elevations which influences, as well as forest stands and soil-geological conditions, deposition and dynamics of substances from polluted air and thus water chemistry of surface sources.

METHODOLOGY

Description of plots

Deposition of substances and water chemistry of surface sources have been investigated on research plots situated in different areas of the Czech Republic. Catchments Červík are in the Beskydy Mts.: catchment Červík A is forested by young, mainly spruce stands and mature spruce stands prevail on catchment Červík B. In another Beskydy catchment Malá Ráztoka original beech

Tab. 3: Average annual deposition of substances on catchments in the Beskydy and Jeseníky Mts. (bulk)

$kg.ha^{-1}.year^{-1}$

Sampling plot	Period	H	SO_4^{2-}	NO_3^-	Cl^-	NH_4	N *	Ca	Mg	K	Na
Červík	1992-1996	0.0144	132.66	17.29	22.04	5.95	8.53	43.96	12.27	5.84	11.75
	1997-2001	0.1178	36.08	22.9	17.77	6.1	9.91	16.85	3.39	3.95	4.17
Malá Ráztoka	1992-1996	0.01286	164.55	36.35	29.1	27.16	29.3	29.55	8.05	11.07	9.64
	1997-2001	0.13574	71.36	33.44	31.31	20.72	23.64	23.79	5.53	12.69	7.66
U Vodárny	1992-1996	0.0155	78.36	29.01	16.99	8.76	12.66	30.25	5.36	4.9	5.24
	1997-2001	0.0216	58.08	33.77	22.54	12.08	19.69	29.33	4.6	9.59	5.01

* N (NO_3^- + NH_4^+)

Tab. 4: Average concentrations of substances in stream waters in the Beskydy and Jeseníky Mts.

$mg.l^{-1}$

Water source	Period	pH	SO_4	NO_3	Cl	Ca	Mg	K	Na	Al	Alkalinity*
Červík A	1992-1996	6.82	21.2	1.72	1.79	6.25	2.5	1.11	1.92	0.122	0.11
	1997-2001	6.73	15.83	1.32	2.18	6.21	2.26	1.01	1.82	0.082	0.119
Červík B	1995-1996	6.37	24.82	3.65	2.45	5.47	2.83	1.15	2.37	0.073	-0.006
	1997-2001	6.33	19.53	4.31	2.62	5.04	2.51	1.22	2.65	0.071	0.071
Malá Ráztoka	1995-1996	6.94	19.08	5.63	2.37	12.84	1.91	0.76	1.99	0.082	0.348
	1997-2001	6.93	15.64	5.37	2.36	11.83	1.53	0.76	1.72	0.065	0.33
U Vodárny	1995-1996	7.21	19.65	11.97	2.38	25.14	2.17	1.37	2.35	0.075	0.899
	1997-2001	7.4	22.1	7,.9	2.4	26.01	1.91	1.19	2.25	0.034	0.929

* $mmol^+$ (Ca^{2+} + Mg^{2+} + K^+ + Na^+) - $mmol^-$ (SO_4^{2-}+ NO_3^- + Cl^-)

stands were regenerated mostly by spruce on more than 75 % of the plot. Catchment U Vodárny lies on the left-handed tributary of the Šumný brook and is covered mainly by the older spruce stands. Older spruce stands are also growing on the largest part of Želivka plot included in the catchment of Pekelský brook, right-handed tributary of reservoir for drinking water "Želivka".

Plots Zdíkov are in the foothills of the Šumava Mts. in the catchment "U Lizu" and are managed by the Institute of Hydrodynamics of the Academy of Sciences CR. Research plot Vojířov (in vicinity of Lásenice) is in southern Bohemia, water springs are observed on plots Strouha in vicinity of Temelín. Older spruce stands prevail on all three plots.

Deposition of substances and water chemistry were investigated already before cutting of spruce stands (1981) in a stand and on clearcut in the Krušné Mts. in catchment of the spring U Moldavy and continued in the substitute stand. In the Orlické Mts. research of water chemistry was carried out in the left-handed tributary of Bělá brook at Šerlišský Mlýn and throughfall was observed on slopes of the Šerlich Mt. This catchment involves both diverse forest stands and State Nature Reserve Bukačka.

Geographical data on catchments are presented in table 1. Water discharges on catchments Červík, Mala Ráztoka, U Vodárny and Pekelský brook (object Želivka) were investigated on spillway (Bíba et al. 2001). Specific runoffs from other catchments were taken from the Atlas of ČSSR (1966). For brook catchment in the area of Šerlich Mt. runoff according to Kantor (1994) is presented.

The assessed catchments of streams and springs differ one from another by elevation, precipitation and runoff situation and soil geologic conditions and are characterized in table 2. More detailed data on mentioned catchments and research plots are presented in publications (Lochman 1996, 1997, Lochman, Šebková 1998, Lochman, Fadrhonsová 2000, Lochman et al. 2001, 2002).

Description of investigation

Bulk precipitation on open space (clearcut) and under forest stands was captured into open containers usually in month intervals and in the same intervals water sampling was done from streams on spillways or from springs.

Water samples were analysed in the FGMRI laboratory at Jíloviště-Strnady according to methodology based on demands of international program of monitoring of forest state ICP Forests (Level II). Throughfall chemistry on open space and under stands and spring water were investigated on catchments (objects) Želivka, Moldava, Zdíkov and Šerlich year-round already before 1992. Since 1992 results of year-round investigations of throughfall on open space and water chemistry in streams are at disposal for catchments Červík A, Červík B, Malá Ráztoka and U Vodárny. Since this year deposition of substances on open space and under stand and concentrations of substances in spring water have been observed on the objects Vojířov and Strouha. Research results on the objects in southern Bohemia for year 2002 are assessed separately due to extraordinary precipitation and runoff situation in this area in this year.

RESULTS

Bulk water on catchments Červík and Malá Ráztoka in the Beskydy Mts. and U Vodárny in the Jeseníky Mts. is captured into open containers only on open space. Ombrometers are placed in vicinity of spillways in the catchment valley so that air flowing through stream valleys influences substance composition of bulk water by emission fallout from local sources. Data do not represent deposition of substances on catchments but reflect trends in their lower part.

Tab. 5: Average annual deposition of substances on plots in south Bohemia

Sampling plot	Period	kg.ha^{-1}.year^{-1}										
		H	**SO_4^{2-}**	**NO_3^-**	**Cl^-**	**NH_4^+**	**N***	**Ca**	**Mg**	**K**	**Na**	**Al**
Zdíkov												
spruce stand	1987-1991	0.5007	74.55	26.58	15.4	10.66	14.28	15.84	3.34	15.02	3.16	1.224
throughfall	1992-1996	0.173	56.93	14.45	11.5	5.77	7.75	13.08	4.4	17.35	3.53	0.884
	1997-2001	0.0709	25.57	17.12	10.72	2.81	6.05	9.67	2.86	12.31	2.67	0.218
	2002	0.1277	22.48	16.05	7.35	2.79	5.0	7.33	1.92	14.32	2.45	0.244
beech stand	1990-1991	0.1068	30.8	13.61	8.94	7.74	9.09	8.18	1.66	12.01	1.86	0.466
throughfall	1992-1996	0.0334	28.2	17.53	8.24	3.78	6.89	9.14	2.85	14.11	2.88	0.245
	1997-2001	0.0229	10.56	13.99	7.57	2.24	4.9	6.32	1.68	11.91	1.88	0.088
	2002	0.1148	16.5	29.45	4.46	2.59	8.67	5.55	1.13	19.55	1.58	0.106
Vojířov												
open space	1992-1996	0.0796	32.7	24.6	27.77	5.28	9.66	20.34	3.27	5.06	3.01	
bulk	1997-2001	0.2134	18.58	19.7	30.05	5.15	8.45	15.22	2.18	2.8	2.78	
	2002	0.383	17.43	37.37	18.22	5.84	12.98	7.45	0.87	3.43	1.61	0.141
spruce stand	1992-1996	0.2856	80.76	26.12	12.01	7.76	11.92	17.13	4.22	20.98	3.07	1.178
throughfall	1997-2001	0.1964	43.08	29.15	11.13	6.24	11.43	12.09	2.89	17.84	2.84	0.359
	2002	0.122	45.01	32.28	7.12	8.84	14.15	11.84	2.35	23.02	2.2	0.181
mixed stand	1992-1996	0.071	44.39	17.31	9.22	5.6	8.26	11.29	3.02	18.26	2.36	0.108
throughfall	1997-2001	0.087	23.64	20.46	9.62	5.85	9.16	9.64	2.34	18,.6	2.22	0.172
	2002	0.11	20.37	27.33	3.64	4.86	9.95	6.07	1.25	14.89	1.18	0.096
Strouha												
open space	1992-1996	0.0965	23.23	15.7	27.9	5.81	8.06	14,99	2.86	2.23	2.15	
bulk	1997-2001	0.1843	15.45	21.01	16.34	2.11	6.39	10.33	2.18	4.79	2.29	
	2002	0.2613	23.47	45.68	21.8	1.23	11.27	17.56	3.18		1.87	
spruce stand	1992-1996	0.2021	86.73	23.1	12.58	6.64	10.37	17	4.07	24.12	2.99	
throughfall	1997-2001	0.0729	42.78	25.04	12.12	8.48	12.24	11.43	2.51	19.13	2.4	
	2002	0.0516	37.82	18,81	10.25	11.69	13.2	10,62	2.21	30.2	2.05	

* N (NO_3^- + NH_4^+)

Tab. 6: Average concentrations of substances in surface sources in south Bohemia

Water source	Period	pH	mg.l^{-1}								mmol
			SO_4^{2-}	**NO_3^-**	**Cl^-**	**Ca**	**Mg**	**K**	**Na**	**Al**	**Alkalinity**
Zdíkov brook	1987-1991	6.73	11.15	4.43	3.16	4.05	1.57	1.03	3.58	0.119	0.121
(U Lizu)	1994-1996	6.43	12.41	3.04	2.24	4.11	1.57	0.88	3.86	0.069	0.155
	1997-2001	6.58	11.24	3.24	2.35	4.57	1.61	0.84	3.92	0.063	0.199
	2002	6.54	12.34	3.22	1.29	3.97	1.6	0.83	3.76	0.088	0.169
Vojířov spring	1992-1996	5.54	48.61	2.51	2.95	10.85	2.44	1.78	6.82	0.612	-0.054
	1997-2001	5.19	50.66	2.4	2.9	11.24	2.39	1.74	6.65	0.673	-0.081
	2002	4.89	53.43	2.03	2.13	12.3	2.57	1.86	6.37	1.419	-0.055
Strouha spring	1992-1996	7.05	99.22	8.31	13.87	30.64	10	9.51	17.61	0.056	0.769
	1997-2001	6.42	85.18	4.91	10.13	23.54	8.99	5.43	15.58	0.018	0.592
	2002	6.53	138.2	4.21	8.75	33.08	12.47	6.58	18.32	0.04	0.449

Data from catchment Červík presented in table 3 show that in years 1992 to 2001 deposition of SO_4^{2-}, Cl^- and basic cations Ca, Mg, K, Na markedly dropped and at the same time fallout of mineral forms of nitrogen (N/NO_3^-+ NH_4^+) mildly increased. These changes resulted in enhanced amount of protons (H^+) and pH decrease in captured bulk water. In years 1992 to 2001 fallout of SO_4^{2-}, NO_3^-, NH_4^+, Ca, Mg, Na decreased in the sampled locality within catchment Malá Ráztoka and deposition of K and Cl^- and markedly of H^+ ions mildly increased.

Tab. 7: Average annual deposition on plots Moldava

kg.ha^{-1}.year^{-1}

Sampling plot	Period	H	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	N*	Ca	Mg	K	Na	Al
Moldava clearcut	1985-1990	0.1773	84.4	40.26	29.07	14.37	20.25	32.56	4.71	6.93	5.31	1.94
bulk	1991-1996	0.212	62.26	25.96	23.07	9.41	13.17	23.09	5.19	10.88	7.22	1.36
	1997-2002	0.1843	37.25	26.88	30.51	7.81	12.13	17.8	3.64	3.94	5.6	0.255
rowan stand	1985-1990	0.288	110.3	39.09	31.26	20.21	24.51	26.41	5.53	8.85	5.82	3.63
throughfall	1991-1996	0.129	87.93	33.54	22.21	12.65	17.4	25.89	5.94	23.27	7.04	1.78
	1997-2002	0.074	52.33	32.27	34.72	7.84	13.37	23.55	5.08	31.28	8.42	0.298

* N (NO_3^- + NH_4^+)

Tab. 8: Average concentration of substances in spring water Moldava

mg.l^{-1}

	Period	pH	SO_4^{2-}	NO_3^-	Cl^-	N	Ca	Mg	K	Na	Al	Alkalinity*
Moldava spring	1985-1990	5.65	20.87	15.6	10.21	4.17	6.25	3.91	1.14	6.06	0.145	-0.048
	1991-1996	5.85	22.21	10.36	10.39	2.84	6.13	3.78	1.03	5.71	0.056	-0.031
	1997-2002	5.9	20.49	8.93	19.3	2.03	7.44	4.66	1.11	7.59	0.028	-0.021

* mmol$^+$ (Ca^{2+} + Mg^{2+} + K^+ + Na^+) - mmol$^-$ (SO_4^{2-}+ NO_3^- + Cl^-)

Tab. 9: Average annual deposition on plots Želivka

kg.ha^{-1}.year^{-1}

Plot	Period	H	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	N*	Ca	Mg	K	Na	Al
Želivka clearcut	1985-1990	0.3078	39.39	34.65	20.1	9.71	15.36	16.8	3.05	6.13	2.88	1.43
bulk	1991-1996	0.113	29.29	25.42	14.08	6.82	11.03	14.47	3.06	4	3.36	0.348
	1997-2002	0.0807	17.1	23.41	12.47	4.55	8.82	10.45	1.91	4.91	2.42	0.157
spruce stand	1985-1990	0.8317	199.7	59.72	23.17	24.28	32.34	37.76	6.12	30.46	4.03	3.45
throughfall	1991-1996	0.423	147.82	44.88	18.44	20.48	26.03	32.35	6.31	29.99	4.6	1.93
	1997-2002	0.105	45.04	51.61	11.89	11.97	20.82	18.25	4.24	27.43	2.97	0.432

* N (NO_3^- + NH_4^+)

Tab. 10: Average concentration of substances in water of Pekelský brook - object Želivka

mg.l^{-1}

Plot	Period	pH	SO_4^{2-}	NO_3^-	Cl^-	N	Ca	Mg	K	Na	Al	Alkalinity*
Želivka brook	1985-1990	7.17	14.78	2.33	4.72	1.01	8.67	2.81	1.66	6.78	0.136	0.523
	1991-1996	7.01	15.96	2.07	3.46	0.99	9.86	3.11	1.53	6.94	0.102	0.624
	1997-2002	7.35	16.41	2.33	3.6	0.6	10.42	3.07	1.46	7.16	0.023	0.638

* mmol$^+$ (Ca^{2+} + Mg^{2+} + K^+ + Na^+) - mmol$^-$ (SO_4^{2-}+ NO_3^- + Cl^-)

On the measuring station of catchment U Vodárny annual depositions of SO_4^{2-}, Ca, Mg, Na also dropped in the mentioned period but increased for NO_3^-, NH_4^+, Cl^-, K and mildly also for H^+ (protons).

Analyses of water sampled in streams on measuring spillways show that concentrations of SO_4^{2-}, NO_3^-, Ca, Mg, K, Na and Al decreased on catchment Červík A (with regenerated stands) in the period

Tab. 11: Average annual deposition on plots Šerlich Mt.

kg.ha^{-1}.year^{-1}

Sampling plot	Period	H^+	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	N*	Ca	Mg	K	Na
clearcut plot I	1987-1991	0.41	74.9	42.1	34.9	23.5	27.75	25	3.21	3.65	4.54
bulk	1992-1997	0.162	58.95	27.9	30.6	10.64	14.57	23.49	5.57	3.14	5.85
younger spruce stand plot II	1988-1991	2.12	252.7	57.1	31.6	25.6	32.26	29.3	6.28	28.4	7.34
throughfall	1992-1997	0.693	141.16	24.8	17.04	15.85	17.9	23.56	6.84	20.53	6.23
mature spruce stand plot III	1988-1991	2.48	262.87	94.86	38.4	42.59	54.49	31.7	6.09	29.6	8.21
throughfall	1992-1997	0.71	160.06	52.08	23.29	38.35	41.53	29.31	8.04	21.62	7.92
beech stand plot V	1988-1991	0.65	102.1	43.4	20.8	22.68	27.41	19.5	4.06	20.5	4.97
throughfall	1992-1997	0.173	69.34	31	11.41	9.06	14.04	15.93	4.83	11.13	5.4

* N (NO_3^- + NH_4^+)

Tab. 12: Average concentration of substances in brook of tributary Bělá at Šerlišský Mlýn

mg.l^{-1}

Sampling plot	Period	pH	SO_4^{2-}	NO_3^-	Cl^-	N	Ca	Mg	K	Na	Al	Alkalinity*
brook	1988-1991	6.53	15.61	12.21	2.68	3.56	8.79	2.2	0.96	1.53	0.17	0.114
	1992-1998	6.49	17.03	7.75	2.32	1.91	8.46	2.28	0.76	1.65	0.08	0.156

* mmol$^+$ (Ca^{2+} + Mg^{2+} + K^+ + Na^+) - mmol$^-$ (SO_4^{2-} + NO_3^- + Cl^-)

1992 - 2001, and mildly decreased also water pH (table 4). On catchment Červík B (with prevailed older stands) only concentrations of SO_4^{2-}, Ca, Mg decreased in the brook water and concentrations of NO_3^-, Cl^-, K and Na increased. Average annual values for pH were dropping as well.

Concentrations of most ions mildly decreased in the brook of Malá Ráztoka and changes were not apparent for K, Cl^- and H^+.

In decade 1992 to 2001 average concentrations of NO_3^- and Al distinctly dropped in the brook at catchment U Vodárny, less distinct concentration increase showed Mg, K and Na. Concentrations were higher for SO_4^{2-} and Ca, evident was also increase of pH values.

Different ions concentrations in water of brooks in the Beskydy and Jeseníky Mts. catchments result in different water alkalinity that is expressed by difference of sum for molar values of basic cations Ca, Mg, K, Na and sum for molar values of anions of strong acids SO_4^{2-}, NO_3^-, Cl^-. In the investigated period (1992 – 1996 and 1997 – 2001) the lowest water alkalinity (-0.006 and 0.071 meq.1^{-1}) was reached at Červík B, higher (0.110 -0.190 meq.1^{-1}) was at Červík A. Water alkalinity at Malá Ráztoka was 0.348 and 0.330 meq.1^{-1} being high in brook U Vodárny (0.899 and 0.929 meq.1^{-1}).

Southern Bohemia, where the FGMRI research objects Zdíkov, Vojířov and Strouha lie, is the region with the lowest load within the Czech part of CR. On the research plot Zdíkov water chemistry and deposition of substances were investigated in spruce and beech stands. In 1992 to 2001 fallout of SO_4^{2-}, NH_4^+, Cl^-, F^-, Ca, Mg, K, Na, Al and protons (H^+) in spruce stands was decreasing with throughfall. Despite nitrate increase (NO_3^-) total deposition of nitrogen was dropping down. Compared to the preceding period (until 1991) annual depositions of ions H^+, SO_4^{2-}, NH_4^+, Cl^- and Al fallout markedly decreased during 1992 to 2001 (table 5).

In the research period deposition of all observed ions in beech stand decreased with throughfall. This trend had started already in preceding years (1990, 1991).

In 2002, despite high sum of precipitation, fallout of SO_4^{2-}, Cl^-, NO_3^-, NH_4^+, Ca, Mg and Na was lower in spruce stand than the average for preceding five years (1997 - 2001). This reflects continuing decrease of air pollutions. In 2002 fallout of majority of evaluated substances (H^+, SO_4^{2}, NO_3^-, NH_4^+, K, Mn and Al) in beech stand was higher than the 1997 to 2001 average. Fallout drop occurred only for Cl^-, Ca, Mg and Na causing enhanced acidification of bulk water.

On plots Vojířov bulk precipitation was sampled on open space in spruce stand and mixed stand with beech dominance. During years 1992 to 2001 fallout of SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Ca, Mg, K and Na was dropping down with bulk precipitation sampled on open space, since the late 1990s deposition of protons (H^+) had increased.

In those years (1992 - 2001) deposition of nearly all investigated substances, except NO_3^-, decreased in throughfall of spruce stand. In mixed stands annual fallouts in throughfall decreased only for SO_4^{2-}, Ca, Mg, Na and Mn, and on contrary fallout increased for NO_3^-, NH_4^+, Cl^-, Al and hydrogen ions (H^+).

In 2002 high bulk sum on open space caused increase of annual fallout of H^+, NO_3^-, NH_4^+, K compared to the period of 1997 to 2001. This year's high sum of bulk precipitation also resulted in enhancement of SO_4^{2-}, NO_3^-, NH_4^+, K and Mn intake into soil with throughfall in spruce stand; throughfall in mixed stand brought only NO_3^-, Mn and H^+ enhancement compared with average from the preceding five years.

On plot Strouha fallout with bulk precipitation on forest-free area decreased for SO_4^{2-}, NH_4^+, Cl^-, Ca, Mg and increased for NO_3^-, K, Na and H^+ in the investigated years 1992 to 2001. Deposition of the most observed ions (H^+, SO_4^{2-}, Cl^-, Ca, Mg, K and Na) decreased in throughfall of spruce stand, increasing only for inorganic forms of nitrogen (NO_3^-, NH_4^+).

Extraordinary high amount of precipitation in year 2002 brought also more ions of H^+, SO_4^{2-}, NO_3^-, Cl^-, Ca, Mg, K onto open space when related to average values in the preceding years 1997 to 2001. Total annual fallout of most ions in spruce stand did not get over their average deposition from the preceding investigated period and only NH_4^+, K and Mn ions deposition increased.

Monitoring of water chemistry development in surface sources was carried out also on research objects Zdíkov, Vojířov and Strouha (table 6).

Concentrations of ions in water of brook U Lizu at Zdíkov were observed in 1987 to 1991, and then had continued since 1994. If evaluating the period of 1994 to 2001, then increment of pH, concentrations for NO_3^-, Cl^-, Ca, Mg and Na and a mild fallout for SO_4^{2-}, K and Al are evident. Concentrations of Al and K had been decreasing and of Ca, Mg increasing since 1987. Concentrations of NO_3^- and Cl^- also decreased in comparison to the initial measuring. Average values from year 2002 are lower for Cl^-, Ca and Na than those from years 1997 to 2001. However, enhanced runoff in 2002 did not substantially influence average annual concentrations of substances in runoff water. Sum of molar values for average concentrations of anions of heavy acids (SO_4^{2-}, NO_3^-, Cl^-) was lower than sum of molar values for basic cations (Ca, Mg, K, Na) during the investigation and the difference had been further increasing.

During 1992 to 2001 growth of average annual concentrations of H^+ (drop of pH), SO_4^{2-}, Al, Mn and also Ca was found in spring water on Vojířov plot. On the contrary decrease of average annual values was observed for NO_3^-, Cl^-, Mg, K and Na. Significant increase of ions H^+, SO_4^{2-}, Al and Mn occurred in years 1996 and 1997, probably in dependence with enhanced fallout of acidic substances in winter 1995/1996. The similar phenomenon was observed in spring water in 2002, when more acidic substances were brought into catchment by high precipitation. Sum of molar values for acidic anions SO_4^{2-}, NO_3^-, Cl^- was higher than the sum of values for basic cations Ca, Mg, K, Na for the whole investigation period.

Water taken from the spring on plot Strouha showed decrease of pH as well as of average concentrations of SO_4^{2-}, NO_3^-, Cl^-, Al, Ca, Mg, K and Na in the investigation period. Nevertheless,

Tab. 13: Deposition and losses of substances with running-off water on catchment of Pekelský brook (Želivka)

kg.ha^{-1}.year^{-1}

Period	Sampling plot	SO_4^{2-}	NO_3^-	Cl^-	N*	Al	Ca	Mg	K	Na	Runoff (mm)
1975-1979	clearcut	38.28	19.93	8.14	8.88		24.17	2.47	1.77	1.67	
	falout stand	178.88	24.95	5.52	12.56		49.85	4.69	22.66	3.06	
	loss brook	19.73	0.936	7.95	0.259		14.16	3.69	1.74	9.58	143.8
1990-1993	clearcut	26.8	24.7	14.9	11.87	1.21	12.8	2.5	4.39	2.1	
	fallout stand	183.9	62.1	22.95	33.59	2.95	36.3	6.9	32.4	4.9	
	loss brook	7.91	1.36	2.2	0.807	0.102	5.65	1.78	0.97	4.08	60
1997-2000	clearcut	17.1	22.73	15.46	8.82	0.138	10.45	1.91	4.91	2.42	
	fallout stand	66.58	56.19	13.31	20.32	0.486	18.25	4.24	27.43	2.97	
	loss brook	15	2.07	3.56	0.481	0.024	9.53	2.81	1.33	6.55	91.45

* N (NO_3^- + NH_4^+)

Tab. 14: Deposition and losses of substances with run-off water on catchment of spring at Moldava

kg.ha^{-1}.year^{-1}

Period	Sampling plot	SO_4^{2-}	NO_3^-	Cl^-	N*	Al	Ca	Mg	K	Na	Runoff (mm)
1978-1979	falout clearcut	91.11	31.43	20.12	18.57	5.29	39.15	4.32	3.85	9.41	
	spruce stands	440.91	63.89	14.52	31.99	13.31	79.89	7.32	35.21	7.91	
	loss spring	66.17	93.19	57.16	24.22	3	49.6	26.54	5.52	38.66	536
1990-1993	clearcut	24.34	29.2	22	16.77	2.26	26.2	5.2	8.3	6	
	fallout rowan regeneration	85.5	37.5	25	22.06	3.18	31.8	6.2	13.8	7.2	
	loss spring	118.2	60.9	56.36	18.09	0.62	30.35	19.93	5.72	29.83	536
200-2002	clearcut	28.68	22.31	21.11	9.46	0.234	13.33	2.09	3.97	4.17	
	fallout rowan stand	38.04	33.27	21.84	12.72	0.234	16.95	3.02	27.32	7.72	
	loss spring	101.07	53.4	138.88	12.08	0.179	42.99	29.02	6.09	48.15	536

* N (NO_3^- + NH_4^+)

average concentrations of SO_4^{2-}, Ca, Mg and Na remained relatively high in relation to values observed in water of the other assessed surface sources. Molar values of basic cations were significantly higher than values of acidic anions. In 2002, due to extraordinary runoff conditions, average concentrations of SO_4^{2-}, basic cations and Al grew.

Bulk precipitation was sampled on clearcut and in a stand of young rowan on the long-term investigated research plots at Moldava in the Krušné hory Mts. (table 7). In the investigation period 1991 to 2002 deposition trend of protons (H^+), SO_4^{2-}, NH_4^+ and cations Ca, Mg, K and Na was decreasing on the clearcut. Mild growth was observed for NO_3^- and marked for Cl^-.

Average annual fallouts with throughfalls in rowan stand decreased for H^+, SO_4^{2-}, NO_3^-, NH_4^+, Ca, Mg, but deposition increase was found for Cl^-, K and Na. When compared with the preceding period (until 1990) fallout of air pollutants decreased both on clearcut and in young rowan stand. Release of K from the leaf surface of rowan was increasing. Winter precipitation contamination (snow) as well as containers for deicing salt from a nearby road evidently increase Cl^- and Na concentration.

In the investigation period (1991 to 2002) average annual concentrations of SO_4^{2-}, NO_3^-, Al and H^+ decreased (its pH increased) in spring water and concentrations of Ca, Mg and K mildly increased (table 8). The same growth of Cl^- and Na ions can be explained by more intensive application of deicing salts on the road Moldava – Nové Město in the Krušné hory Mts. that leads through the spring catchment and westward of the research plots. Despite higher molar values of anions of heavy acids SO_4^{2-}, NO_3^-, Cl^- in comparison to sum of basic cations Ca, Mg, K, Na in spring water, concentrations of Al and Mn in water remained on the low level.

Investigation of substances fallout with bulk precipitation started on research plot Želivka in the catchment of Pekelský brook in 1973. Maximal deposition of protons (H^+) and S/SO_4^{2-} occurred here in the 1980s. The highest fallout of inorganic nitrogen was found at the turn of 1980/1990s. This contribution presents deposition development of air pollutants in the period of 1991 to 2002 on two plots, on the clearcut and in mature spruce stand (table 9).

In the mentioned period fallout of evaluated ions (H^+, SO_4^{2-}, NO_3^-, NH_4^+, Cl^-, Ca, Mg, K, Na, Al) decreased in bulk precipitation on the clearcut. Ions deposition, except NO_3^-, decreased in throughfall of spruce stand but total fallout of mineral nitrogen ($N/NO_3^- + NH_4^+$) was also decreasing.

In 1991 to 2002 average pH in water of Pekelský brook increased together with concentrations of SO_4^{2-}, NO_3^-, Cl^-, Ca and Na (table 10). On the contrary, average values for Al, Mg and K fell down. Here it must be mentioned the road going through this part of catchment with its salt deicing in winter that influences occurrence of Na and Cl^- in water of the brook. When pH of brook water is neutral, molar values of basic cations (Ca, Mg, K, Na) essentially prevailed the sum of molar values of anions SO_4^{2-}, NO_3^- and Cl^- and water alkalinity mildly increased.

Since 1988 to 1997 deposition of substances caught with bulk water had been investigated on research plots Šerlich in the Orlické hory Mts. Table 11 presents results from two measuring periods, until 1991 and since 1992. These data prove that deposition of H^+, SO_4^{2-}, NO_3^-, Cl^-. NH_4^+, Ca and K was dropping down on the clearcut and increasing for Mg and Na. In young spruce stand (plot II) fallout of nearly all observed substances was lower in throughfall, except of Mg. The same trend was occurring for deposition of ions in mature spruce stand (plot III). Similarly, since 1992 lower amounts of substances were caught with precipitation under beech crowns (plot V) than until 1991. Growth showed only Mg and Na.

Analyses of water sampled in the brook at Šerlišský Mlýn show a certain drop of its pH, concentrations of Cl^-, Ca and K as well as of NO_3^- and Al concentrations substantially dropped after 1992 (table 12). Increment occurred only for Mg and Na. Enhancement of SO_4^{2-} losses during decrease of their deposition can be explained by releasing from bonds in soil. In both investigated periods water from brook is of certain alkalinity (valence sum of basic cations prevails the sum of anions of heavy acids).

Balance of elements

Balance definition of elements must be based on their entry with deposition and on losses with running-off water. More accurate determination of substances fallout for larger forest catchments with stands of different mensurational parameters in ragged terrain is difficult. Level of deposition usually differs in dependence on stand character and its exposition to air circulation.

Table 13 presents results of deposition sampled on clearcut and in mature spruce stand for the catchment of Pekelský brook (object Želivka) where the lowest and highest values had been measured since 1973. Losses of substances running off with water were calculated on base of average concentrations of substances and average annual runoffs (H_o in evaluated periods). Balance of fallout and runoff of elements in periods 1975 – 1979, 1990 – 1993 and 1997 – 2000 show accumulation of S/SO_4^{2-}, $N/NO_3^- + NH_4^+$, Ca and usually also Cl^- in ecosystems of catchments. Losses are evident for Na. Positive balance of elements in the 1990s was due to measured low water runoffs. Positive balance of above mentioned ions persists even when long-term average of water runoff 129.3 mm, taken from the Atlas ČSSR (1966), was used.

Calculation of fallout on clearcut and on the plot "stand" in the catchment of observed spring at Moldava in the Krušné hory Mts. was based on data from localities with heavy damaged mature spruce stands in years 1978 to 1979. In 1990 to 1993 measurement was done in rowan advance regeneration that developed in the young stand in 2000 to 2002 (table 14). In 1981 spruces were felled down in the whole spring catchment. Ions losses in all evaluated periods together with average concentrations were defined on base of annual runoff height 536 mm, derived from data in Atlas of ČSSR (1965).

In years 1978 to 1979 depositions of SO_4^{2-} and Al on clearcut and in the stand exceeded the losses in runoff as well as of $N/NO_3^- + NH_4^+$, Ca and K in the stand. Losses were unambiguous for Cl^-, Mg and Na. In 1990 to 1993 higher loss was calculated for SO_4^{2-}, Cl^-, Mg, Na than fallout measured on clearcut and in rowan advance regeneration. Only Al accumulated. Much higher difference between observed fallout and loss by runoff showed to be for SO_4^{2-}, Cl^-, Ca, Mg and Na in the period of 2000 to 2002. These clearly higher runoffs of Cl^- and Na compared to their fallout with throughfall can be explained by introduction of these ions during application of deicing salt, in the last year more intensive, on the road crossing the upper part of the catchment. The elaborated balances show that SO_4^{2-} accumulation changed due to its leaching from the catchment during the 1980s. Mild accumulation of nitrogen began to be balanced.

DISCUSSION

Maximal acidic deposition was reached within the Czech Republic territory in the 1980s when water pH of surface sources had been decreasing. The lowest average values (< 6.5) were measured on catchments Červík A, Červík B and Malá Ráztoka in the Beskydy Mts. (Lochman et al. 2002), at Moldava (Lochman et al. 1996) and in the object Želivka (Lochman et al. 1997) in the first half of 1980s. Deposition of protons and anions of strong acids ((SO_4^{-2}, NO_3^-, Cl^-, F) gradually decreased together with increase of pH of water sources on the level presented in this contribution. Water in evaluated periods in streams of catchments Červík, Malá Ráztoka, U Vodárny and Želivka (Pekelský brook) was in accordance with the standard for using drinking water (Decree of Ministry of Health 2000) having the lowest limit of pH 6.5. Average annual water pH in brooks U Lizu (Zdíkov), at Šerlich and in the spring of the plot Strouha balance on the lower standard limit. In catchment Červík B average pH does not have the demanded value, at Moldava it is below 6.0 and on Vojířov it dropped below 5.5 (in 2002< 5.0).

Such low values of pH are caused by increase of Al concentrations, limiting value for drinking water is 0.2 $mg.1^{-1}$. Also concentrations of other metals, above all Mn, are increasing. Water acidification in forested catchments of hills and uplands that are the source for drinking water in the Czech Republic makes its use difficult. The similar problems from the catchments in Germany and northern Europe and Great Britain are mentioned by Alewell et al. (2001).

Together with marked decrease of SO_4^{2-} deposition and further anions (NO_3^-, Cl^-) in the 1990s fallout drop of basic cations, Al and other metals was observed as a consequence of changes in dust and ash emission that decreased, according to the Czech Hydrometeorological Institute, onto less than one tenth in 2002 in comparison with year 1988 (Air pollution 1999, 2001). Also Driscoll et al. (1989), Hedin et al. (1994), Messerburg et al. (1995), Alewell et al. (2000) take reduction of emissions with solid substances for the cause of cations decrease in Europe (in North America as well). In the 1990s deposition of basic cations with throughfall and on some catchments also their concentrations in stream water decreased in majority of observed catchments in Germany. Drop of bases occurred on catchment Steile Bramke (Harz) in stream water despite initial liming of this locality (Alewell et al. 2001). Catchment Malá Ráztoka was limed by dolomitic limestone in the 1980s; during this investigation deposition of Ca and Mg decreased as well as their concentrations in stream water.

In the catchment U Vodárny dolomitic limestone was applied in 1992. Deposition of Ca reduced here only negligible and its concentrations in stream water slightly increased. Fallout of Mg and its concentrations in water decreased markedly. Increase of Ca in stream water may be caused by increase of dominant anion SO_4^{2-} concentration.

The 1980s and 1990s decrease of sulphur deposition and acid substances within the territory of Czech Republic is one of the greatest in Europe; this is related to the highest pollution load in the preceding years (Wright et al. 1993, Hultberg et al. 1998, Gundersen et al. 1998). Decrease of S/SO_4^{2-} deposition on investigated catchments was not parallelly followed by reduction of losses in sulphates, the drop was much lower and in surface sources of some catchments their concentrations increased.

This phenomenon prevails for the most investigated sources in Europe except catchments in Scandinavia where decrease of sulphur loss was parallel with fallout decrease between years 1986 to 1999 (Prechtel et al. 2001).

Drop of SO_4^{2-} depositions was relatively soon reflected in decrease of their concentrations in water of mountain lakes in the Šumava Mts. – Černé, Čertovo and Plešné lakes (Veselý et al. 1998) and at Vyšné and Wahlenbergovo in the High Tatras (Kopáček et al. 1998, 2001). However, during the drop of SO_4^{2-} fallout on catchments of the Šumava Mts. lake of 78 to 82 % in the period 1990 to 1999 (Evans et al. 2001) losses of sulphur from the catchment decreased slower and in years 1993 and 1994 soils on these catchments within the Šumava Mts. became an evident source of S/SO_4^{2-} (Kopáček et al. 2001). The 1990 drop of sulphur fallout in the catchments in Germany did not unambiguously influence drop of SO_4^{2-} concentrations in streams (Alewell et al. 2001, Prechtel et al. 2001). In dependence on decrease of sulphate concentrations in precipitation SO_4^{2-} concentrations dropped significantly in water running off the catchment Lehstenbach (Fichtelberg). Streams observed in program RECOVER: 2010, except for Lange Bramke (Harz), had decreasing values for SO_4^{2-} concentrations in 1990s. Ability of ecosystems in catchments to influence sulphur dynamics is caused above all by soil. Deep clayey and loamy soils on thick mantle rocks can contain high supply of absorbed SO_4^{2-} ions; in Germany it is a case of Lange Bramke. Young shallow soils in mountain catchments and in Scandinavia with their low capacity to retain sulphates therefore respond to sulphur deposition faster by marked drop of SO_4^{2-} in running-off water. Supply of S/SO_4^{2-} found in soils can be a source of sulphates in streams for several decades. In Germany catchments Villingen (Ambruster 1998, Alewell 2001), Lange Bramke (Melesa 1995), Lehstenbach (Manderscheit et al. 2000, Alewell 1995) are of concern. Growth of SO_4^{2-} concentrations in running-off water can be influenced by mineralization of soil organic mass supported by enhanced summer temperatures. Course of long-term trends of SO_4^{2-} streams result in short-term stream balancing (Prechtel et al. 2001).

Table of elements balance for catchment of spring at Moldava shows sulphur loss since the 1990s even when sulphate concentrations decreased in the spring water. However, sulphur is still accumulated on the catchment of Pekelský brook (object Želivka) despite reduction of S/SO_4^{2-} fallout and growth of concentrations in the brook. Negative sulphur balance was calculated in ecosystems of spring catchment at plot Vojířov. In years 1995 – 2000 average SO_4^{2-} fallout reached on plots 22.73 to 61.14 $kg.ha^{-1}.year^{-1}$ and loss by run-off 102.75 $kg.ha^{-1}.year^{-1}$ (Lochman et al. 2002).

In catchment of spring Strouha SO_4^{2-} fallout reached 86.73 kg.ha^{-1} in years 1992 – 1996 and loss by runoff 90.73 kg.ha^{-1} per year. In years 1997 – 2001 both annual fallout and runoff of sulphates decreased onto 42.78 and 77.89 kg.ha^{-1} and sulphur losses increased (Lochman et al. 2004). In the catchment of brook flowing down the Šerlich Mt. sulphur fallout in stands exceeded the loss in the brook until 1991. In the next years sulphur fallouts in the spruce stands decreased on loss level equalled to runoff in stream, losses in deciduous stands and a clearcut were substantially lower (Lochman et al. 2004).

This lasting sulphur accumulation in the object Želivka reflects the ability of deep soils and thick mantle rock to create unstable (reversible) SO_4^{2-} compounds and oxides of Al (Khana, Ulrich 1985, Matzner, Ulrich 1990). According to the above mentioned results from investigation in Germany gradual release of sulphates from these complexes can be supposed for tens of years. This leaching of SO_4^{2-} causes also losses of cations Ca, Mg, Na, K.

Change of nitrogen deposition ($N/N_3^- + NH_4^+$) on experimental plots was not so obvious in the 1990s. Fallout decrease occurred on most plots but on open space of the catchments Červík and U Vodárny, in mixed stand at Vojířov and in spruce stand on plot Strouha fallout increased. According to Kopáček et al. (2001) NO_x emission began to drop down quickly from 1989 to 1994, later already less distinctly. Also NH_3 emissions were growing until the 1980 and were reduced in the 1990s so that in 1999 they were comparable with the situation 100 years ago. Depositions of NO_3^- and NH_4^+ were also dropping down in accordance with emission development, NO_3^- of 30 – 35 % and NH_4^+ of 25 – 27 %.

Diese et al. (1998) reminds that total nitrogen deposition with throughfall is probably lower than nitrogen amount penetrating with precipitation and with crown interception (wet plus dry), because nitrogen is assimilated by leaves of tree species. But we must also consider that throughfall dripping down the leaves washes both epiphyte microflora and substances arisen from insect activity, especially in summer period and in deciduous tree species.

Based on results of measurement from 30 forested catchments observed in program RECOVER: 2010 Wright et al. (2001) derived dependence of nitrates concentrations in streams on nitrogen deposition. Average concentrations below 5 μeq.1^{-1} NO_3^-, (0.31 NO_3^- mg.1^{-1}) correspond with annual nitrogen fallout in catchment lower than 10 kg.ha^{-1}. Variable annual concentrations were found in catchments with annual fallout of nitrogen 10 to 25 kg per ha, and averages over 10 μeq.1^{-1} NO^{3-} (0.62 mg.l^{1-}NO_3^-) appeared in streams with annual fallouts higher than 25 kg.ha^{-1}. The presented concentrations of nitrates in water of surface sources, found also in catchments in Scandinavia (Skjelkvåle et al. 1996, 2001b) and in less polluted regions of Great Britain (Allot et al. 1959), are low when related to conditions in the Czech Republic. In years 1987 to 1992 all the observed catchments in Germany, except for Villingen (Schwarzwald), showed higher concentrations of NO_3^- than 0.62 mg.1^{-1} in stream water.

Deposition of 10 kg N per ha per year is taken for limit and its exceeding results in significant changes in forest ecosystems (Gundersen et al. 1998, Diese et al. 1998, Gundersen, Kristiansen 2001). According to Ulrich (1993) forest stands are able to consume annually deposition of 10 kg. ha^{-1} per year. High fallout of nitrogen influences above all decrease of carbon and nitrogen ratio (C : N) in forest floor and in surface horizons of mineral soil. The lower is the ratio C/N, the lower is soil ability to retain nitrogen from fallout and its larger amount flows away with runoff (Matzner, Grosholz 1997).

Process of saturation of forest ecosystems by nitrogen lasts many years and sites saturated by nitrogen are leaching enhanced amount of NO_3^- only when another nitrogen is at disposal from deposition. Long-term experiments in which plot covering prevents from supplying with acid deposition show immediate great drop of NO_3^- leaching (Beier et al. 2001, Wright et al. 1993, Wright, Jenkins 2001, Xu et al. 1998) despite nitrogen saturation. That proves that contamination of water sources by nitrates after decrease of nitrogen deposition would not continue. Dangerous can be enhanced decomposition of soil organic mass during increasing summer temperatures and drop of water level in soil in hydrogen form of humus. Besides these natural factors decomposition enhancement of humus substances and human activities (large-scale logging of stands, fertilization) can play a role in this process.

These processes occurred on large clearcuts after immission felling or after target regeneration of stands in catchments (Červík A, Malá Ráztoka) in the 1970/80s. In the 1990s nitrogen fallout did not substantially change in catchments Červík, and in catchment Červík A the NO_3^- concentrations were dropping being now at low level (1.32 mg.1^{-1}). Due to growth of young stands biomass and nitrogen are accumulating. Catchment Červík B involves older stands with higher fallouts and lower nitrogen accumulation, here leaching of nitrates was increasing. In stream water at Malá Ráztoka with prevalence of young stands NO_3^- concentrations were falling down together with drop of nitrogen deposition NO_3^-.

Since the 1980s average concentrations of nitrates in spring water on the Moldava catchment had decreased as well as the total nitrogen deposition. Fallout of nitrogen nearly balanced with loss of this element. This phenomenon can be explained in many ways. Nitrogen fallout can be higher in the upper parts of catchment than on plots in the lower part or a part of nitrogen carried with precipitation is assimilated by rowan leaves or due to higher temperatures during the investigated period decomposition of soil organic mass increases. The opposite phenomenon is still high retention of nitrogen in ecosystems of the object Želivka with prevalence of older spruce stands that exceeded 10 kg.ha^{-1}.$year^{-1}$.

For catchments of spring plots Vojířov and Strouha and in the object Šerlich Mt. nitrogen consumption by forest ecosystems was calculated approximately 10 kg.ha^{-1} per year (Lochman et al. 2002, 2004a, b).

CONCLUSION

In the 1990s and at the beginning of this century SO_4^{2-} deposition in forest stands decreased but this trend was not unambiguous in stream waters. The cause is that flow of these ions in soil environment is impacted by bond in unstable compounds and in the recent years, especially in polluted areas, by their release from complex compounds with Al oxides and other metals. Permanent release of SO_4^{2-} into water sources can be expected in catchments with deep clay-loam soils (catchments Želivka, U Vodárny).

Deposition decrease of mineral forms of nitrogen (NO_3^- and NH_4^+) found in central Europe, occurred also on the investigated FGMRI plots. However, growth of nitrogen fallout occurred on territorial but more on local level. This growth differently influenced nitrates concentration on catchments Červík in the Beskydy Mts. Nitrates increased in stream water in catchment B with older stands and decreased in catchment A. Annual average concentrations dropped below 10 mg.1^{-1} in catchments with high immission load in the last years and with NO_3^-concentrations in stream water higher than 10 mg.1^{-1} (Moldava, Šerlich, U Vodárny). Their values negligibly increased on catchments with prevalence of mature stands and relatively low NO_3^- content in stream water (Želivka, U Lizu).

Reduction of air pollution by solid substances resulted in general decrease of cations fallout which caused decrease of pH values in bulk precipitation caught in the open containers on open space. In all the observed spruce stands fallout of protons (H^+) dropped down, less distinctly in beech stands. Even in water sources concentrations of cations decreased, except for streams where SO_4^{2-} contents grew.

Deposition of substances in stands is influenced by composition and age of the species. Its distinct decrease in spruce stands approached to deposition in deciduous tree species. Water composition in sources depends not only on deposition of substances but also adsorption properties, soil permeability and mineral composition of mantle rock play an important role especially in SO_4^{2-} adsorption and protons neutralization. Leaching of nitrates is supported by water regime of mountain soils. Low runoffs can cause enhancing of SO_4^{2-} concentrations and low concentrations of nitrates because they enable their more effective consumption in forest ecosystems.

Development of changes in chemical composition of water in sources can be disturbed by weather irregularities. Long and cold winter season caused growth of acid substances. Torrential rain increases content of undemanded substances in surface water runoff, and high summer temperatures cause mineralization of soil organic mass and leaching of nitrate and sulphur compounds into the runoff water in soil.

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CHEMISMUS VODY V LESÍCH VE VAZBĚ NA ZMĚNY IMISNÍHO ZATÍŽENÍ

Souhrn

Tento příspěvek hodnotí vývoj depozice imisních látek a chemismu vody povrchových zdrojů na zalesněných povodích sledovaných VÚLHM od počátku 90. let minulého století do počátku tohoto století (do roku 2002). Výzkumné objekty leží v místech rozdílného imisního zatížení a v rozdílných nadmořských výškách. Depozice látek je ovlivněna dřevinnou skladbou a stářím porostů v povodí. Chemismus odtékající vody ovlivňují i půdně-geologické poměry.

Výzkum byl prováděn na povodích Červíku A, Červíku B a Malá Ráztoka v Beskydech, v Jeseníkách na povodí U Vodárny a v Orlických horách na svahu Šerlichu v potoce vlévajícím se do Bělé u Šerlišského Mlýna. V Krušných horách bylo sledováno povodí pramene u Moldavy. Objekt Želivka je povodím Pekelského potoka, pravostranného přítoku vodní nádrže Želivka. V předhůří Šumavy, v povodí U Lizu je objekt Zdíkov. V jižních Čechách leží další výzkumný objekt Vojířov (poblíž Lásenice) a nedaleko Temelína je objekt Strouha.

Výsledky uvedené v tabulkách ukazují, že na výzkumných plochách VÚLHM v letech 1992 (1991) až 2001 (2002) probíhal pokles spadu S/SO_4^{2-}, Ca, dalších bazických kationtů a Al na všech plochách.

Na povodích Červíku a U Vodárny se v uvedeném období ve srážkách na volné ploše (bulk) zvýšil spad N (NO_3^-+ NH_4^+). Také narostla depozice minerálního dusíku v podkorunových srážkách na ploše Vojířov (pod porostem smrku a buku) a na ploše Strouha (pod porostem smrku). Na ostatních plochách probíhal pokles depozice N. Zvýšení depozice protonů (H^+) se projevilo především ve srážkách zachycovaných na volné ploše (bulk) v povodích Červík, Malá Ráztoka, U Vodárny, Vojířov a Strouha. Tento jev vyvolává pokles obsahu bazických kationtů a Al ve srážkových vodách, který souvisí s obecným poklesem spadu tuhých látek (popílku a prachu).

Relativně jednoznačné trendy v depozicích imisních látek nesouhlasí se změnou jejich koncentrací ve vodních zdrojích. Přes plošný pokles spadu síry se v odebírané odtékající vodě na povodích Šerlichu, U Vodárny, Vojířov a Želivka (Pekelský potok) projevily zvýšené koncentrace SO_4^{2-}. Jen malé snížení koncentrací síranů nastalo ve vodě U Lizu a v pramenu Strouha. Zřetelnější pokles koncentrací SO_4^{2-} je vidět ve vodě pramenu na Moldavě a v potocích na povodích v Beskydech.

Nárůst obsahu nitrátů ve vodě zdrojů proběhl na povodí Červíku B a mírně i na povodích U Lizu a Pekelský potok, kde se však ve stejném období snižovaly v porostech depozice dusíku. Všechna tři povodí jsou porostlá staršími převážně smrkovými porosty. Na ostatních povodích se ve vodních zdrojích koncentrace NO_3^- snižovaly.

I při poklesu spadu Ca a dalších bazických kationtů narůstaly jeho koncentrace (stejně jako valenční suma bazických kationtů) ve vodě zdrojů na povodích Moldava, U Lizu, U Vodárny, Vojířov a Želivka (Pekelský potok). Tento nárůst zřejmě ovlivňoval zvýšení pH vody těchto zdrojů. Výjimkou je pH vody pramene na Vojířově, kde při podstatném nárůstu koncentrací síranových iontů klesly průměrné roční hodnoty pH v roce 2001 na 5,04 a v roce 2002 na 4,89. Mírný pokles pH byl také stanoven na povodích Červíku A, Červíku B, Strouha a Šerlich.

Příčinou nárůstu obsahu SO_4^{2-} ve vodách toků, při obecném poklesu spadu síry v 90. letech, je jejich uvolňování z vazeb v nestálých sloučeninách s oxidy Al a dalších kovů. Proto na většině lesních povodí v oblastech střední Evropy, které byly v minulosti silně zasaženy imisemi, je v současnosti zjišťována pasivní bilance S. Na bilanci dusíku v povodích má vliv charakter lesních porostů. Starší smrkové porosty zvyšují jeho depozici, ekosystémy mladých porostů mají vyšší spotřebu N a proto působí na snižování NO_3^- v odtékající vodě; příkladem je povodí Červíku A. Vymývání rozpustných nitrátů z půd lesních porostů usnadňuje vyšší promyvnost vodního režimu v horských lesích.

Vývoj změn chemického složení vody ve zdrojích mohou narušit výchylky počasí. Dlouhé a hladné zimy působí na zvýšení depozice kyselých látek. Přívalové srážky vyvolávající povrchový odtok srážkové vody do zdrojů a vysoké letní teploty způsobující zvýšenou mineralizaci půdní organické hmoty a uvolňování sloučenin dusíku a síry jsou příčinou zhoršení kvality vody v povrchových zdrojích.

CHEMISTRY OF WATER IN FORESTS IN RELATION TO CHANGES OF AIR POLLUTION LOAD

Summary

This contribution evaluates development of deposition of air polluted substances and water chemistry in surface sources on forested catchments observed by the FGMRI since the 1990s until the beginning of this century (until 2002). Research objects are situated into localities of different elevations with different immission load. Deposition of substances is influenced by tree species

composition and age of stands in catchments. Chemistry of running-off water depends also on soil-geologic conditions.

Research was carried out on catchments Červík A, Červík B and Malá Ráztoka in the Beskydy Mts., in the Jeseníky Mts. on catchment U Vodárny and in the Orlické hory Mts. on the slope of Šerlich Mt. in the brook flowing into Bělá brook at Šerlišský Mlýn. In the Krušné hory Mts. catchment at Moldava was observed. Object Želivka is the catchment of Pekelský brook, right-handed tributary of water basin Želivka. Zdíkov is the object lying in the foothills of the Šumava Mts., in catchment U Lizu. There is another research plot Vojířov (near Lásenice) lying in south Bohemia and one more object Strouha is in vicinity of Temelín.

Results presented in tables show that in years 1992 (1991) to 2001 (2002) fallout of S/SO_4^{2-}, Ca, other basic cations and Al decreased on all plots. On catchments Červík, U Vodárny fallout of N (NO_3^-+ NH_4^+) increased in bulk precipitation in the mentioned period. Also deposition of mineral nitrogen in throughfall increased on plot Vojířov (under spruce and beech stand) and on plot Strouha (under spruce stand). On the other plots nitrogen deposition decreased. Increment of proton deposition (H^+) occurred mainly in bulk precipitation caught on open space in catchments Červík, Malá Ráztoka, U Vodárny, Vojířov and Strouha. This phenomenon results in drop of basic cations content and Al in bulk precipitation that is related to common decrease of fallout with solid substances (ash and dust).

Relatively decreasing trends in depositions of immission substances are not in accordance with change of their concentration in water sources. Despite common reduction of sulphur fallout there were found increased SO_4^{2-} concentrations in runoff water in catchments Šerlich, U Vodárny, Vojířov and Želivka (Pekelský brook). Decrease of sulphate concentrations was low in water U Lizu and in spring Strouha. More distinct decrease of SO_4^{2-} concentrations is observed in spring water at Moldava and in brooks of catchments in the Beskydy Mts.

Increase of nitrates content in water sources occurred in catchment Červík B and mildly also in catchments U Lizu and Pekelský brook, where at the same time nitrogen depositions reduced in the stands. All three catchments are covered by older mostly spruce stands. On the other catchments concentrations of NO_3^- in water sources decreased.

Despite drop of Ca fallout, and other basic cations as well, Ca concentrations (similarly like valence sum of basic cations) increased in water sources in catchments Moldava, U Lizu, U Vodárny, Vojířov and Želivka (Pekelský brook). This growth was probably caused by increment of water pH of these sources. Exception is water pH of spring at Vojířov where average annual pH values dropped to 5.04 in 2001 and to 4.89 in 2002 during substantial concentration growth of sulphate ions. Mild decrease of pH was also found in catchments Červík A, Červík B, Strouha and Šerlich Mt.

Growth of SO_4^{2-} content in stream water, in situation of general decrease of sulphur fallout in the 1990s, is caused by their release from bonds in unstable compounds with oxides of Al and other metals. That is why on majority of forest catchments in areas of central Europe, hit by air pollution in the past, passive sulphur balance is observed at present. Nitrogen balance in catchments depends on character of forest stands. In the older spruce stands nitrogen deposition is increasing, ecosystems of young stands consume higher amount of nitrogen and so influence reduction of NO_3^- in running-off water; as an example can be mentioned catchment Červík A. Higher leaching of water regime in mountain forests is easier due to leaching of soluble nitrates from soils of forest stands.

Development of changes in chemical composition of water in sources can be disturbed by weather irregularities. Long and cold winter seasons influence enhancement of acid substances. Torrential rain causing surface runoff of bulk precipitation into sources and high summer temperatures causing mineralization of soil organic mass and leaching of nitrate and sulphur can result in worsened water quality in surface sources.

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