

Thinning experiments in Norway spruce stands after 40 years of investigation – 1st series

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ABSTRACT: Forestry and Game Management Research Institute at Jíloviště-Strnady has created a new experimental base for thinning research since 1956. A total of 46 experimental series were founded in Norway spruce (*Picea abies* [L.] Karst.); 24 series are still maintained. This paper focuses on the series established in young Norway spruce stands in 1958 (Rumburk, Mostek, Vimperk I, Vimperk II and Nisa). The goal of thinning experiment was to compare two basic methods of thinning: positive selection from above (2a) and negative selection from below (3b or 5b). Each experimental series has a control plot (1c) where no thinning was conducted. The effect of thinning by positive selection from above carried out in the 40-year period of investigations was a 10–45% decrease in the abundance of trees in lower diameter classes compared with control plots. Negative selection from below resulted in a more pronounced decrease in thin trees abundance (50–69% compared with control plots). The abundance of thick trees (diameter of 30 cm and more) increased by 5–50% on all comparative plots with thinning. Static stability characterised by the 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 considerably lower).

Keywords: positive selection from above; negative selection from below; thinning; Norway spruce

The proper investigation of the impact of various thinning methods on forest stand structure depends on availability of a sufficient number of permanent research plots and their regular and long-term observations, preferably lasting at least one rotation. The theoretical problems of thinning in forest stands of the Czech Republic before 1955 were investigated using small-scale research on Forestry Faculties of Czech universities. Attention was paid to a few experiments founded by the Institute in Mariabrunne (Austria) before World War I or several experiments founded after WW II. The experimental design was small-scale and insufficient, evaluating measurements were made only over short intervals. Therefore the results could not be applied to management situations that substantially differed from the conditions of narrowly-focused research plots.

For that reason, it was decided to create a new experimental base with the aim of long-term experimental data collection from various thinning regimes in 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 the Forestry and Game Management Research Institute at Jíloviště-Strnady. In the framework of the project, 46 experimental series were founded in Norway spruce stands in four time groups between the years 1956 and 1973 (1st group in 1956–1958, 2nd in 1960, 4th in 1963–1964 and 5th in 1971–1973). One

group (chronologically the 3rd group) was founded in Scotch pine stands and will be evaluated separately.

Out of the original 46 experimental series, only 24 have persisted to the present (NOVÁK, SLODIČÁK 2001). Other series were partly or completely destroyed by snow, wind or other harmful factors. Since 1997, data collection in these long-term experimental series has been the responsibility of the subproject *Thinning of Forest Stands in Changing Growing Conditions* of the complex project *Silviculture in Ecotopes Disturbed by Human Activities* (SLODIČÁK, NOVÁK 2002).

This paper focuses on the series established in young Norway spruce stands in 1958 (Table 1).

METHOD

The methods for founding and evaluation of long-term thinning experiments is based on standardised techniques and methods used in forestry research. This methodology was established by the Forestry and Game Management Research Institute in 1956–1957 (PAŘEZ 1958).

The following eminent Czech and Slovak forest specialists provided valuable comments regarding the methodology: 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,

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

Series	Name	Age	Comparative 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.	1,020	Spruce-beech	acid
4	Vimperk II	51	3	13 – The Šumava Mts.	1,045	Spruce-beech	acid
5	Nisa	35	3	21a – The Jizerské hory Mts.	820	Spruce-beech	acid

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 evaluate the effect of two types of thinning, 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, focused on the quantity and quality of production of forest stands, were published in research reports (PAŘEZ 1972, 1975, 1979, 1980, 1985).

Explanation of used terms

Experimental series is defined as a part of forest stand designated for thinning experiment, i.e. for observation of one or more silvicultural treatments. Experimental series consists of two or more partial comparative plots with different thinning regimes.

Partial comparative plot (comparative plot) is defined as a part of experimental series that used for investigation of one silvicultural treatment and consequent comparison with other treatments and with 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 dead, broken or uprooted trees, i.e. salvage cutting. The control plot serves as evidence of natural development of forest stands, including natural mortality.

Group of experimental series consists of two or more experimental series in one climatic region at a similar elevation with the same management system, etc.

Stand characteristics (N – number of trees, G – stand basal area) are calculated on a per-hectare basis. For description of stand development the following common abbreviations are used: d – diameter at breast height, h – mean height, h/d – ratio of slenderness (height/diameter ratio), d_{200} – diameter of 200 largest-diam-

eter trees, h_{200} – height of 200 largest-diameter trees, h/d_{200} – height/diameter ratio of 200 largest-diameter trees.

Forest stand selection for investigation

As Norway spruce stands take up 55% of the forested area in the Czech Republic and are a primary source of raw material for wood production and for other non-wood-producing functions of forests, attention was primarily paid to this species. In establishing the 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 of the main Czech mountain ranges: the Šumava Mts., Krušné hory Mts., Jizerské hory Mts., Krkonoše Mts., Orlické hory Mts., Jeseníky Mts., Beskydy Mts. and the Českomoravská vysočina Mts., mostly at elevations above 600 m on spruce sites. One portion of the series was established at a lower elevation (below 600 m a.s.l.), on the sites where Norway spruce was introduced artificially.

The recommended initial stand age was set at 30 years with the goal of minimising the effect of different stand regeneration techniques (planting, sowing, natural regeneration) upon our experiment. Only high forest locations (of seed origin) with medium site index were acceptable.

Although according to valid growth tables of SCHWAP-PACH (1943) all chosen experimental stands had 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 large even-aged pure and untreated stands, at least 3–4 hectares in size, on the same aspect, similar soil conditions and parent rock. Border stands or localities endangered by wind, snow and ice damage were avoided as well as steep slopes.

Area and form of partial comparative plots

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

All trees around the comparative plot (outside of the plot) were marked with 5 cm wide yellow strip facing the interior of the plot. On the corner tree, series number and comparative plot was written in yellow paint. All trees over 4 cm diameter on each comparative plot are numbered individually and the points for diameter measurement are marked.

Comparability of partial plots

Before initiating the first experimental treatments, the difference between stand characteristics on particular comparative plots in number of trees – N , basal area – G , mean diameter – d , and mean height – h was tested using Student's t -test ($\alpha = 0.05$). Only after the preliminary differences in given parameters were found insignificant, could the experiment be initiated.

Observations

The experimental series are surveyed as a rule in five-year periods out of the vegetation season and all trees are measured by callipers in mm over bark. The diameter of each tree is measured twice: the first measurement against the label, the second at a perpendicular angle. The height of the stands is measured with telescopic poles or Blume-Leisse altimeter on representative groups of trees (30 individuals of all tree classes) and height curves are calculated to assess the mean and top height. After finishing the initial survey, trees designated for the 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 in 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 compared two thinning techniques:

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

Some of the experimental series were complemented by the variant of heavy thinning, i.e. the opening up of stand canopy. Each experimental series has a control plot without thinning.

Positive selection from above

Thinning with positive selection from above was conducted in accordance with the 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 one or two of the most vigorous competitors. Every future crop tree with the best stem and crown form was surrounded by several alternates. The crop tree (as a rule from higher tree classes) and alternates comprise a so-called stand

cell. Thinning focused on releasing the growing space for future crop trees' crowns and creating suitable growing conditions so that high quality increment would be created on superior individuals. Dead, ill or damaged trees were removed except where they supported the selected future crop trees.

After the culmination of height growth, approximately 500 best crop trees were selected and their crowns kept free by removing adjacent individuals. This process will be finished by release cutting that opens the canopy and consequently encourages the establishment of the next generation of trees.

This way of tending evaluated the retention of secondary crop trees that consist of intermediate, suppressed and overtopped individuals. The main benefit of secondary crop lies in the shading of forest soil and improvement of self-pruning of selected best stems.

Negative selection from below

Thinning with negative selection from below focused on removal of dead and dying trees (Kraft class 5), slower-growing trees (Kraft class 4) and poor quality, mechanically injured and diseased trees of higher classes. Healthy, well-shaped dominant trees were removed only to release the groups of trees with similar dimensions and quality. Before removing a healthy dominant tree with unsatisfactory crown or stem characteristics, the canopy condition was taken into account to minimise upper canopy disturbance.

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

Release cutting

Release cutting is a very heavy thinning by negative selection from below; 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 at a more or less regular spacing. The aim of release cutting is to release the growing space for the best individuals by reducing competition.

Control plot

Control plot is used for investigation of natural mortality in the 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 dead, broken or uprooted trees are removed. Those trees that were removed were measured like on other comparative plots.

Intensity of investigated thinning

The intensity of one thinning treatment was set to be 15–10% of basal area during 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. Where stocking is less than 1.0 (for example 0.8–0.9), the thinning intensity decreased to 30–50% of the original amount. Thinning always reflected the actual state of the stand. Heavier reduction of basal area to 30% or more was used where situations required release cuttings.

Evaluation of acquired data

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

The second step was calculation of height curves for all variants of each series and periods of investigation using Näslund's 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 entering the mean d or d_{200} diameter.

The data on diameter and height were used for computation of h/d and h_{200}/d_{200} ratios, which serve 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 distributions before and after each treatment of a particular series using 1 cm diameter classes (i.e. diameter class 15 cm involves trees with diameter from 14.6 cm to 15.4 cm).

Due to the lack of replication in individual variants of a particular series, thinning variants could not be entirely evaluated by statistical methods.

For statistical evaluation of diameter growth of mean stem and dominant trees (200 trees per hectare) and changes in diameter structures, statistical system UNISTAT® (version 5.1) was used. Procedures ANOVA and sequentially Multiple Comparisons (Student – Newman – Keuls and Scheffe) were applied (GROFIK, FLAK 1990; MELOUN, MILITKY 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). The diameter distributions on partial comparative plots were analysed by goodness of fit tests (chi-square). In all analyses, confidence level of 0.95 was used.

Static stability of dominant trees (h_{200}/d_{200} ratio for 200 dominant trees per hectare) was analysed separately. For all dominant trees on partial plots, height from func-

tional analysis (by Näslund's equation) was calculated. Received h_{200}/d_{200} ratio was analysed by the same methods as diameter growth data (see above).

As we did not have a sufficient number of sample trees to derive a series of volume curves, volume calculations could not be included in this report. 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, a complete study of growth and changes in stand volume will be a part of the last report.

RUMBURK EXPERIMENTAL SERIES

An experimental series at Rumburk was founded in forest area 20 – the Lužická pahorkatina Hills – in 1958 in a 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 50°54'07'' N latitude and 32°09'13'' E longitude. The experimental stand is located on a gentle eastern slope (2–3%) in the 5th (Fir-Beech) Forest Altitudinal Zone at an elevation of 510 m. The prevailing soil type is brown forest soil, acid – fertile ecological series, soil category I (S). The experimental stand is included in Management Unit 54 – spruce management of fertile sites at higher locations affected by air pollution. According to data from the Czech Hydrometeorological Institute (CHMI) for the period 1961–1990, the mean annual precipitation was 800 mm and mean annual temperature 6°C.

The experimental series consists of two comparative plots 50 × 50 m in size, i.e. 0.25 ha each. Comparative plot 1c is a control plot without thinning, where only dead, broken or uprooted trees were 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 canopy opening and subsequent observation of development of left trees and natural regeneration.

History of the experiment

During the establishment of the Rumburk series in 1958, the experimental stand was a 37-year-old Norway spruce monoculture with density of 1,984–2,016 trees per hectare planted at a regular spacing of ca. 2 m (i.e. 2,500 trees per hectare) in 1921 on a clear-cut after nun moth injury. The stand was not thinned before the first experimental treatment and, subsequently, it was characterised by a distinct diameter distribution (diameter at breast height ranged from 5 to 30 cm).

The initial diameter of mean stem (d) on both partial plots 1c and 2a was 14.2 and 14.0 cm, diameter d_{200} (mean diameter of 200 thickest trees per hectare) 21.2 and 20.4 cm respectively. The differences in mean and top height (h 14.2 and 14.4 m and h_{200} 17.0 and 17.2 m) were also minimal and differences between all investigated

Table 2. Basic data on Rumburk experimental series

Rumburk	1958 37 years			1963 42 years			1968 47 years			1973 52 years			1978 57 years	1998 77 years	1 37-77		1 37-77-SC	SC 37-77
	Before thinning	T	T _%	After thinning	Before thinning	T	T _%	After thinning	Before thinning	T	T _%	After thinning	Before thinning	After thinning				
1c	2,016	279	14	1,740	1,740	216	12	1,524	1,524	432	28	1,092	892	440	*	*	*	1,576
2a	1,984	348	18	1,636	1,636	268	16	1,368	1,368	456	33	912	680	508	*	*	*	172
1c	32.3	2.3	7	30.0	35.9	2.2	6	33.7	38.7	6.2	16	32.6	35.1	30.4	28.3	-1.9	30.2	
2a	31.0	3.9	13	27.1	33.2	3.6	11	29.6	34.6	6.3	18	28.3	31.7	41.2	33.9	28.8	5.1	
1c	14.2	10.4	*	14.8	16.1	11.3	*	16.7	17.8	13.5	*	19.3	22.4	29.6	10.5	*	*	
2a	14.0	11.9	*	14.5	16.0	13.1	*	16.5	17.7	13.2	*	19.6	24.4	32.2	12.9	*	*	
1c	14.2	12.1	*	14.4	17.1	14.3	*	17.3	18.8	16.5	*	19.5	21.6	25.5	9.3	*	*	
2a	14.4	13.2	*	14.6	16.7	15.2	*	16.9	18.6	15.9	*	19.5	22.0	26.1	9.5	*	*	
1c	100	116	*	97	106	127	*	104	106	122	*	101	96	86	-1.5	*	*	
2a	103	111	*	101	104	116	*	102	105	120	*	99	90	81	-9.1	*	*	
1c	21.2	*	*	*	25.7	*	*	*	27.0	*	*	*	29.9	35.6	14.4	*	*	
2a	20.4	*	*	*	25	*	*	*	27.4	*	*	*	30.6	39.3	18.9	*	*	
1c	17.0	*	*	*	20.9	*	*	*	22.3	*	*	*	23.8	25.5	8.5	*	*	
2a	17.2	*	*	*	20.4	*	*	*	22.2	*	*	*	24.0	27.8	10.6	*	*	
1c	80	*	*	*	81	*	*	*	83	*	*	*	80	73	-7	*	*	
2a	84	*	*	*	82	*	*	*	81	*	*	*	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, T – increment, SC – salvage cut

characters (N , G , d , h , h_{200} , d_{200}) were found statistically insignificant (Table 2). On the basis of the initial evaluation of the main stand characteristics, both partial plots 1c and 2a were found comparable.

Number of trees and basal area

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

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

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

At the same time basal area (G) per hectare amounted to:

- 1c – 35.1 m² on control plot (increase by 2.8 m²),
- 2a – 31.7 m² on comparative plot (decrease by 0.7 m²).

Total periodic increment of basal area (during the first 20 years of the study) on comparative plot 2a was 19.2 m², i.e. by 16 m² higher than on control plot 1c without thinning (2.8 m²).

Since the last experimental thinning at the age of 52 years (1973), both comparative stands of the experimental series have continued to develop without any thinning. All treatments consisted in removal of dead, broken and uprooted trees. The number of trees per hectare at the last re-measurement in 1998 (age 77 years) decreased to:

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

Mortality during the last 20-year period (age 57–77 years) was influenced by air pollution stress. On the more seriously impacted 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 of 37–52 years only 172 trees (25% of N at the age of 57 years) were removed. The highest rate of mortality on the control plot 1c (18% of N , i.e. 116 trees and 19% of G , i.e. 6.5 m²) was observed by the 6th re-measurement at the age of 66 years (1987). The basal area of the control plot 1c decreased below 28 m² in a similar manner and as the mortality in the next five-year period exceeded the increment again, the basal area by the 7th re-measurement at the age of 71 years decreased to 27.1 m².

Basal area at the age of 77 years, i.e. 40 years after the beginning of the experiment (last re-measurement), increased on the comparative plot 2a (41.2 m²), whereas the control plot 1c decreased below the initial level to 30.4 m², due to higher 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 during the study period was 5.6 m² higher on high thinning plot 2a compared with control plot 1c (28.3 m² on control plot 1c and 33.9 m² on plot 2a). In addition on control plot 1c, 30.2 m² of basal area (107% of basal area increment) had to be salvaged during the study period, due to mortality, damage and uprooting, whereas salvage removals on thinned plot 2a amounted to only 5.1 m² (i.e. 15% of basal area increment).

When including the basal area of deliberately thinned trees only (salvage cut excluded), the basal area increment in the study period (age of 37–77 years) was:

- 1.9 m² on plot 1c, i.e. the reduction of initial basal area,
- 28.8 m² on plot 2a.

Diameter structure

The 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 at the age of 37, 42, 47 and 52 years, i.e. in the period of active treatment. The 5th last evaluation was made on the data collected in 1998, when the trees were 77 years old.

At the age of 77 years (last revision), the diameter of the trees in experimental stands ranged from 14 to 53 cm (Fig. 4). The lowest diameter classes 14–20 cm with the highest and most unfavourable h/d ratio (110–140) was the most abundant on control plot 1c (72 individuals per hectare compared with 44 individuals per hectare on comparative plot 2a with positive selection from above). On the other hand, the number of trees 30 cm and more in diameter and with favourable h/d ratio (85–54) was 43% higher on thinned plot 2a than on control plot 1c (264 ha vs. 184 ha on the control plot). The thinning effect is especially apparent when one looks at the number of the largest diameter trees (40 cm and more) on high thinned plot 2a, where these trees accounted for 200% of control plot (72 individuals on plot 2a compared with 36 individuals on plot 1c).

Although the thinned plot 2a had the highest number of large-diameter trees and the lowest number of small-diameter trees, the frequency distribution of diameters was not statistically significantly different (chi-square test) from that of the control plot at the age of 77 years (last revision).

Static stability

At the beginning of the study, the static stability of experimental stands, as measured by the h/d ratio of mean stem and dominant trees (d_{200}), was relatively unfavourable in spite of rather low initial density. The h/d ratio of mean stem at the age of 37 years (1958) ranged from 103 on plot 2a to 100 on plot 1c (Table 1, Fig. 2) and was in the increment phase, which reached its maximum

106 on control plot 1c at the age of 47 years (3rd revision). In the next period, the h/d ratio of mean stem on control plot decreased, partly as a result of the increase in mortality of trees with the highest h/d ratio.

Experimental thinning on comparative plot 2a did not halt the increase in the h/d ratio which reached its maximum similarly like on control plot 1c at the age of 47 years with the value 105. Subsequent to this period, the elevated proportion of large trees with higher diameter increment on the thinned plot caused a greater decline in the mean h/d ratio compared with control plot.

When evaluating dominant trees (200 thickest trees per hectare, i.e. the same number of individuals on each comparative plot), the initial h_{200}/d_{200} ratio on comparative plots 1c and 2a was 80 and 84, respectively.

On the control plot, the height/diameter ratio increased to 83 at the age of 47 years, and afterwards it decreased to 73 at the age of 77 years (last revision). On the comparative plot 2a with positive selection from above, the h_{200}/d_{200} ratio decreased since the beginning of experiment to the final value 72 measured at the last revision in 1998.

Although thinning resulted in significantly higher d_{200} on comparative plot 2a with high thinning at the age of 66, 71 and 77 years (Fig. 3), the h_{200}/d_{200} ratio was balanced by height increment of dominant trees and therefore, the differences in h_{200}/d_{200} ratio at the age of 77 years (last revision) between control plot without thinning and plot 2a were not found statistically significant.

Conclusions from the Rumburk experiment

- At the age of 37–47 years, the basal area of experimental Norway spruce stands increased on both comparative plots. On control plot 1c after that period, mortality exceeded the basal area increment due to tree growth and basal area per hectare decreasing gradually to 27.1 m² at the age of 71 (1992). During the entire 40-year study, a total of 30.2 m² of basal area (107% of increment) was removed as salvage cutting (dead and broken trees) and stand basal area on control plot 1c at the age of 77 was therefore lower by 1.9 m² compared with its initial value. On the other hand, on comparative plot 2a with positive selection from above, the stand basal area decreased due to four thinning treatments to 28.1 m² at the age of 52 years. Since that time it continually increased to 42.1 m² at the age of 77 years (1998). The periodic basal area increment over the 40-year period of investigation was 33.9 m² on this plot and it was by 5.6 m² (20%) higher than on control plot; salvage removals amounted to only 5.1 m² (15%).
- Effect of thinning by positive selection from above over 40 years resulted in a decreased abundance of trees in lower diameter classes and an increased abundance of trees in higher diameter classes compared with the control stand without thinning. The number of small-diameter trees (20 cm and lesser) was lower by 39% on plot 2a with thinning compared

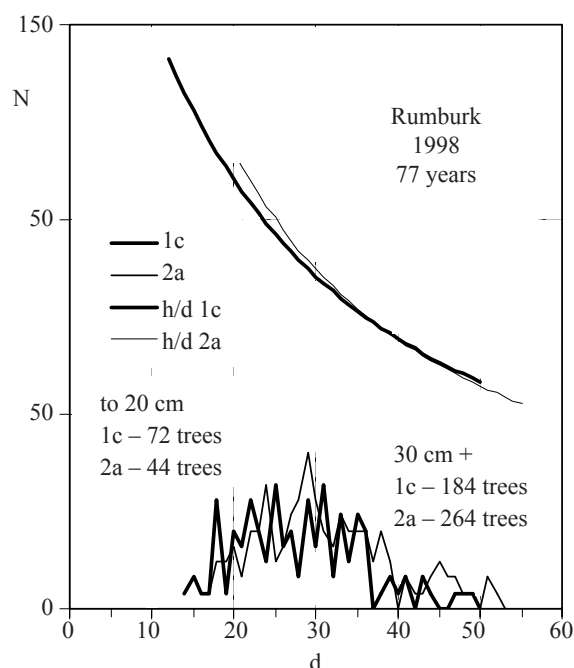


Fig. 1. Diameter structure and h/d ratio for diameter classes on Rumburk experimental series at the age of 77 years – last revision (d – diameter in cm, N – number of trees per hectare)

with control plot 1c (44 and 72 trees, respectively). On the other hand, the number of large-diameter trees (30 cm and more) on plot 2a was higher by 43% (and 184 trees, respectively). However, differences in the frequency distribution of diameter structure on control plot 1c and thinned plot 2a were not found statistically significant.

- Development of the h/d ratio of mean stem since the beginning of the study was similar on both comparative plots. The reason is that the selection from above on plot 2a removed the trees from larger diameter classes and left the smaller trees that had more unfavourable static stability. The maximum h/d ratio was observed at the age of 47 years (1c – 106, 2a – 105). Thinning resulted in a more pronounced decline in the h/d ratio with the final value 81 on plot 2a compared with 86 on the control plot at the age of 77 years.
- The slenderness ratio of dominant trees h_{200}/d_{200} (200 largest diameter trees per hectare) on control plot 1c showed an increasing tendency with culmination at the age of 47 years (from initial value 80 to value 83) and the following decrease continuing until the age of 77 years (value 73). On comparative plot 2a with positive selection from above, the h_{200}/d_{200} ratio decreased since the beginning of experiment from initial value 84 to final value 72 found by the last revision in 1998. The difference between the final values of h_{200}/d_{200} ratio on both comparative plots was not significant.

An experimental series at Mostek was founded in forest area 23 – the Podkrkonoší Piedmont in 1958 in a 38-year-old Norway spruce stand growing in Forest Management-Plan Area Hostinné (stand 627 C1 according to Forest Management Plan 1993). The co-ordinates of the series are 50°29'22'' N latitude and 33°20'35'' E longitude. The experimental stand is located on a gentle western slope (3–4%) in the 5th (Beech-Fir) Forest Vegetation Zone at an elevation of 530 m. The prevailing soil type is gleyic brown forest soil, acid ecological series, soil category K. The experimental stand is included in Management Unit 53 – spruce management of acid sites at higher locations. According to data from the Czech Hydrometeorological Institute (CHMI) for the period 1961–1990, the mean annual precipitation was 700 mm and mean annual temperature 7°C.

The experimental series consists of three comparative plots 50 × 50 m in size, i.e. 0.25 ha each. Comparative plot 1c is a control plot without thinning, where only dead, broken or uprooted trees were removed. Comparative plots 3b and 5b are 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 canopy opening and subsequent observation of development of left trees and natural regeneration.

History of the experiment

During the establishment of the Mostek series in 1958, the experimental stand was a 38-year-old Norway spruce monoculture with density of 2,072–2,404 trees per hectare. With respect to the initial large diameter differentiation (tree diameters before the first experimental thinning ranged 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. The initial diameter of mean stem (d) on these partial plots was 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 the two previous stands by a lower number of trees especially in mean diameter classes. The total number of trees per hectare on plot 5b was 2,072, i.e. by 330 less than in the control stand 1c. The initial mean diameter 13.1 cm was not found statistically significant and differences in mean height (12.8 m, 13.5 m and 13.6 m in stands 1c, 3b and 5b respectively) were accepted (Table 3). Additional evaluation of d_{200} showed that dominant trees on plot 5b differed significantly since the beginning of observations (Fig. 6) probably as a result of previous undocumented thinning.

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 comparative plot 3b, and 35% N and 13% G in the stand of comparative plot 5b.

Treatments with negative selection from below were repeated three times in five-year periods until 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.

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

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

At the same time basal area (G) per hectare amounted to:

- 35.8 m² on control plot 1c (increase by 7.9 m²),
- 31.5 m² on comparative plot 3b (increase by 4.1 m²),
- 30.3 m² on comparative plot 5b (increase by 6.1 m²).

Together with the basal area of intentionally removed trees by thinning periodic increments of basal area (the first 20 years of the study at the age of 38–58 years) amounted to 18.7 and 19.6 m² on comparative plots 3b and 5b, and they were by more than 10 m² higher than usable basal area increment on control plot 1c without thinning where 11.8 m² of increment was represented mostly by unmarketable waste (dry trees and breaks).

Since the last experimental thinning at the age of 53 years (1973), all three comparative stands of the experimental series have continued to develop without any thinning. All treatments consisted in removal of dead, dry and broken and uprooted trees. The number of trees per hectare until the last revision in 1998 (age 78 years) spontaneously decreased to:

- 592 individuals on plot 1c (mortality at the age of 38–78 years 1,812 individuals),
- 656 individuals on plot 3b (mortality in the last 20-year period 152 individuals),
- 468 individuals on plot 5b (mortality in the last 20-year period 44 individuals).

Basal area G at the age of 78 years, i.e. 40 years after the beginning of the experiment, achieved nearly 44 m² per hectare on all comparative plots (Table 3). During the period of investigation (age of 38–78 years) it increased by:

- 14.7 m² on plot 1c,
- 13.4 m² on plot 3b,
- 16.1 m² on plot 5b.

After including the basal area of all removed trees (i.e. including salvage cut), the periodic basal area increment on thinned plots was 35 m². The periodic basal area incre-

Table 3. Basic data on Mostek experimental series

Mostek	1958 38 years			1963 43 years			1968 48 years			1973 53 years			1978 58 years	1998 78 years	I 38-78	I 38-78-SC	SC 38-78
	Before thinning	T	T %	Before thinning	T	T %	Before thinning	T	T %	Before thinning	T	T %	After thinning	After thinning	*	*	*
1c	2,404	212	9	2,192	304	14	1,888	564	30	1,324	272	21	1,052	592	*	*	1,812
3b	2,388	540	23	1,848	328	18	1,520	412	27	1,108	300	27	808	656	*	*	152
5b	2,072	736	35	1,336	320	24	1,016	316	31	700	188	27	512	468	*	*	44
1c	29.1	1.2	4	27.9	33.2	1.6	31.6	6.8	19	29.3	34.8	3.4	31.5	43.8	37.9	14.7	23.1
3b	30.2	2.7	9	27.4	32.9	2.4	30.6	6.8	20	27.6	32.4	5.4	27.0	43.6	35.0	30.8	4.2
5b	27.9	3.6	13	24.2	30.0	2.6	27.4	6.3	20	25.7	30.8	4.6	26.2	44.0	35.3	33.2	2.1
1c	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	10.4	*	*
3b	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	11.0	*	*
5b	13.1	7.9	*	15.2	16.9	10.2	18.5	20.0	16.0	21.6	23.7	17.6	25.5	27.4	13.9	*	*
1c	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	11.8	*	*
3b	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	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	11.9	*	*
1c	103	118	*	102	109	122	107	109	120	107	105	121	102	105	*	*	*
3b	106	118	*	104	110	126	108	108	115	106	108	119	104	103	*	*	*
5b	104	118	*	99	101	119	97	98	108	94	93	108	89	90	*	*	*
1c	19.0	*	*	*	21.2	*	*	23.2	*	*	26.1	*	*	28.2	17.9	*	*
3b	18.6	*	*	*	20.8	*	*	22.6	*	*	25.2	*	*	27.2	16.4	*	*
5b	21.9	*	*	*	24.3	*	*	26.8	*	*	29.9	*	*	32.0	18.7	*	*
1c	16.0	*	*	*	19.5	*	*	21.0	*	*	23.1	*	*	25.1	15.3	*	*
3b	17.1	*	*	*	20.0	*	*	21.3	*	*	23.6	*	*	25.4	13.8	*	*
5b	18.3	*	*	*	20.6	*	*	22.6	*	*	24.2	*	*	26.0	13.1	*	*
1c	84	*	*	*	92	*	*	91	*	*	89	*	*	89	*	*	*
3b	92	*	*	*	96	*	*	94	*	*	94	*	*	93	*	*	*
5b	84	*	*	*	85	*	*	84	*	*	81	*	*	81	*	*	*

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

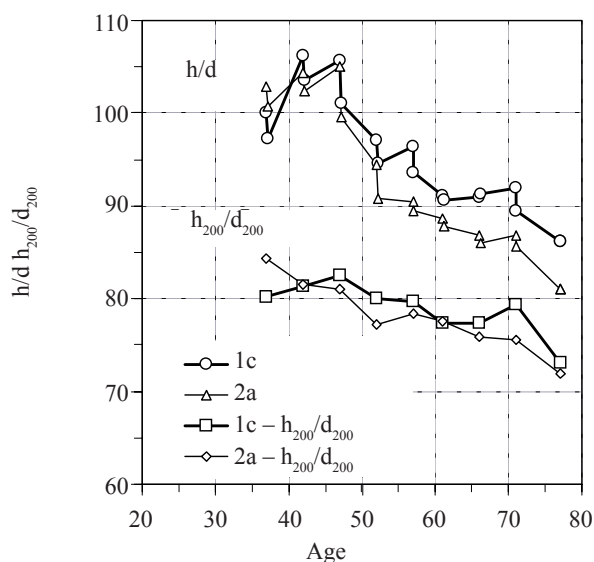


Fig. 2. Development of the h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Rumburk experimental series at the age of 37–77 years

ment on control plot 1c was higher – 38 m², but more than 23 m² of the increment (60%) had to be removed during the period of study as salvage cut (breaks, dry trees, etc.), whereas salvage removals on thinned plots 3b and 5b amounted to only 4.2 and 2.1 m² (i.e. 12% and 6% of increment).

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

- 14.7 m² on plot 1c,
- 30.8 m² on plot 3b,
- 33.2 m² on plot 5b.

Diameter structure

The 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 and last evaluation was made on the data collected by the revision at the age of 78 years (1998).

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

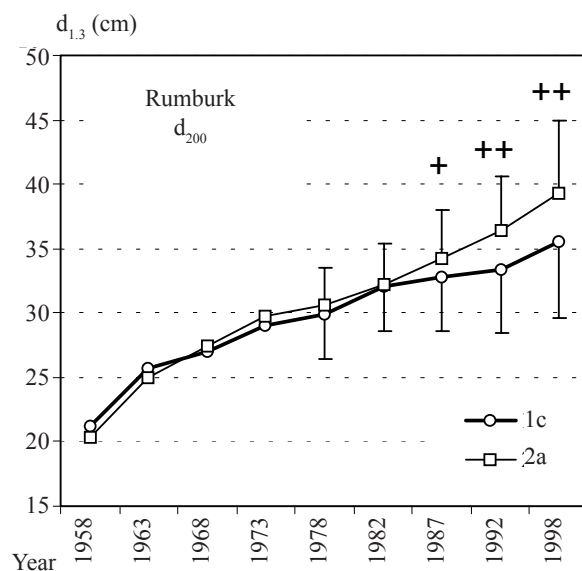


Fig. 3. Development of d_{200} (with standard deviation) of dominant trees (200 largest diameter trees per hectare) on Rumburk experimental series in the period 1958–1998 (age 37–77 years). Statistical analysis (t -test) – significant differences on confidence level 0.95 (+) and 0.99 (++)

At the age of 78 years (last revision), the diameter of trees in experimental stands ranged from 15 to 54 cm (Fig. 4). The lowest diameter classes 15–29 cm with the highest and most unfavourable h/d ratio (92–126) were the most abundant on comparative plots 1c and 3b (276 and 372 individuals per hectare, respectively, com-

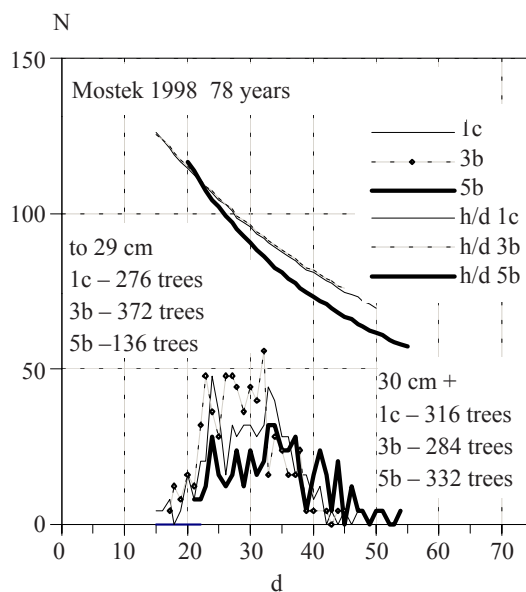


Fig. 4. Diameter structure and h/d ratio for diameter classes on Mostek experimental series at the age of 78 years – last revision (d – diameter in cm, N – number of trees per hectare)

pared with 136 individuals on comparative plot 5b with heavy thinning by negative selection from below).

The abundance of trees with diameter 30 cm and more with favourable h/d ratio (96–57) was nearly the same on all comparative plots 1c, 3b and 5b (316, 284, 332, respectively).

There were differences between the compared thinning regimes only in the abundance of trees with diameter 40 cm and more, only in the case of heavy low thinning (plot 5b). On control plot 1c and on plot 3b with moderate low thinning, the number of these thickest trees was 36 and 16 whereas on plot 5b with heavy low thinning it was 112 (more than three times higher compared with control plot). The effect of thinning on the frequency distribution of diameter structure on plot 3b with moderate low thinning at the age of 78 years was not found statistically significant nor on comparative plot 5b with heavy low thinning.

Static stability

At the beginning of observations, the static stability of experimental stands evaluated by the h/d ratio of mean stem and dominant trees (d_{200}) was relatively unfavourable in spite of relatively low initial density (Fig. 2). The h/d ratio of mean stem at the age of 38 years (1958) ranged from 103 on plot 1c to 106 on plot 3b (Table 3, Fig. 5) and was in the phase of increment culminating on control plot 1c by the value 109 at the age of 43 years (2nd revision) and on plot 3b by the value 108 at the age of 48 years (3rd revision).

Subsequent 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 (the last revision) it achieved the values 94 and 98, respectively. The more pronounced decrease in 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 a decreasing tendency from the beginning of observations, mainly as a result of heavy low thinning at the age of 38, 43, 48 and 53 years removing nearly all thin unstable individuals. The applied heavy low thinning resulted in acceleration of diameter increase of left trees and consequently in very favourable low h/d ratio (the value 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 cm at the age of 53 years and by 6.6 cm at the age of 58 years compared with mean diameter on control plot 1c.

Evaluation of dominant trees (200 thickest trees per hectare, i.e. the same number of individuals on each comparative plot) showed that the initial h_{200}/d_{200} ratio on comparative plots 1c and 5b achieved the same value 84 and on plot 3b the value 92. Subsequent development of slenderness ratio on control plot 1c showed an increasing tendency with culmination at the age of 43 years by the values 92, 96 and 85 on plots 1c, 3b and 5b, respectively. The following decrease continued until the age of 78 years (last revision), when the h/d ratio on plot 3b with moderate low thinning reached the value 88, which was significantly higher than the value 85 on control plot 1. A positive effect of thinning on the static stability of dominant trees was recognised only in the case of heavy low thinning investigated on plot 5b where the final h/d ratio of dominant trees was lowest (77) and significantly different from the other two comparative variants (1c and 3b). Development of h_{200}/d_{200} ratio depended on d_{200} , which was significantly higher at the age of 38–78 years on comparative plot 5b and significantly lower on plot 3b compared with control plot 1c without thinning (Fig. 6). So the positive effect of thinning on the static stability of dominant trees consisted in lower height increment and higher diameter increment after very heavy thinning from below on comparative plot 5b compared with control plot 1c without thinning.

Conclusions from the Mostek experiment

- In the period of investigation (age of 38–78 years), the basal area increased by 38 m² on control plot 1c without thinning. From this amount more than 23 m² (60%) were 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 m² and salvage cut on these plots amounted to 4.2 and 2.1 m² only (i.e. 12% and 6% of increment).
- Effect of thinning on diameter structure by negative selection from below lasting 40 years was evident only on comparative plot 5b with heavy low thinning,

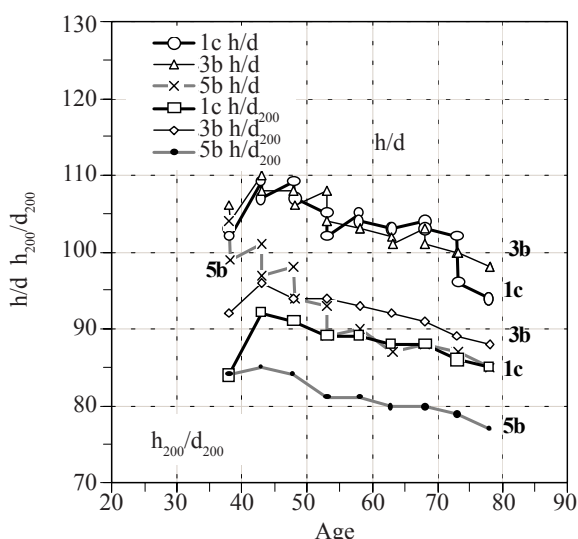


Fig. 5. Development of h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Mostek experimental series at the age of 38–78 years

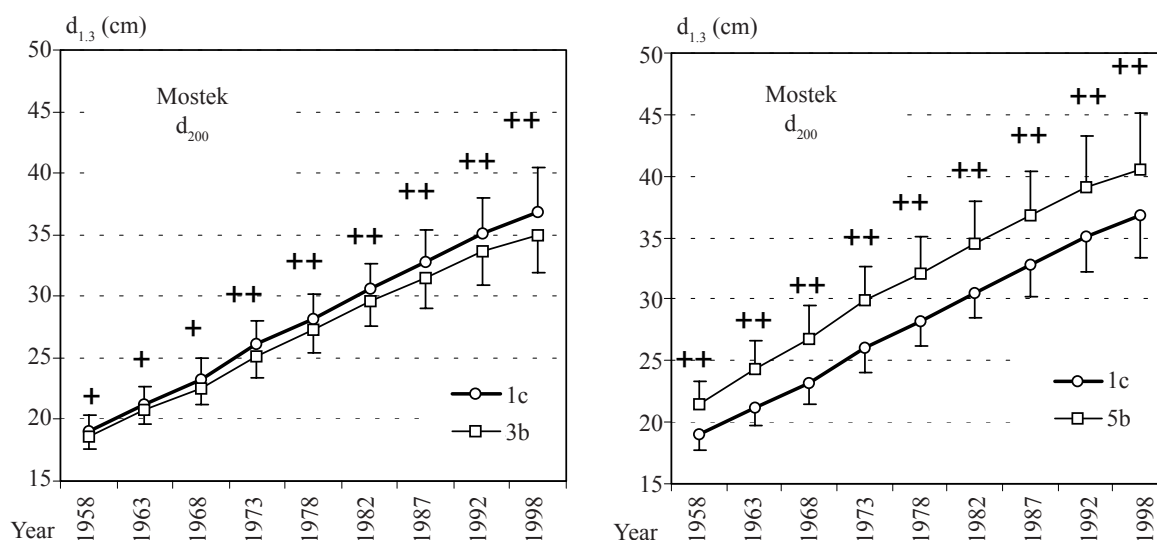


Fig. 6. Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on Mostek experimental series (1c/3b – left, 1c/5b – right) in the period 1958–1998 (age 38–78 years). Statistical analysis (t -test) – significant differences on confidence level 0.95 (+) and 0.99 (++)

where the abundance of thickest trees with diameter 40 cm and more was more than 300% of control plot (112 individuals compared 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 twice lower on plot 5b compared with control plot 1c and three times lower compared with plot 3b (136 on plot 5b, 276 and 372 on plots 1c and 3b). But the differences between variants in the frequency distribution of diameter structure were not found statistically significant.

- Static stability characterised by the 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 decreased after culmination as a result of removing mostly thin unstable individuals on all comparative plots. The applied heavy low thinning on plot 5b resulted in acceleration of diameter increase of left trees and consequently in a very favourable low h/d ratio (value 85 at the age of 78 years).
- Static stability of dominant trees (200 thickest trees per hectare, i.e. the same number of individuals on each comparative plot) was significantly influenced by thinning only in the case of heavy low thinning on comparative plot 5b. The increase in h_{200}/d_{200} ratio on this plot reduced after the first thinning and after culmination at the age of 43 years with the value 85 continually decreased to the significantly different value 77 at the age of 78 years (last revision). The h_{200}/d_{200} ratio on comparative plots 1c and 3b culminated by the values 92 and 96 at the age of 43 years and decreased to the values 85 and 88 until the last revision (insignificant difference).

VIMPERK I EXPERIMENTAL SERIES

An experimental series at Vimperk (I) was founded in forest area 13 – the Šumava Mts. in 1958 in 32-year-old Norway spruce stand growing in Forest Management-Plan Area Vimperk (stand 413 C5 according to Forest Management Plan 1997). The co-ordinates of the series are 49°03'11'' N latitude and 31°21'53'' E longitude. The experimental stand is located on a moderate western slope (7%) in the 6th (Spruce-Beech) Forest Vegetation Zone

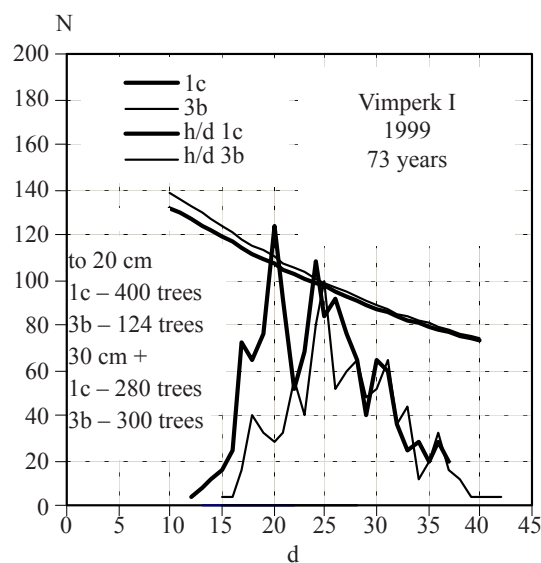


Fig. 7. Diameter structure and h/d ratio for diameter classes on Vimperk I experimental series at the age of 73 years – last revision (d – diameter in cm, N – number of trees per hectare)

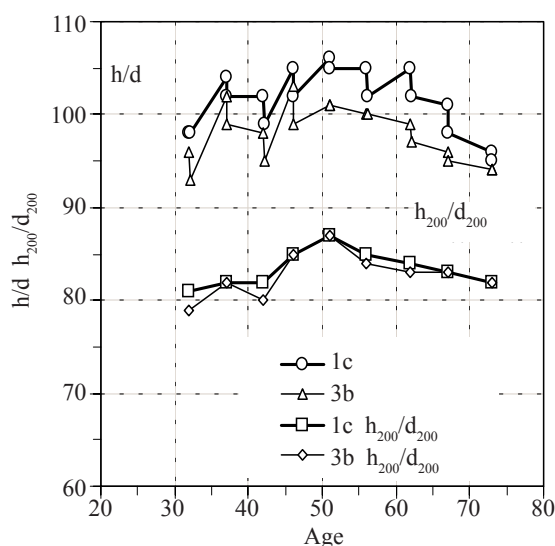


Fig. 8. Development of the h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Vimperk I experimental series at the age of 32–73 years (1c – control plot, 3b – thinning from below)

at an elevation of 1,020 m. The prevailing soil type is brown forest soil, acid ecological series, soil category K. The experimental stand is included in Management Unit 53 – spruce management of acid sites at higher locations. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period 1961–1990, the mean annual sum of precipitation was 1,000 mm and mean annual temperature 4°C.

The experimental series consists of two comparative plots 50 × 50 m in size, i.e. 0.25 ha each. Comparative plot 1c is a control plot without designed thinning, where only dead, broken or uprooted trees were 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 canopy opening and subsequent observation of development of left trees and natural regeneration.

History of the experiment

In the period of foundation of 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 that originated artificially by planting at a regular spacing of ca. 1.25–1.5 m (i.e. 5,000–6,000 trees per hectare) in the period of 1920–1930 clear-cut. The experimental stand was not thinned before the first experimental treatment and, subsequently, it was distinctly differentiated (diameter breast height ranged from 3 to 23 cm).

The initial diameter of mean stem (d) on both partial plots 1c and 3b was 10.6 and 11.0 cm and the differences in mean and top height (h 10.4 and 10.5 m and h_{200} 13.8 and

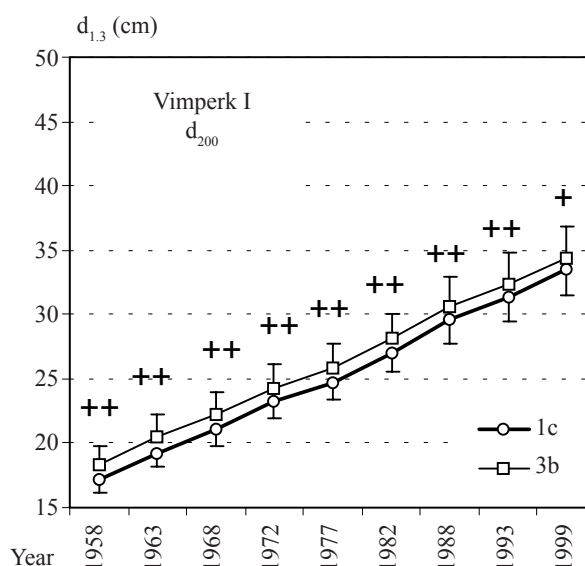


Fig. 9. Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on Vimperk I experimental series in the period 1958–1999 (age 32–73 years). Statistical analysis (t -test) – significant differences on confidence level 0.95 (+) and 0.99 (++)

14.4 m) were also 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 (Table 4). 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 observations (Fig. 9).

Number of trees and basal area

By the first experimental thinning on 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 were repeated three times in five-year periods until the age of 46 years (1972) removing 14, 26 and 32% N (5, 13 and 20% G).

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

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

At the same time basal area (G) per hectare amounted to:

- 57.5 m² on control plot 1c (increase by 16.8 m²),
- 42.4 m² on comparative plot 3b (increase by 1.7 m²).

Together with basal area of intentionally removed trees by thinning the periodic increment of basal area (at the age of 32–52 years) was 24.1 m² on comparative plot 3b 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 Vimperk I experimental series have developed without designed thinning. All treatments consisted in removal of dead dry and incidentally broken and uprooted trees. The number of trees per hectare until the last revision in 1999 (age 73 years) spontaneously decreased to:

- 1,248 individuals on plot 1c (mortality at the age of 32–73 years 3,384 trees),
- 928 individuals on plot 3b (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 a 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 compared 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 amounted to 11 m² only (i.e. 23% of basal area increment).

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

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

Diameter structure

The effect of thinning on diameter structure was investigated at the age of 32–46 years, in five-year periods 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 represented by lines, thinned trees are shown by open columns and mortality on control plot 1c by solid columns. Diameter structure on both comparative plots before the beginning of the experiment at the age of 32 years (1958) was nearly identical, especially in the 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.

It is obvious from the aspect of particular treatments that all four thinnings on comparative plot 3b were made by negative selection from below. Displacement of thinning into higher diameter classes compared with natural mortality is apparent in all four treatments.

At the age of 73 years (last revision), the diameter of trees in experimental stands ranged from 12 to 41 cm (Fig. 7). The lowest diameter classes 12–20 cm with the highest and most unfavourable h/d ratio (110–130) were the most abundant on control plot 1c (400 individuals per hectare compared with 124 individuals per hectare on comparative plot 3b with negative selection from below). On the other hand, the 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 compared with 280 individuals per hectare on control plot 1c). Differences in the frequency distribution of diameter structure were found significant.

Static stability

At the beginning of observations, the static stability of experimental stands evaluated by the h/d ratio of mean stem and dominant trees (d_{200}) was relatively unfavourable in spite of relatively low initial density. The h/d ratio of mean stem at the age of 32 years (1958) was similar on both comparative plots 1c and 3b and ranged from 98 to 96 (Table 4, Fig. 8) and culminated on control plot 1c by the value 106 at the age of 52 years (4th revision). In the next period, the h/d ratio of mean stem on control plot decreased, 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 by the value 103. A decrease in h/d ratio after culmination was similar on both comparative plots, and at the age of 73 years, the ratio reached the values 95 (1c) and 94 (3b). The relatively rapid decrease in slenderness ratio of mean stem on control plot 1c was mostly caused 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 only 464 individuals (33%) at the same time.

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

Because of similar development of d_{200} (significantly higher on comparative plot 3b with low thinning in all periods of observations, Fig. 9), the differences in h_{200}/d_{200} ratio at the age of 73 years (last revision) between control plot without thinning and plot 3b were not found statistically different.

Table 4. Basic data on Vimperk 1 experimental series

Vimperk I		1958 32 years			1963 37 years			1968 42 years			1972 46 years			1978 52 years	1998 73 years	I 32-73	I 32-73-SC	SC 32-73
		Before thinning	T	T %	After thinning	Before thinning	T	T %	After thinning	Before thinning	T	T %	After thinning	Before thinning	After thinning			
1c	N	4,632	476	10	4,156	4,156	520	13	3,636	3,636	444	12	3,192	2,620	1,248	*	*	3,384
3b	(trees/ha)	4,332	1,104	25	3,228	3,228	440	14	2,788	2,788	724	26	2,064	1,396	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	57.5	63.4	56.6	22.6	34.0
3b	(m ² /ha)	40.7	4.5	11	36.3	43.5	2.1	5	41.4	46.9	6.3	13	40.6	42.4	54.7	47.0	36.0	11.0
1c	d	10.6	7.0	*	10.9	12.0	6.1	*	12.6	13.5	8.4	*	14.0	16.7	25.4	9.4	*	*
3b	(cm)	11.0	7.2	*	12.0	13.1	7.8	*	13.8	14.6	10.5	*	15.8	19.7	27.4	11.9	*	*
1c	h	10.4	7.8	*	10.7	12.5	7.8	*	12.8	13.6	9.8	*	13.9	17.8	24.2	11.2	*	*
3b	(m)	10.5	7.5	*	11.1	13.3	9.1	*	13.6	14.3	11.5	*	15.0	19.8	25.7	12.5	*	*
1c	h/d	98	111	*	98	104	128	*	102	101	116	*	99	106	95	13	*	*
3b		96	104	*	93	102	117	*	99	98	109	*	95	101	94	7	*	*
1c	d_{200}	17.1	*	*	*	19.3	*	*	*	21	*	*	*	24.7	33.5	16.4	*	*
3b	(cm)	18.3	*	*	*	20.5	*	*	*	22.3	*	*	*	25.8	34.4	16.1	*	*
1c	h_{200}	13.8	*	*	*	15.8	*	*	*	17.3	*	*	*	21.6	27.3	13.5	*	*
3b	(m)	14.4	*	*	*	16.8	*	*	*	17.9	*	*	*	22.4	28.1	13.7	*	*
1c	h/d_{200}	81	*	*	*	82	*	*	*	82	*	*	*	87	82	1	*	*
3b		79	*	*	*	82	*	*	*	80	*	*	*	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

Conclusions from 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 observations, the stand basal area increased by 56.6 m² on control plot 1c, but 34.0 m² of this amount (60%) had to be removed as salvage cut (breaks, dry trees, etc.). At the same time, basal area increment on comparative plot 3b with low thinning amounted to 47.0 m² and salvage cut was 11 m² only (23% of basal area increment). After including the basal area of all removed trees (i.e. including salvage cut), the increment in the period of investigation was higher by 9.6 m² on control plot 1c, but when including only the basal area of intentionally removed trees (salvage cut excluded), the periodic increment was higher by 13.4 m² 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 compared with control stand 1c without thinning. The number of thin trees (diameter 20 cm and less) was lower by 69% on plot 3b with thinning compared with control plot 1c (124 trees on plot 3b and 400 trees on plot 1c). On the other hand, the number of thick trees in higher diameter classes (diameter 30 cm and more) was higher by 7% on plot 3b (300 trees on plot 3b and 280 trees on plot 1c). Especially the difference in the number of thin trees resulted in significant differences in the frequency distribution 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 the 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 the h/d ratio of mean stem on comparative plot 3b with thinning from below compared with control plot were caused mainly by calculation shifts after removal of thin and unstable individuals. At the age of 73 years (last revision), the h/d ratio of mean stem reached nearly the same values 95 and 94 and the h/d ratio of dominant trees the same value 82 on both unthinned and thinned plots.

VIMPERK II EXPERIMENTAL SERIES

An experimental series at Vimperk (II) was founded in forest area 13 – the Šumava Mts. in 1958 in 51-year-old Norway spruce stand growing in Forest Management-Plan Area Vimperk (stand 413 B1 according to Forest Management Plan 1997). The co-ordinates of the series are 49°03'11'' N latitude and 31°22'03'' E longitude. The experimental stand is located on a moderate western

slope (11%) in the 6th (Spruce-Beech) Forest Vegetation Zone at an elevation of 1,045 m. Prevailing soil type is brown forest soil, acid ecological series, soil category K. The experimental stand is included in Management Unit 53 – spruce management of acid sites at higher locations. According to the data of the Czech Hydrometeorological Institute (CHMI) for the period of 1961–1990, the mean annual sum of precipitation was 1,000 mm and mean annual temperature 4°C.

The experimental series consists of three comparative plots 50 × 50 m in size, i.e. 0.25 ha each. Comparative plot 1c is a control plot without designed thinning, where only dead, broken or uprooted trees were removed. Comparative plot 2a is the stand with thinning by positive selection from above and plot 3b is the stands 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 canopy opening and consequent observation of development of left trees and natural regeneration.

History of the experiment

In the period of foundation of 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 that originated artificially by planting on clear-cut at a regular spacing of 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 ranged from 3 to 21 cm).

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. The initial diameter of mean stem (d) on these partial plots was 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 the two previous stands first of all by the 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 were not found statistically significant nor the differences in other investigated characteristics (Table 5).

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 on comparative plot 2a and 23% N and 10% G by negative selection from below in the stand on comparative plot 3b.

Treatments were repeated three times in five-year periods until the age of 66 years (1973) removing 15, 19 and 36% N (8, 12 and 26% G) on comparative plot 2a

Table 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
		Before thinning	T	T %	After thinning	Before thinning	T	T %	After thinning	Before thinning	T	T %	After thinning	Before thinning	After thinning			
1c	N	4,828	488	10	4,340	4,340	568	13	3,772	3,772	412	11	3,360	2,948	1,584	*	*	3,244
2a	(trees/ha)	4,988	740	15	4,248	4,248	644	15	3,604	3,604	684	19	2,920	1,856	1,096	*	*	760
3b		4,952	1,156	23	3,796	3,796	728	19	3,068	3,068	864	28	2,204	1,556	1,108	*	*	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	59.2	38.0	11.8	26.2
2a	(m ² /ha)	46.5	5.3	11	41.2	47.4	3.6	8	43.8	48.6	5.7	12	42.8	48.3	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	52.5	41.0	30.9	10.1
1c	d	11.2	7.1	*	11.6	12.1	7.0	*	12.7	13.4	8.5	*	13.9	14.6	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	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	24.6	7.9	*	*
1c	h	11.7	8.7	*	11.9	12.7	9.2	*	13.1	13.7	10.6	*	13.9	15.4	22.7	8.5	*	*
2a	(m)	11.4	10.5	*	11.5	12.3	10.0	*	12.6	13.6	11.7	*	13.9	15.4	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	24.0	9.9	*	*
1c	h/d	104	122	*	103	105	132	*	103	102	124	*	100	106	104	0	*	*
2a		104	111	*	103	103	118	*	101	103	114	*	101	106	98	-6	*	*
3b		103	120	*	99	101	119	*	98	96	109	*	93	97	98	-5	*	*
1c	d_{200}	18.2	*	*	*	19.6	*	*	*	21.2	*	*	*	22.5	29.9	11.7	*	*
2a	(cm)	17.8	*	*	*	19.5	*	*	*	21.0	*	*	*	22.3	32.1	14.3	*	*
3b		18.1	*	*	*	19.7	*	*	*	21.3	*	*	*	22.7	31.0	12.9	*	*
1c	h_{200}	14.8	*	*	*	15.6	*	*	*	16.7	*	*	*	18.6	25.8	11.0	*	*
2a	(m)	14.1	*	*	*	15.6	*	*	*	17.0	*	*	*	19.1	26.3	12.1	*	*
3b		14.5	*	*	*	15.7	*	*	*	16.7	*	*	*	18.4	26.1	11.5	*	*
1c	h/d_{200}	81	*	*	*	80	*	*	*	79	*	*	*	83	86	5	*	*
2a		79	*	*	*	80	*	*	*	81	*	*	*	86	82	3	*	*
3b		80	*	*	*	80	*	*	*	78	*	*	*	81	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

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.

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

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

At the same time basal area (G) per hectare amounted to:

- 57.5 m² on control plot 1c (increase by 10.1 m²),
- 40.2 m² on comparative plot 2a (decrease by 6.3 m²),
- 30.3 m² on comparative plot 3b (decrease by 6.7 m²).

Together with basal area of intentionally removed trees by thinning the periodic increment of basal area in the first 20 years of investigation (at the age of 51–71 years) was 20.9 and 20.3 m² on comparative plots 2a and 3b, respectively, and it was by more than 10 m² higher than the usable basal area increment on control plot 1c without thinning (10.1 m²).

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 removal of dead dry and incidentally broken and uprooted trees. The number of trees per hectare until the last revision in 1999 (age 92 years) spontaneously decreased to:

- 1,584 individuals on plot 1c (mortality at the age of 51–92 years 3,244 trees),
- 1,096 individuals on plot 2a (mortality at the age of 71–92 years 760 trees),
- 1,108 individuals on plot 3b (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 the highest value on control plot 1c (59.2 m²) and was by 9 m² higher than on comparative plot 2a with high thinning (50.2 m²) and by 6.7 m² on plot 3b with low thinning (52.2 m²).

After including the basal area of all removed trees (i.e. including salvage cut), the periodic basal area increment on thinned plots 2a and 3b was by ca. 3 m² higher than on control plot 1c (38 m² on plot 1c, and 40 and 41 m² on plots 2a and 3b). But on control plot 1c, 26.0 m² 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 amounted to 10 m² only (i.e. 24% of basal area increment). When including the basal area of only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigation (age of 51–92 years) amounted to:

- 11.8 m² on plot 1c,
- 30.8 m² on plot 2a,
- 30.9 m² on plot 3b.

Diameter structure

The 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).

Distribution of trees in diameter classes before thinning is represented by lines; thinned trees are shown by open columns and mortality on control plot 1c by solid columns. Diameter structure on all three comparative plots was nearly identical before the beginning of the experiment at the age of 51 years (1958). Significantly different (chi-square test) frequency distribution of diameter structure was found only between thinned plots 2a and 3b.

From the aspect of particular treatments it is obvious from the diameter structure of stands that all four thinning on comparative plot 2a were carried out by positive selection from above and on plot 3b by negative selection from below. Numerous breaks and declining individuals had to be removed by experimental thinning 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 compared with natural mortality is apparent in all four treatments, but especially in the 2nd and 4th thinning at the age of 56 and 66 years.

At the age of 92 years (last revision), the diameter of trees in experimental stands ranged from 10 to 40 cm (Fig. 10). The lowest diameter classes 10–20 cm with the highest and 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, the abundance of trees with diameter 30 cm and more with relatively favourable h/d ratio (86–70) on thinned plot increased and represented 150% of control on comparative plot 2a with high thinning and 117% of control on comparative plot 3b with low thinning (120, 180 and 140 on plots 1c, 2a and 3b, respectively). Differences in the frequency distribution of diameter structure in all investigated variants at the age of 78 years (last revision) were found statistically significant (chi-square test).

Static stability

At the beginning of observations, the static stability of experimental stands evaluated by the h/d ratio of mean stem and dominant trees (d_{200}) was relatively unfavourable because of very high initial stand density (Table 5).

The h/d ratio of mean stem at the age of 51 years (1958) ranged from 103 on plot 3b to 104 on plots 1c and 2a (Table 5, Fig. 11) and on control plot 1c, it was in the phase

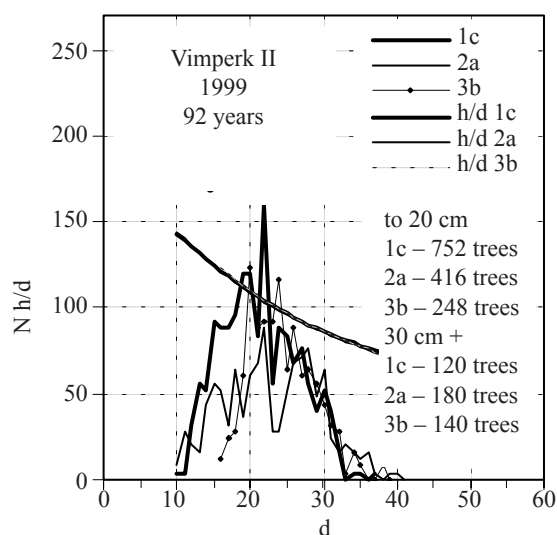


Fig. 10. Diameter structure and h/d ratio for diameter classes on Vimperk II experimental series at the age of 92 years – last revision (d – diameter in cm, N – number of trees per hectare)

of increment culmination by the value 110 at the age of 71 years (4th revision). Subsequent development of h/d ratio on control plot 1c is characterised by a decreasing tendency caused mainly by natural mortality of trees with very disadvantageous static attributes (high h/d ratio).

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

Development of the h/d ratio of mean stem on comparative plot 3b with low thinning was different from the other two variants. Relatively heavy low thinnings at the age of 51, 61 and 66 years with removal of thin unstable individuals resulted in a stepwise decrease in the ratio by calculation shifts and its slower increase to the value 96 at the age of 76 years. In the next period (age 76–92 years), the h/d ratio of mean stem on this plot stagnated and reached the final value 98, similarly like the 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 was 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_{200}/d_{200} ratio was nearly equal on all comparative plots and ranged from 79 on comparative plot 2a to 81 on control plot 1c. The culmination of h_{200}/d_{200} ratio was registered at the age of 71 years similarly like in the h/d ratio of mean stems, when it reached the values from 85 (3b) to 87 (2a).

In the next period, the h_{200}/d_{200} ratio on control plot 1c stagnated at the value 86 and on comparative plots 2a and 3b with thinning it showed a decreasing tendency finishing

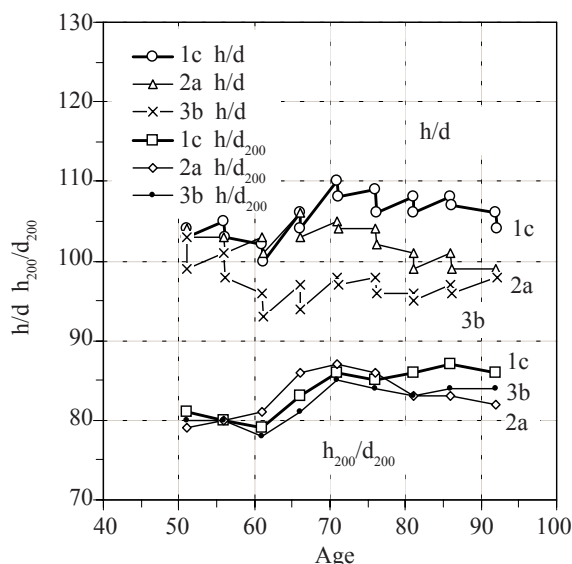


Fig. 11. Development of the h/d ratio of mean stem and dominant trees (200 thickest trees per hectare) on Vimperk II experimental series at the age of 51–92 years

at significantly different values 82 on plot 2a and 84 on plot 3b at the age of 92 years (last revision). Development of h_{200}/d_{200} ratio was influenced by significantly higher d_{200} at the age of 81–92 years (last three revisions) on thinned plots 2a and 3b compared with control plot 1c without thinning (Fig. 12).

Conclusions from 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 observations, the stand basal area increased by 38.0 m² on control plot 1c, but 26.2 m² 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 m² and 41.0 m² and salvage cut amounted to 10.0 and 10.1 m² only (24% of basal area increment). A positive effect of thinning on basal area increment was observed on Vimperk II series. Periodic basal area increment was by ca. 3 m² higher on both thinned variants (2a and 3b) than on control plot 1c and, after excluding salvage cut, the differences between thinned and unthinned variants increased to ca. 19 m² in favour of thinned stands.
- 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) compared with control stand 1c without thinning. The number of thin trees (diameter 20 cm and less) was by

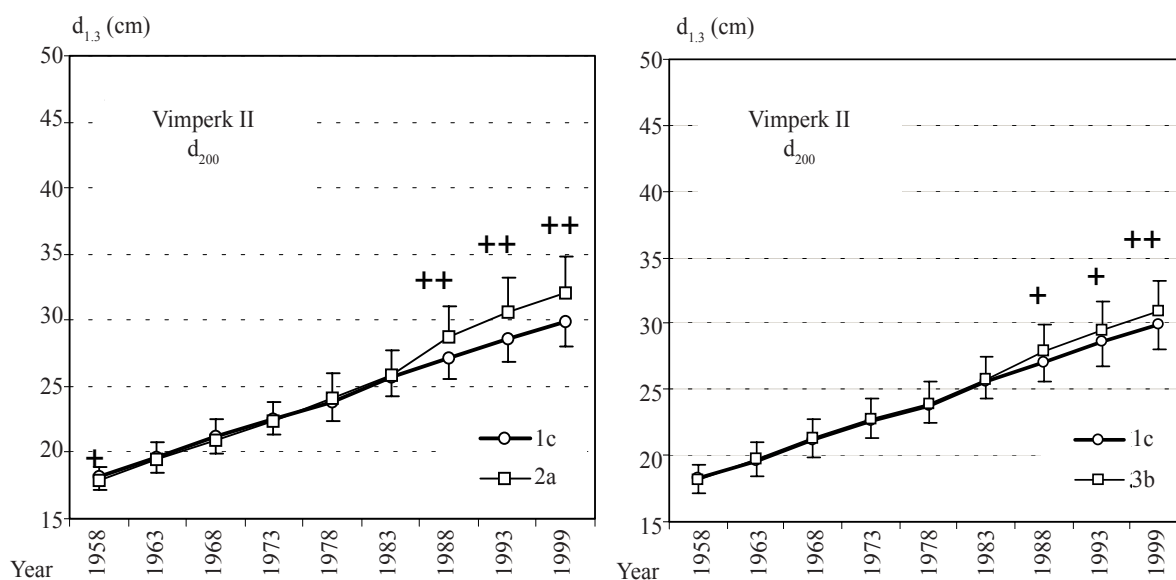


Fig. 12. Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on Vimperk II experimental series (1c/2a – left, 1c/3b – right) in the period 1958–1999 (age 51–92 years). Statistical analysis (t -test) – significant differences on confidence level 0.95 (+) and 0.99 (++)

45% lower on plot 2a with high thinning and by 67% lower on plot 3b with low thinning compared with control plot 1c (752, 416 and 248 thin trees on plots 1c, 2a and 3b). On the other hand, the number of thick trees in higher diameter classes (diameter 30 cm and more) increased by 50% on plot 2a and by 17% on plot 3b compared with control plot 1c (120, 180 and 140 thick trees on plots 1c, 2a and 3b). Differences in the frequency distribution 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 the 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 the h/d ratio of mean stem on comparative plot 3b with low thinning compared with control plot was caused partly by calculation shifts after removal of thin and unstable individuals and partly by better diameter increment. The volume of the h/d ratio of mean stem on comparative plot 2a with high thinning was initially (age 51–66 years) similar like on control plot 1c, then the higher diameter increase resulted in improved stability. At the age of 91 years (last revision) the h/d ratio of mean stem reached the value 98 on both thinned plots (control plot 104).
- Static stability of experimental stands of Vimperk II experimental series assessed by development of the h_{200}/d_{200} ratio of dominant trees (200 thickest trees per hectare, i.e. the same number of individuals on each comparative plot) showed a similar course on all three comparative plots until the age of 71 years. After

then, the h_{200}/d_{200} ratio on control plot 1c stagnated at the value ca. 86 and on plot 3b with low thinning it decreased to significantly different value 84. The best final h_{200}/d_{200} ratio (82), significantly different from other variants, was found on comparative plot 2a with positive selection from above.

NISA EXPERIMENTAL SERIES

An experimental series at Nisa was founded in forest area 21a – the Jizerské hory Mts. in 1958 in 35-year-old Norway spruce stand growing in Forest Management-Plan Area Nisa (stand 547 B8 according to Forest Management Plan 1993). The co-ordinates of the series are 50°48'02'' N latitude and 32°55'55'' E longitude. The experimental stand is located on a 20% northern slope in the 6th (Spruce-Beech) Forest Vegetation Zone at an elevation of 820 m. Prevailing soil type is brown forest soil, acid ecological series, soil category K. The experimental stand is included in Management Unit 52 – spruce management of acid sites at 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 was 1,200 mm and mean annual temperature 4°C.

The experimental series consists of three comparative plots 50 × 50 m in size, i.e. 0.25 ha each. Comparative plot 1c is a control plot without designed thinning, where only dead, broken or uprooted trees were 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

canopy opening and consequent observation of development of left trees 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 large diameter differentiation (tree diameters before the first experimental thinning ranged 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.

For the Nisa experimental series, primary data for the period 1958–1973 were lost, so this period was reconstructed on the basis of available preliminary evaluation. For this reason, dominant trees are characterised by 100 thickest individuals per hectare used in 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. The initial diameter of mean stem (d) on all three partial plots was 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 10.8–11.4 m, h_{100} 14.3–14.7 m) and were not found statistically significant nor the differences in other investigated characteristics (Table 6).

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 on comparative plot 2a and 33% N and 16% G by negative selection from below in the stand on comparative plot 3b.

Treatments were repeated three times in five-year periods until 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.

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

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

At the same time basal area (G) per hectare amounted to:

- 38.2 m² on control plot 1c (increase by 6.1 m²),
- 31.5 m² on comparative plot 2a (decrease by 0.1 m²),
- 30.3 m² on comparative plot 3b (decrease by 5.5 m²).

Together with basal area of intentionally removed trees by thinning the periodic increment of basal area in the first 20 years of investigation (at the age of 35–55 years) was 18.8 and 18.2 m² on comparative plots 2a and 3b, and it was higher by more than 12 m² than the 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 removal of dead dry and incidentally broken and uprooted trees. The number of trees per hectare until the last revision in 1998 (age 75 years) spontaneously decreased to:

- to 552 individuals on plot 1c (mortality at the age of 35–75 years 2,052 trees),
- to 536 individuals on plot 2a (mortality at the age of 55–75 years 232 trees),
- to 480 individuals on plot 3b (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 comparable on all three comparative plots (32.1, 31.7 and 30.5 m²).

After including the basal area of all removed trees (i.e. including salvage cut), the periodic basal area increment on comparative plots 1c, 2a and 3b amounted to 28.3, 26.9 and 27.6 m², respectively.

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 cuts on both thinned plots 2a and 3b were only 7.7 and 7.1 m² (i.e. 29 and 26% of basal area increment).

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

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

Diameter structure

The 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 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 represented by lines; thinned trees are shown by open columns and mortality on control plot 1c by solid columns. Diameter structure on all three comparative plots was similar before the beginning of the experiment at the age of 35 years (1958).

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 adjusted by the first experimental thinning at the age of 35 years.

Table 6. Basic data on Nisa experimental series

Nisa	1958 35 years			1963 40 years			1968 45 years			1973 50 years			1978 55 years	1999 75 years	1 35-75	1 35-75-SC	SC 35-75
	Before thinning	T	T %	After thinning	Before thinning	T	T %	After thinning	Before thinning	T	T %	After thinning	Before thinning	After thinning	1 35-75	1 35-75-SC	SC 35-75
1c	2,604	416	16	2,188	2,188	408	19	1,780	1,780	708	40	1,072	1,072	552	28.3	*	2,052
2a	2,656	348	13	2,308	2,308	620	27	1,688	1,688	684	41	1,004	1,004	536	26.9	*	232
3b	2,860	940	33	1,920	1,920	432	23	1,488	1,488	736	49	752	668	480	27.6	*	188
1c	32.1	1.5	5	30.6	37.6	2.2	6	35.5	39.9	9.3	23	30.6	34.8	32.1	28.3	0.0	28.3
2a	31.6	2.9	9	28.6	35.3	3.8	11	31.4	35.6	7.6	21	27.7	32.7	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	30.5	27.6	20.5	7.1
1c	12.5	6.8	*	13.3	14.8	8.3	*	15.9	16.9	12.9	*	19.0	20.3	27.2	8.1	*	*
2a	12.3	10.2	*	12.6	14.0	8.9	*	15.4	16.3	11.9	*	18.7	20.4	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	28.4	9.6	*	*
1c	11.0	6.6	*	11.4	13.1	8.8	*	13.7	15.2	12.7	*	16.2	17.3	20.3	7.1	*	*
2a	10.8	9.5	*	11.0	12.6	8.9	*	13.4	14.9	11.9	*	16.1	17.2	20.8	7.3	*	*
3b	11.4	8.6	*	12.3	13.4	9.9	*	14	15.1	13.8	*	16.0	16.8	20.2	6.2	*	*
1c	88	97	*	86	89	106	*	86	90	98	*	85	85	74	-14	*	*
2a	88	93	*	87	90	100	*	87	91	100	*	86	84	76	-12	*	*
3b	91	101	*	90	88	100	*	85	86	92	*	80	78	71	-20	*	*
1c	21.2	*	*	*	24.2	*	*	*	26.3	*	*	*	28.9	35.7	14.5	*	*
2a	21.2	*	*	*	24.2	*	*	*	26	*	*	*	28.6	34.6	13.4	*	*
3b	20.7	*	*	*	23.3	*	*	*	25.5	*	*	*	27.5	35.6	14.9	*	*
1c	14.6	*	*	*	17	*	*	*	19.1	*	*	*	20.2	22.6	8.0	*	*
2a	14.3	*	*	*	17	*	*	*	18.9	*	*	*	20	22.4	8.1	*	*
3b	14.7	*	*	*	16.4	*	*	*	17.9	*	*	*	18.8	22.0	7.3	*	*
1c	69	*	*	*	70	*	*	*	73	*	*	*	70	63	*	*	*
2a	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_{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

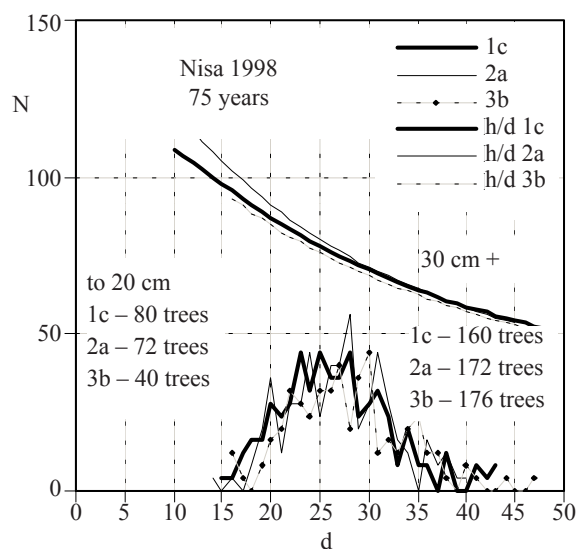


Fig. 13. Diameter structure and h/d ratio for diameter classes on Nisa experimental series at the age of 75 years – last revision (d – diameter in cm, N – number of trees per hectare)

From the aspect of particular treatments it is obvious from the diameter structure of stands that the 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 treatment, numerous breaks and declining individuals had to be removed as well, and so the distribution of thinned trees had a left-sided form typical of low thinning on comparative plot 3b. Displacement of thinning into higher diameter classes compared with 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 trees in experimental stands ranged from 14 to 47 cm (Fig. 13). The lowest diameter classes 10–20 cm with the highest 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, the abundance of trees with diameter 30 cm and more with favourable h/d ratio (65–50) on thinned plots slightly increased and represented 108% of control on comparative plot 2a with high thinning and 110% of control on comparative plot 3b with low thinning (160, 172 and 176 on plot 1c, 2a and 3b, respectively). A low effect of thinning after 40 years (at the age of 75 years) was confirmed by the analysis of distribution of diameter structures (chi-square test) when no statistically significant differences between control plot 1c and thinned plots 2a and 3b were found.

Static stability

The h/d ratio of mean stem at the age of 35 years (1958) ranged from 88 on plots 1c and 2a to 91 on plot 3b (Table 6,

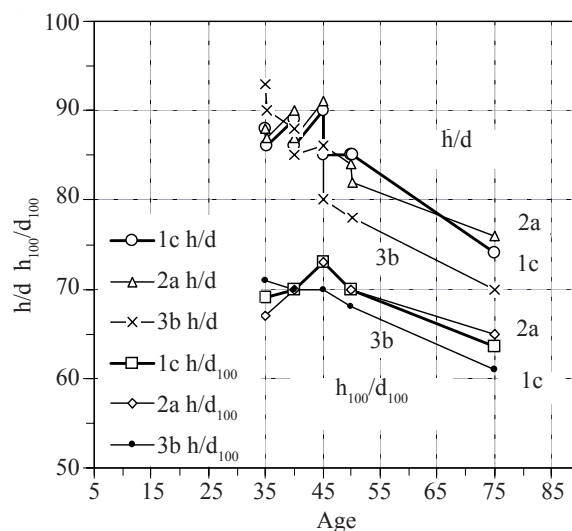


Fig. 14. Development of the h/d ratio of mean stem and dominant trees (100 thickest trees per hectare) on Nisa experimental series at the age of 35–75 years

Fig. 14) and it was in the phase of increment culminating by the value 88–91 at the age of 40–45 years (2nd and 3rd revision). Subsequent 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 negative static attributes (high h/d ratio). At the age of 75 years (last revision), the h/d ratio of mean stem reached the values 74 and 76 on these plots.

Development of the h/d ratio of mean stem on comparative plot 3b with low thinning differed from the other two variants. The relatively heavy low thinnings at the age of 35, 40 and 45 years with removal of thin unstable individuals resulted in a stepwise decrease in the ratio by calculation shifts, its slower increase to the value 86 at the age of 45 years and relatively quick decrease after culmination to the final value 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 was nearly equal on all comparative plots and ranged from 67 on comparative plot 2a to 71 on control plot 3b. The culmination of h_{100}/d_{100} ratio was registered on plots 1c and 2a similarly like that of the h/d ratio of mean stems at the age of 45 years by the value 73 and the following decrease in the ratio finished by the values 63 and 65 (insignificant differences). A decreasing tendency since the beginning of observations was found on comparative plot 3b (from initial 71 to significantly different final value 61 at the age of 75 years).

Although thinnings resulted in a 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 with-

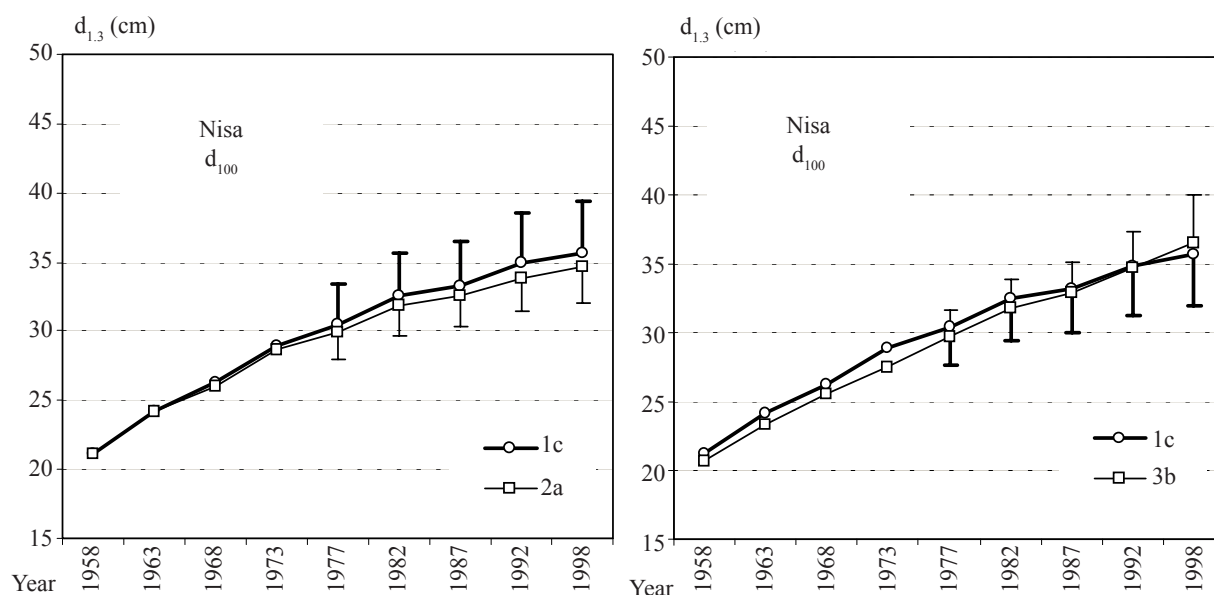


Fig. 15. Development of d_{200} (with standard deviations) of dominant trees (200 thickest trees per hectare) on Nisa experimental series (1c/2a – left, 1c/3b – right) in the period 1958–1999 (age 35–75 years). Statistical analysis (t -test) – significant differences on confidence level 0.95 (+) and 0.99 (++)

out thinning and thinned plots 3b and 2a were statistically insignificant (Fig. 15).

Conclusions from Nisa experiment

- During 40 years of observations of experimental Norway spruce stands of Nisa series (age of 35–75 years), the stand basal area increased by 28.3 m² on control plot 1c, but this whole 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 m² and 27.6 m² and salvage cut amounted to only 7.7 and 7.1 m² (i.e. 29 and 26% of basal area increment). Total periodic basal area increment was by 1.4 and 0.7 m² lower on both thinned variants (2a and 3b) than on control plot 1c, but after excluding salvage cut, the differences between thinned and unthinned variants increased to 19.2 and 20.5 m² 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) compared with control stand 1c without thinning. The number of thin trees (diameter 20 cm and less) was by 10% lower on plot 2a with high thinning and by 50% lower on plot 3b with low thinning compared with control plot 1c (80, 72 and 40 thin trees on plots 1c, 2a and 3b). On the other hand, the number of thick trees in higher diameter classes (diameter 30 cm and more) slightly

increased by 8% on plot 2a and by 10% on plot 3b compared with control plot 1c (160, 172 and 176 thick trees on plots 1c, 2a and 3b). A low effect of thinning on diameter structure after 40 years (at the age of 75 years) was confirmed, by insignificant differences in the frequency distribution of diameter structure on investigated variants.

- Static stability of experimental stands of Nisa experimental series assessed by development of the h/d ratio of mean stem was influenced by thinning only on comparative plot 3b with low thinning. The lower h/d ratio of mean stem on this variant finishing with the value 70 at the age of 75 years was caused partly by calculation shifts after removal of thin and unstable individuals and partly by better diameter increment of left trees. The volume of the 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 by the value 90 and decreasing to the final value 75.
- Static stability of experimental stands of Nisa experimental series assessed by development of the 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 2a with high thinning, with culmination at the age of 45 years by the value 73 and following decrease to the final values 63 and 65 (insignificant differences). Development of the h/d ratio of dominant trees on comparative plot 3b with low thinning was characterised by a decreasing tendency since the beginning of observations from initial 71 to significantly different final value 61 at the age of 75 years.

DISCUSSION AND CONCLUSIONS

The method used in the thinning experiment did not suppose any replication inside the individual series, and the use of particular variants inside the group of the series as replications was not possible because of high initial differences between series. Especially high differences were found in the initial density of experimental stands that ranged 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 occurred in basal area (from 29.1 m² on Mostek series to 47.4 m² on Vimperk II series). The 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 with 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. 16). Therefore the final evaluation of the 1st group of series established in 1958 was aimed at common phenomena observed on particular series.

Production

The effect of thinnings on the production of experimental stands evaluated from the periodic basal area increment was different (Table 7).

Positive selection from above (2a) carried out on the series Rumburk, Nisa and Vimperk II resulted in two cases in higher and in one case in lower total periodic basal area increment (including salvage cut) compared with control plot without thinning. Higher BA increment was found on series Rumburk (+5.6 m², i.e. +20%) and Vimperk II (+2.8 m², i.e. +7%) and lower increment on Nisa series (−1.4 m², i.e. −5%).

Negative selection from below (plots 3b or 5b) carried out on the series Mostek, Nisa, Vimperk I and Vimperk II resulted in one case in higher and in three cases in lower total periodic basal area increment (including salvage cut) compared with control plot without thinning. Higher BA increment was found on Vimperk II series (+3 m², i.e. +8%) and lower increment on series Mostek (−3 m², i.e. −8% on both plots 3b and 5b), Nisa (−0.7 m², i.e. −2.5%) and Vimperk I (+9.6 m², i.e. −17%).

The most pronounced effect of thinning consisted in a decreased volume of basal area that 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 ranged 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 periodic basal area increment.

When excluding mostly unmarketable salvage cut, the basal area increment of thinned plots was by 59% higher on Vimperk I series and more than twice higher on Mostek and Vimperk II series compared 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 the effect of thinning by positive selection from above (comparative plots 2a of Rumburk, Nisa and Vimperk II series) lasting in the 40-year period of inves-

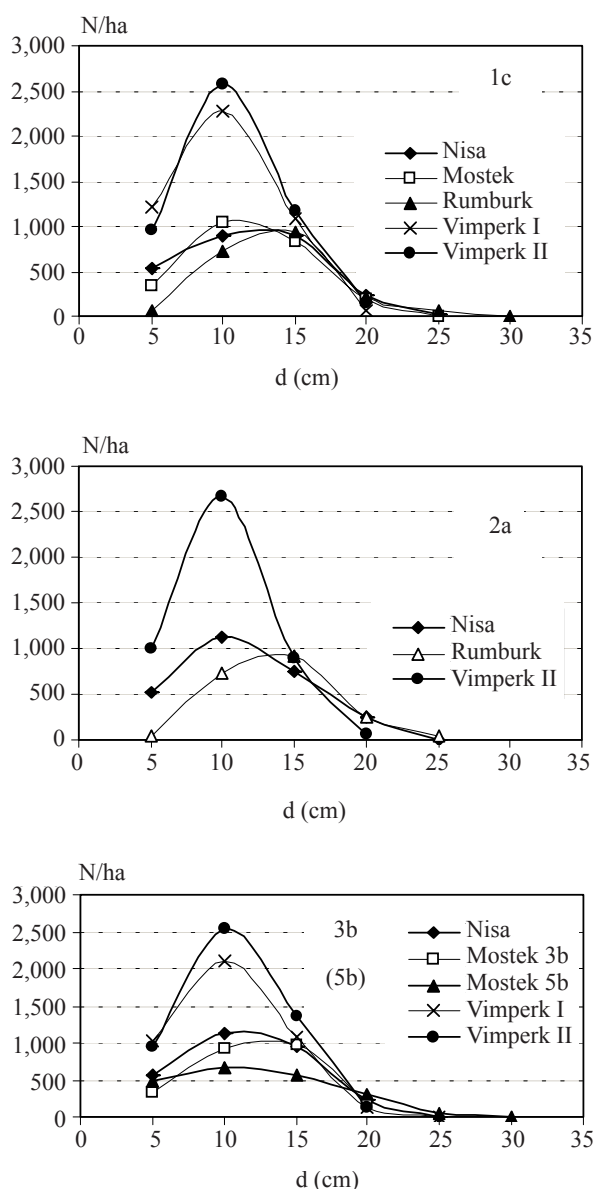


Fig. 16. Initial diameter distribution (in 1958) in particular series of the 1st group of series, 1c – control plots without thinning, 2a – comparative plots with thinning from above, 3b (5b) – comparative plots with thinning from below

Table 7. Total periodic basal area increment (including salvage cut) and periodic 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	27.6	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

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

Series	Thin trees (< 20 cm) (N/ha)				Thick trees (> 30 cm) (N/ha)				Differences in frequencies of diameter distribution		
	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

tigation resulted in 10–45% decreased abundance of trees in lower diameter classes compared with control plots of the particular series (Table 8). On the other hand, negative selection from below (variants 3b and 5b of Mostek, Nisa, Vimperk I and II) resulted in a more pronounced decrease of thin trees abundance (by 50–69% compared with control plots).

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

thinning from below applied to comparative plot 5b of Mostek series, where the number of trees with diameter 40 cm and more increased by more than 200% compared with control, but this comparative plot showed significant differences in diameter distribution already at the beginning of observations.

The only exception among the 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 frequen-

Table 9. Values of the 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

cies of diameter distribution). The reason is probably different site conditions of particular comparative plots of this experimental series.

Static stability

Static stability characterised by the 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 markedly lower (by 1–10%) on thinned plots compared with control plot without thinning (Table 9). The only exception was plot 2a with high thinning (Nisa series) and problematic plot 3b with low thinning (Mostek series), where the final h/d ratio increased by 3–4% compared with control.

A similar picture was found by evaluation of the h/d ratio of dominant trees (200 thickest trees per hectare, i.e. the same number of individuals on each comparative plot). A mostly positive effect (with the 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 the h/d ratio of dominant trees decreased by 10% compared with control plot (85 on control plot 1c and 77 on comparative plot 5b).

References

ČERNÝ M., PAŘEZ J., MALÍK Z., 1996. Růstové a taxační tabulky hlavních dřevin České republiky. (Smrk, borovice, buk, dub.) Jílové u Prahy, IFER: 245.
GROFÍK R., FLÁK P., 1990. Štatistické metódy v poľnohospodárstve. Bratislava, Príroda: 344.
MELOUN M., MILITKÝ J., 1998. Statistické zpracování experimentálních dat. Praha, East Publishing: 839.

NOVÁK J., SLODIČÁK M., 2001. Současná experimentální základna pro výzkum obnovy a výchovy lesních porostů. In: 50 let pěstebního výzkumu v Opočně. (Sbor. z celost. konf. 12.–13. 9. 2001 v Opočně.) Jíloviště-Strnady, VÚLHM: 209–218.
PAŘEZ J., 1958. Návrh postupu při zakládání, sledování a vyhodnocování trvalých pokusných ploch se zvláštním zřetelem k pokusným plochám probírkovým a výnosovým. Jíloviště-Strnady, VÚLHM: 248.
PAŘEZ J., 1972. Škody sněhem a větrem ve smrkových porostech probírkových pokusných ploch v období 1959–1968. Jíloviště-Strnady, VÚLHM: 97.
PAŘEZ J., 1975. Vliv výchovných zásahů na kvantitativní a kvalitativní produkci smrkových porostů. Jíloviště-Strnady, VÚLHM: 77.
PAŘEZ J., 1979. Diferenciace probírek ve smrkových porostech jedlo-bukového až dubo-bukového vegetačního stupně. Jíloviště-Strnady, VÚLHM: 48.
PAŘEZ J., 1980. Vliv podúrovňové a úrovňové probírky na produkci smrkových a borových porostů v ČSR. Jíloviště-Strnady, VÚLHM: 30.
PAŘEZ J., 1985. Zhodnocení výzkumných ploch ve smrkových a borových porostech. Jíloviště-Strnady, VÚLHM: 102.
PRODAN M., 1965. Holzmesslehre. Frankfurt a. M., J. D. Saurländers Verlag: 644.
SCHWAPPACH A., 1943. Ertragstabellen der wichtigeren Holzarten. 4th ed. Praha, Merkur: 74.
SLODIČÁK M., NOVÁK J., 2002. Forest thinning research in Opočno Research Station. In: KENK G. (Hrsg.), Deutscher Verband forstlicher Forschungsanstalten. Sektion Ertragskunde. Beiträge zur Jahrestagung. Schwarzburg, 13.–15. Mai 2002. Schwarzburg, Deutscher Verband forstlicher Forschungsanstalten: 56–64.

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Experimenty s výchovou porostů smrku ztepilého po 40 letech sledování – 1. série

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ABSTRAKT: Nová experimentální základna pro výzkum výchovy lesních porostů vznikala ve Výzkumném ústavu lesního hospodářství a myslivosti Jíloviště-Strnady od roku 1956. Z původních 46 experimentálních sérií založených v porostech smrku ztepilého (*Picea abies* [L.] Karst.) se jich doposud dochovalo pouze 24. Práce se zabývá první skupinou sérií, založenou v mladých smrkových porostech v roce 1958 (Rumburk, Mostek, Vimperk I, Vimperk II a Nisa). Cílem experimentu bylo srovnání dvou základních metod výchovy lesních porostů: úrovňové zásahy s pozitivním výběrem (2a) a podúrovňové zásahy s negativním výběrem (3b nebo 5b). Každá experimentální série obsahuje kontrolní variantu (1c) bez úmyslných výchovných zásahů. Po 40 letech sledování bylo zjištěno na plochách s pozitivním výběrem v úrovni o 10 až 45 % méně stromů v nižších tloušťkových třídách ve srovnání s kontrolními plochami. U ploch s negativním výběrem v podúrovni byl zaznamenán výraznější úbytek tenkých stromů (o 50–69 % ve srovnání s kontrolními plochami). Zastoupení silnějších stromů ($d_{1,3}$ 30 cm a více) bylo na všech vychovávaných plochách o 5–50 % vyšší ve srovnání s plochami bez výchovy. Statická stabilita charakterizovaná štíhlostním

kvocientem (h/d) středního kmene a horního stromového patra (200 nejsilnějších stromů na hektar) byla výchovou ovlivněna pozitivně (výsledná hodnota h/d byla při poslední revizi principiálně nižší).

Klíčová slova: pozitivní výběr v úrovni; negativní výběr v podúrovni; výchova lesa; smrk ztepilý

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 Jiloviště-Strnady. V rámci projektu bylo založeno ve smrkových porostech v letech 1956–1973 celkem 46 experimentálních sérií ve čtyřech časových skupinách (1. skupina sérií v letech 1956–1958, 2. skupina sérií v roce 1960, 4. skupina sérií v letech 1963–1964 a 5. skupina sérií v letech 1971–1973). 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. 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 tříhektarových až čtyřhektarových stejnověkových 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: úrovněvé zásahy s pozitivním výběrem (2a) a podúrovněvé 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 obmýtní na asi 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 štihllostní kvocienty h/d (pro střední kmen) a h_{200}/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 zabranuje použití metod porovnávání dílčích variant výchovy (obr. 16). 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 m²/ha na sérii Mostek do 47,4 m²/ha 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 – úrovněvá a podúrovněvá) 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 10–45 % 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 nej-silnějších stromů na hektar) byla ovlivněna pozitivně, tj. konečná hodnota štíhlostního kvocientu (středního kmene i horního stromového patra) byla principiálně nižší (o 1 až 10 %) na vychovávaných plochách ve srovnání s plochami bez výchovy (tab. 9). Výjimku tvořily 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 až 4 % vyšší ve srovnání s plochami kontrolními.

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