# Norway spruce thinning experiment Polom (Eastern Bohemia) after 22 years of observation

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**ABSTRACT**: Effects of thinning were studied in an air-polluted young stand of Norway spruce on Polom series in the Orlické hory Mts. (North-Eastern part of the Czech Republic) founded in 1980 in 15 years old spruce stand established by planting with density of 3,500–4,000 trees per hectare in 1965. The stand lies at an elevation of 800 m in the 6$^{th}$ beech with spruce forest vegetation zone. The expected survival of the experimental stand at the beginning of experiments was 40 years (air pollution danger zone B). The thinning experiment is based on a classical comparative method, i.e. on comparing the stands with different thinning regimes (regime with no thinning and regimes with heavy and very heavy first thinning with negative selection from below). Results of the long-term experiment confirmed the positive effect of investigated thinning programme on growth, health condition and resistance to snow-breaks of air-polluted Norway spruce stands in initial phases of disintegration.

**Keywords**: Norway spruce; air pollution; thinning; health condition; snow damage

All forests in the Czech Republic (2.6 mil. ha) are afflicted by anthropogenic activities, mainly by air and soil pollution. About 57% (1.4 mil. ha) of this area are forest stands with visible symptoms of injury, but mostly in initial phases of disintegration (1.23 mil. ha). They are mainly stands of Norway spruce (*Picea abies* [L.] Karst.) prevailing especially in mountain areas of Bohemia. In addition, Norway spruce stands on hills and at mountainous sites at an elevation of 500–800 m are endangered by snow damage and, at a higher elevation, by rime and frost deposits.

Though the air-pollution situation in the Czech Republic has changed in the last decade due to desulphurisation of main thermal power stations (e.g. the concentration of sulphur dioxide decreased from 2 million t in 1988 to ca 270 thousand t in 1999), the load of other pollutants, especially nitrogen, is still considerable. Expected regeneration of the majority of forest ecosystems is slow and the problems associated with the health condition of forest stands will probably continue. Appropriate thinning treatments are therefore expected to increase resistance to air pollution as well as resistance to other relevant stresses.

A very important measure of stabilisation of these stands with lower degree of injury is thinning based on three formerly defined main principles (SLODIČÁK 1996): a) the principle of individual selection, b) the principle of improved growing conditions and c) the principle of mutual shelter.

The first principle of selection is based on the fact that a part of individuals are as a rule damaged heavily and, on the other hand, some only slightly damaged trees can survive even in a strongly afflicted disintegrating forest stand. This individual tolerance of trees can be used for selection by thinning provided that the stands were established at a sufficient initial density (at least 4–5 thousand plants per hectare).

The principle of improved growing conditions is understood as decreased competition in the crown space and rhizosphere, better temperature and moisture conditions and better access of light to more resistant trees left after thinning.

The last principle, the principle of mutual shelter, is in imaginary contradiction with the previous principle of improved growing conditions because the opening up of canopy is connected with the risk of higher penetration of air pollutants into the canopy and consequent decrease of mutual shelter effect. However, the increased air-pollution load at young age when the tree species are very vigorous does not cause any large-scale damage or growth depression. The penetration of pollution decreases due to the fast growth of target or substitute tree species at young age.

In spite of their importance long-term thinning experiments in air-polluted Norway spruce stands are relatively rare (RANFT 1968; TESAŘ 1976; CHROUST, SLODIČÁK 1989). The present paper analyses an experiment with thinning of air-polluted Norway spruce stands in the

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most afflicted area of North-Eastern Bohemia that has been investigated since the eighties.

## EXPERIMENT

Effects of thinning were studied in an air-polluted young stand of Norway spruce on Polom series in the Orlické hory Mts. founded in 1980 in 15 years old spruce stand that was established by 4 years old containerised plants at an irregular spacing with density of 3,500–4,000 trees per hectare in 1965. The stand lies on 5% north-western slope at an elevation of 800 m above sea level on Cambisol in the 6th beech with spruce forest vegetation zone. Mean annual temperature is 5ºC, the mean sum of precipitation is ca 1,000 mm. The long-term mean $SO_2$ concentration in the period of investigation varied around 30 μg/m$^3$. The expected survival of the experimental stand at the beginning of the experiments was 40 years (air pollution danger zone B).

The experimental series is fenced. Trees on comparative plots are numbered. The thinning series consists of three comparative plots 40 × 25 m in size. The area of one comparative plot is 0.1 ha. Each comparative plot is divided into ten blocks by 100 m$^2$. For the statistical evaluation of measured data, comparative plots were divided into 3 partial plots consisting of 3 blocks. The most extreme was block omitted from evaluation.

The thinning experiment is based on a classical comparative method, i.e. on comparing the stands with different thinning regimes including the regime with no thinning (control plot).

Diameters of stems at b.h. of all individuals are measured with mm calliper annually and the height with poles periodically on representative sets of trees on every plot. The health condition of experimental stands was assessed on the basis of foliage in 1982 and 1984 on 10% scale. Since 1987 the health condition was assessed annually. Foliage damage was divided into three classes: healthy trees having 100 and 90% foliage (needle loss up to 10%), slightly and medium damaged trees having 80 and 70% foliage (needle loss 20 and 30%) and heavily damaged trees having 60% and less foliage (needle loss 40% and more).

Development and growth of experimental stands were investigated on the number of trees (*N*) and BA (*G*), health condition on mean foliage and on the number of healthy trees and resistance to stem-breaks on the ratio of slenderness of dominant trees (*h/d* ratio of 200 thickest trees per hectare). Acquired data were evaluated using software system UNISTAT®: number of healthy trees by heterogeneity of regression test and other data sets (e.g. *h/d* ratio) by parametric *t*-test.

### Thinning programmes

Comparative plot 1 is a control plot without intentional thinning. Programme 2 with heavy thinning with negative selection from below in five-year periods recommended

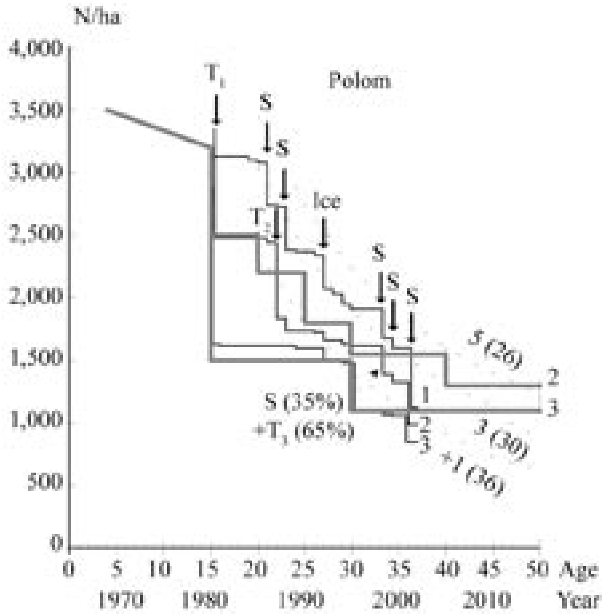


Fig. 1. Number of trees (thin black lines) and thinning programmes (thick grey lines) on partial plots of Polom experiment compared to yield tables (1996). Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below, T – thinning, S – snow damage, Ice – ice damage

by CHROUST (1976) for spruce stands endangered by snow is tested on comparative plot 2 and programme 3 based on one very heavy low thinning at the young age and longer periods recommended by TESAŘ (1976) for air-polluted spruce stands is applied to the stand on comparative plot 3 (Fig. 1). The first experimental thinning on comparative plots 2 and 3 was carried out at the age of 15 years (in 1980), the second low treatment on plot 2 at the age of 22 years (in 1987) and the third high treatment at the age of 33 years (1998). The second low thinning on comparative plot 3 was done at the age of 30 years (1995).

### Progress of experiment

Experiment on the first series Polom started in 1980. The initial number of trees (per hectare) ranged from 2,950 on plot 3 to 3,150 on plot 1. The stand density on comparative plot 2 was reduced by thinning with negative selection from below from 3,110 to 2,490 trees (removed 20% *N* and 16% *G*). The second thinning in 1987 (negative selection from below) was postponed by 2 years against the programme and joined the third one planned in 1990. The number of trees decreased to 1,830 in this treatment (removed 25% *N* and 18% *G*). The last thinning at the age of 33 years (1998) was carried out by removing 230 trees (14% *N*, 13% *G*) by positive selection from above. The programme on comparative plot 3 started by opening the canopy and loosening the crowns of trees by very heavy thinning. The number of trees decreased by negative selection from below from initial 2,950 to 1,630, i.e. by 45%, which amounted to

Table 1. Basic data on Polom experimental series in the Orlické hory Mts. (Eastern Bohemia)

| Polom | | 1980 15 years before thinning | T | *T*% | after thinning | SC | 1987 22 years before thinning | T | *T*% | after thinning | SC | 1995 30 years before thinning | T | *T*% | after thinning | SC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *N* (trees /ha) | 3,150 | 0 | 0 | 3,150 | 420 | 2,730 | | 0 | 2,730 | 820 | 1,910 | 0 | 0 | 1,910 | 0 |
| 2 | | 3,110 | 620 | 20 | 2,490 | 50 | 2,440 | 610 | 25 | 1,830 | 200 | 1,630 | 0 | 0 | 1,630 | 10 |
| 3 | | 2,950 | 1,320 | 45 | 1,630 | 10 | 1,620 | 0 | 0 | 1,620 | 140 | 1,480 | 380 | 26 | 1,100 | 0 |
| 1 | *G* ($m^2$ /ha) | 10.7 | 0.0 | 0 | 10.7 | 1.5 | 24.6 | 0.0 | 0 | 24.6 | 6.8 | 30.2 | 0.0 | 0 | 30.1 | 0.0 |
| 2 | | 9.3 | 1.5 | 16 | 7.8 | 1.9 | 22.0 | 4.0 | 18 | 18.0 | 2.2 | 29.1 | 0.0 | 0 | 29.1 | 0.1 |
| 3 | | 10.3 | 4.0 | 39 | 6.3 | 0.0 | 18.7 | 0.0 | 0 | 18.7 | 1.9 | 29.3 | 4.8 | 16 | 24.4 | 0.0 |
| 1 | *d* (cm) | 6.6 | 0.0 | | 6.6 | 6.7 | 10.7 | 0.0 | | 10.7 | 10.3 | 14.2 | 0.0 | | 14.2 | 0.0 |
| 2 | | 6.2 | 5.5 | | 6.3 | 8.2 | 10.7 | 9.2 | | 11.2 | 11.9 | 15.1 | 0.0 | | 15.1 | 11.3 |
| 3 | | 6.7 | 6.3 | | 7.0 | 0.0 | 12.1 | 0.0 | | 12.1 | 13.1 | 15.9 | 12.7 | | 16.8 | 0.0 |
| 1 | *h* (m) | 4.9 | 0.0 | | 5.0 | 4.8 | 9.2 | 0.0 | | 9.2 | 9.0 | 13.1 | 0.0 | | 13.1 | 0.0 |
| 2 | | 4.5 | 4.2 | | 4.6 | 5.5 | 8.8 | 8.1 | | 9.1 | 9.4 | 13.3 | 0.0 | | 13.3 | 11.0 |
| 3 | | 5.0 | 4.9 | | 5.1 | 0.0 | 9.2 | 0.0 | | 9.2 | 9.5 | 13.2 | 11.4 | | 13.6 | 0.0 |
| 1 | *h/d* | 74 | | | 76 | 71 | 86 | | | 86 | 88 | 92 | | | 92 | |
| 2 | | 73 | 77 | | 72 | 67 | 82 | 88 | | 81 | 79 | 88 | | | 88 | 97 |
| 3 | | 75 | 78 | | 73 | | 76 | | | 76 | 73 | 83 | 90 | | 81 | |

| Polom | | 1998 33 years before thinning | T | *T*% | after thinning | SC | 2001 36 years before thinning | T | *T*% | after thinning | SC | 2002 37 years before thinning | *SC* 15–37 years | *I* 15–37 years | *I* –*SC* | *T* 15–37 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *N* (trees /ha) | 1,910 | 0 | 0 | 1,910 | 310 | 1,600 | 0 | 0 | 1,600 | 480 | 1,120 | 1,550 | | | |
| 2 | | 1,620 | 230 | 14 | 1,390 | 60 | 1,330 | 0 | 0 | 1,330 | 340 | 990 | 320 | | | 1,460 |
| 3 | | 1,100 | 0 | 0 | 1,070 | 40 | 1,060 | 0 | 0 | 1,060 | 210 | 850 | 190 | | | 1,700 |
| 1 | *G* ($m^2$ /ha) | 34.2 | 0.0 | 0 | 34.2 | 3.9 | 35.9 | 0.0 | 0 | 35.9 | 9.5 | 28.3 | 21.7 | 37.4 | 15.7 | |
| 2 | | 32.4 | 4.3 | 13 | 28.2 | 5.1 | 32.4 | 0.0 | 0 | 32.4 | 6.4 | 28.0 | 14.1 | 40.6 | 26.5 | |
| 3 | | 27.6 | 0 | 0 | 27.2 | 0.2 | 32.3 | 0.0 | 0 | 32.3 | 5.1 | 28.1 | 7.2 | 33.3 | 26.1 | |
| 1 | *d* (cm) | 15.1 | 0.0 | | 15.1 | 12.7 | 16.9 | 0.0 | | 16.9 | 15.9 | 17.9 | | 10.3 | | |
| 2 | | 16.0 | 15.3 | | 16.1 | 32.9 | 17.6 | 0.0 | | 17.6 | 15.5 | 19.0 | | 10.7 | | |
| 3 | | 17.9 | 0.0 | | 18.0 | 8.0 | 19.7 | 0.0 | | 19.7 | 17.6 | 20.6 | | 11.7 | | |
| 1 | *h* (m) | 14.6 | 0.0 | | 14.7 | 13.1 | 16.0 | 0.0 | | 16.0 | 15.8 | 16.3 | | 10.9 | | |
| 2 | | 14.7 | 14.3 | | 14.8 | 20.6 | 16.2 | 0.0 | | 16.2 | 15.0 | 16.6 | | 11.2 | | |
| 3 | | 15.1 | 0.0 | | 15.1 | 8.8 | 16.8 | 0.0 | | 16.8 | 15.8 | 17.0 | | 11.3 | | |
| 1 | *h/d* | 97 | | | 97 | 103 | 95 | | | 96 | 100 | 91 | | | | |
| 2 | | 92 | 93 | | 92 | 63 | 92 | | | 92 | 97 | 87 | | | | |
| 3 | | 84 | | | 84 | 110 | 85 | | | 85 | 90 | 83 | | | | |

1 – control plot without thinning, 2 – comparative plot with thinning programme 2, 3 – comparative plot with thinning programme 3, *N* – number of trees, *G* – basal area, *d* – diameter at breast height, *h* – mean height, *h/d* – ratio of slenderness, *T* – thinning, I – increment, *SC* – salvage cut

39% of BA. The treatment was repeated according to the programme after the period of 15 years, i.e. at the age of 30 years again by negative selection from below removing 26% *N* and 16% *G* (Table 1).

During the period of investigations (1980–2002), the experimental stands were damaged five times by snow and once by ice deposit. The number of trees on parallel control plot 1 decreased in this period from initial 3,150 to 1,120 per hectare (by 64%), mainly as a result of the abovementioned snow-break and ice-break events in 1986, 1988, 1992, 1998, 1999 and 2001. Thinned stands on parallel comparative plot 2 and especially on plot 3 were damaged to a lesser extent mostly by ice-break in 1992 and snow-break in 2001 (Fig. 1).

## RESULTS

### Basal area (BA) of experimental stands

On the first series Polom, the stand BA before the first thinning amounted to the respective values 10.7 and 10.3 $m^2$ on comparative plots 1 and 3. The lowest initial BA was on plot 2 (9.3 $m^3$), but the differences were not significant.

The first experimental thinning decreased BA on comparative plot 2 to 7.8 $m^2$, i.e. to 73% of the control plot. Seven years later (the age of 22 years) when BA amounted to 89% of the control, the second thinning with negative selection from below was carried out decreasing BA to 73% of the control again. After an eleven-year period, BA of comparative plot 2 reached the level of control plot (95%) again and was cut down to 82% by positive selection from above removing 13% *G* and 14% *N*. Three years later (the age of 36 years) before the snow damage event in 2001, BA on this variant amounted to 32.4 $m^3$, i.e. 90% of the control.

The first experimental thinning decreased BA on comparative plot 3 to 6.3 $m^2$, i.e. 59% of the control plot. Consequent pronounced increment on plot 3 and several events of snow damage on plot 1 resulted in nearly equal stocking before the second thinning at the age of 30 years (97% of the control plot). The second experimental thinning (for a second time by negative selection from below) decreased the stand BA on comparative plot 3 to 81% of the control plot (from 29.3 to 24.4 $m^2$), but six years later, the stocking of thinned plot was 90% of the control again.

Because the last snow-break event in 2001 (Fig. 4) damaged the control plot to a larger extent, the stand BA on all three comparative plots after damage showed similar values 26.4, 26.0 and 27.2 $m^2$ (Fig. 2).

After including the BA of all removed trees (i.e. including salvage cut), the BA increment in the period of investigations was highest on comparative plot 2 (40.6 $m^2$), followed by the increment on control plot 1 (37.4 $m^2$) and the lowest increment of BA was observed on heavily thinned plot 3 (33.3 $m^2$).

But on control plot 1, 21.7 $m^2$ of BA (58% of the increment) had to be removed during the period of investigations as salvage cut (breaks, dry trees, etc.) whereas salvage cut on the plot thinned by programme 2 amounted to 14.1 $m^2$ (35% of the increment) and on the plot thinned by programme 3 salvage cut amounted only to 7.2 $m^2$ (i.e. 22% of the increment).

When BA included only intentionally removed trees (salvage cut excluded), the BA increment in the period of investigations (age of 15–37 years) amounted to 15.7 $m^2$ on control plot 1 and to 26.5 and 26.1 $m^2$ on thinned comparative plots 2 and 3, i.e. thinning programmes 2 and 3 resulted in 69% and 66% higher production of marketable wood compared to the control plot without thinning even in these adverse growing conditions.

Generally, the stand BA growth on all three investigated comparative plots did not show any visible growth depressions. Growth data are comparable with the mean site indexes which correspond with the site conditions of the experimental stands (elevation of 800 m above sea level, Cambisols, 6[th] beech with spruce forest vegetation zone, mean annual temperature 5ºC, the mean sum of precipitation ca 1,000 mm).

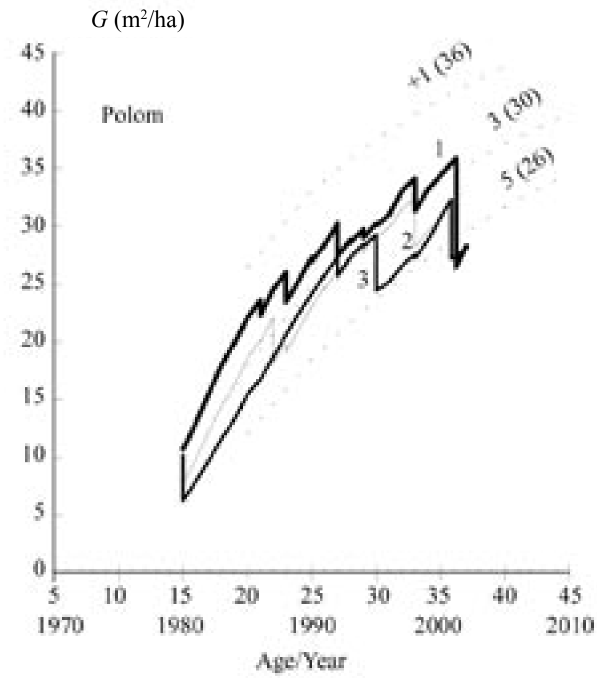


Fig. 2. Basal area of experimental stands on Polom thinning series in the Orlické Mts. compared with growth tables (1996). Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below

### Resistance to snow damage

As air-polluted Norway spruce stands grow frequently in localities endangered by wet snow or wind, an acceptable thinning regime must increase the resistance of trees to stem-breaks, which is the most common form of damage caused by snow and partly by wind.

Effects of investigated thinning programmes on the stance of experimental Norway spruce stands were found statistically significant, especially on thinning variant 3 (Fig. 3). At the beginning of investigations (age of 15 years), the ratio of slenderness (*h*/*d* ratio) of initially equal 200 dominant trees on the series Polom had the same value ca 66 on all three comparative plots. Both thinning programmes, but mainly programme 3 with opening up the canopy, resulted in improved diameter growth and consequently in a slower increase of the *h*/*d* ratio of investigated trees on thinned comparative plots 2 and 3 compared to initially equal trees on control plot 1 without thinning (final values at the age of 36 years on plot 1, 2 and 3 were 90, 85 and 80). Differences were found statistically significant on the most heavily thinned plot 3 in all revised periods and on plot 2 five years after the first thinning and at the age of 30 years (1995).

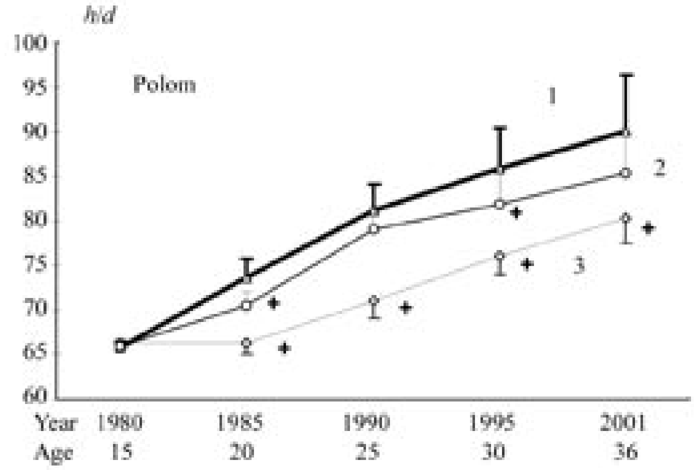


Fig. 3. *h/d* ratio of 200 dominant trees on partial plots of Polom experiment in 1980–2001. Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below, + – statistically significant differences ($\alpha = 0.01$)

Higher static stability of thinned variants was confirmed in the last snow-break event in 2001 (Fig. 4) when 480 trees (per hectare), i.e. 9.5 $m^2$ of BA, were damaged on the control plot while on thinned variants 2 and 3, snow destroyed 340 and 210 trees (6.4 and 5.1 $m^2$ of BA). Trees destroyed by snow mostly belonged to lower tree classes with *h*/*d* ratio higher than the particular mean value for the diameter class.

### Health condition of experimental stands

Dynamic BA increments are in contradiction with the deteriorating health condition of investigated Norway spruce stands. The mean foliage of experimental stands at the beginning of observations in 1982 decreased to ca 90% on all three comparative plots (insignificant differences). The foliage of experimental stands showed a more pronounced decreasing tendency on control plot 1 without thinning (minimum 75% in 1997). Since 1990, the differences between mean foliage on control plot 1 and thinned plots 2 and 3 varied around 5% in favour of thinned plots and they were statistically significant (Fig. 5).

The number of relatively healthy trees with foliage 100 and 90% is a more precise indicator of health condition in young developing forest stands (Fig. 6).

At the beginning of observations, relatively healthy trees on control plot 1 outnumbered healthy trees on thinned plots (2,078 individuals on the control plot, 1,750 and 922 individuals on thinned plots 2 and 3). But the number of healthy trees on control plot and on the plot with thinning programme 2 continually decreased to 1,122 (1) and 933 (2) in the next ca 10 years of investigations, whereas the number of healthy trees in heavily thinned stands of plot 3 showed a slightly increasing tendency in the same time (from initial 922 to 1,089).

The effect of thinning on growth conditions of experimental stands vanished 13 years after the first treatment in 1993 when the stocking of thinned plots 2 and 3 amounted to 96 and 97% of the control plot. Further development of the number of healthy trees is therefore similar on all

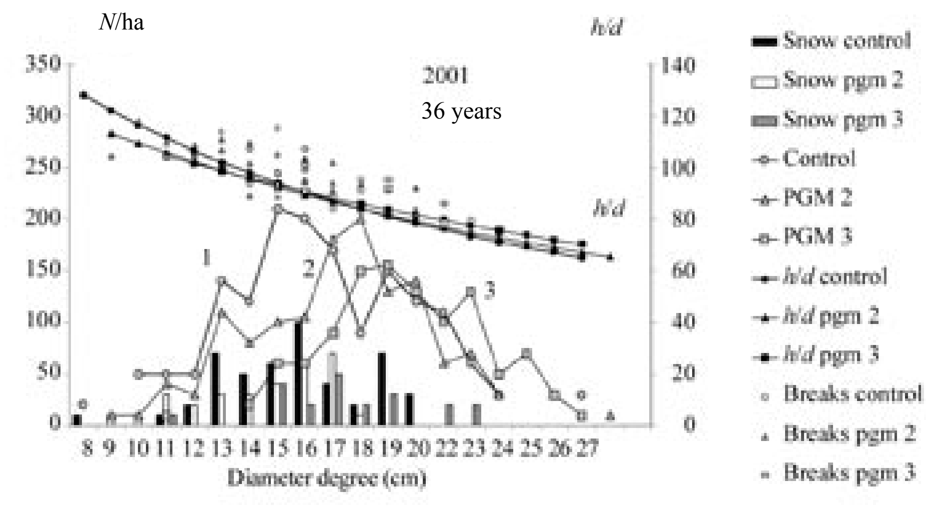


Fig. 4. Diameter structure of experimental stands (lower lines and left axis) and structure of snow-breaks (columns) on partial plots with different thinning programmes on Polom series in 2001 at the age of 36 years. Upper lines show *h/d* ratios for particular diameter classes and marked points the *h/d* ratio of the particular snow-breaks. Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below

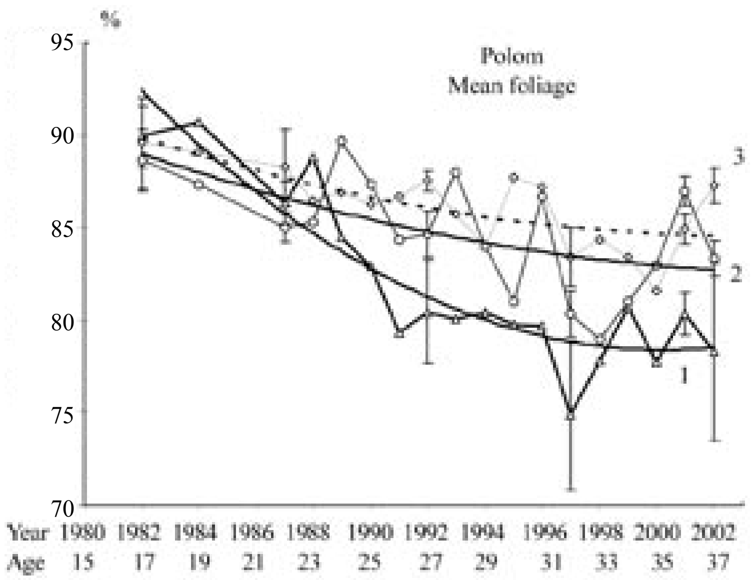


Fig. 5. Mean foliage on partial plots of Polom experiment in 1982–2002 (age 17–37 years). Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below

comparative plots and was not influenced by the second treatment in 1995 (Fig. 7).

## DISCUSSION AND CONCLUSIONS

Conclusions about the possibility of using thinning programmes as measures to slow down the disintegration of spruce stands under the air pollution stress were drawn on the one hand as a result of empirical experience with thinning outside of air-polluted areas (e.g. MATERNA et al. 1957) and, on the other hand, they were drawn from experiments in specific conditions of heavily damaged areas of the Krušné hory Mts. (RANFT 1968) and in conditions of local source of emissions in the 5th beech with fir forest vegetation zone (TESAŘ 1976). The presented results confirmed the importance of thinning in air-polluted areas for growing conditions of the 6th beech with spruce forest vegetation zone, where spruce stands with a lower degree of injury prevail. Therefore the necessity of specific thinning programmes is especially urgent in these areas.

The positive influence of thinning on tree increments in conditions of air pollution as well as on their resistance to snow and wind breaks found in the experiments is in accordance with the results of experiments founded in the 5th beech with fir forest vegetation zone (TESAŘ 1976; CHROUST 1991).

On the basis of new experimental data, several points of thinning programmes have been specified, namely the time of the first treatment and the intensity of the treatments. The thinning programmes based on a reduction in the number of trees to 2–2.5 thousand trees per ha at the age of 24–25 years (TESAŘ 1976) or the initial density 2.5 thousand trees per ha and the first heavy treatment in the period when the top height is 10 m (CHROUST 1991) were found insufficient in air-polluted Norway spruce stands in the 6th beech with spruce forest vegetation zone because they did not stop the process of stand disintegration and did not stabilise the stand against snow-breaks (SLODIČÁK 1992, 1994; SLODIČÁK, NOVÁK 2000, 2001). On the other hand, experimental thinning programme 3

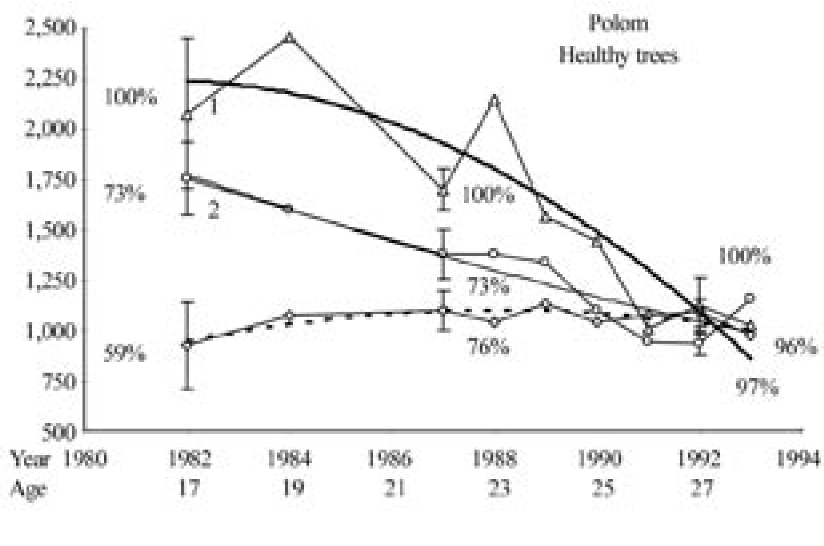


Fig. 6. Number of healthy trees on partial plots of Polom experiment in 1982–1993 (age 17–28 years). Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below. Percent numbers show stocking on basal area (BA of control plot = 100%)

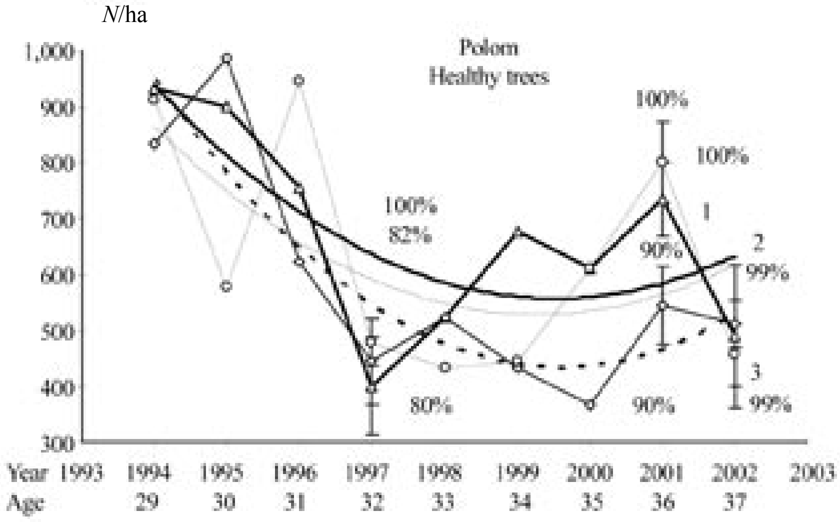


Fig. 7. Number of healthy trees on partial plots of Polom experiment in 1994–2002 (age 29–37 years). Notes: 1 – control plot, 2 – plot with medium low thinning, 3 – plot with heavy thinning from below. Percent numbers show stocking on basal area (BA of control plot = 100%)

based on very heavy thinning from below resulted in full elimination of snow-breaks in the period of 15 years after treatment on the series Polom (small damage in 1992 was caused by ice-break) and stopped the process of stand disintegration as the mean foliage of thinned stands was significantly higher and the number of healthy trees was stabilised.

At the same time, very heavy thinning according to the investigated programme did not cause any significant production losses. When including salvage cut, BA increment in the period of investigation (the age of 15–37 years) was 12% higher on the control plot without thinning compared to plot thinned by programme 3. But after excluding salvage cut (mostly unmarketable dead and broken trees), BA increment of heavily thinned plot 3 overreached the control by 10.4 $m^2$ (66%).

The following conclusions can be drawn on the basis of evaluation of thinning effects on air-polluted Norway spruce stands of Polom experimental series in the Orlické hory Mts.:

– Positive effects of thinning on the growth of air polluted Norway spruce stands were observed. In the period of investigations the BA of the control stand without thinning increased by 147% (15.7 $m^2$) on Polom series (the age of 15–37 years) whereas the BA of thinned stands 2 and 3 increased by 285 and 253% (26.5 and 26.1 $m^2$) at the same time.
– Very heavy thinning with negative selection from below had the positive effect on resistance to stem-breaks even in air pollution danger zone B. The ratio of slenderness (*h/d* ratio) of dominant trees in thinned stands significantly differed from control stands without thinning.
– Deterioration of the health condition of investigated stands was found. The mean foliage of all comparative stands and the number of relatively healthy trees in the stands decreased.
– The investigated thinning programmes based on heavy low thinning resulted in significantly higher foliage of thinned stands compared to the control stand without thinning.
– Investigated thinning programme 3 based on very heavy low thinning in the period of canopy creation slowed the process of disintegration of thinned stand. The number of relatively healthy trees (with foliage 100–90%) was stable in the stand thinned by programme 3 while it decreased on the control plot without thinning and on the plot with thinning programme 2 with medium treatments.
– The period of stabilisation continued in the stand thinned by programme 3 from the beginning of observations to 1993 (i.e. 11 years) when it expired with increased stocking.

It can be concluded from the results presented above that thinning with negative selection from below can be used to improve the health condition and resistance to abiotic factors (especially snow and ice-breaks) of young Norway spruce stands even in extreme growing conditions of air pollution danger zone B with the expected survival of mature Norway spruce stands 21–40 years since the beginning of air pollution stress. Thinnings in spruce stands affected by air pollution are recommended to start at the young age, in the period of canopy closure (TESAŘ 1976; SLODIČÁK 1988, 1992; CHROUST, SLODIČÁK 1989; SLODIČÁK, NOVÁK 2000, 2001) and this first treatment must be very heavy.

A temporarily increased air-pollution load after opening the canopy by thinning at the young age when the trees are very vigorous does not cause any large damage or growth depression. Due to the fast growth of more resistant individuals left after thinning, the penetration of pollution decreases. Later on, when the vitality of individuals falls, a special emphasis must be laid on the principle of mutual shelter, e.g. on low thinning intensity.

Except the air pollution stress, Norway spruce mountain forests are heavily endangered by snow, ice and wind. Preventive measures against these harmful factors are based on keeping the most endangered young Norway spruce stands in loose canopy. This silvicultural practice is accepted in Central Europe as a mean of stabilisation against damage caused by abiotic factors – snow and wind (e.g. CHROUST 1968, 1980; PERSSON 1969; ABETZ 1976;

KRAMER 1980; JOHANN 1980, 1981). After the individual stability of trees has been established, the decreased thinning intensity continually results in full canopy and mutual support of stable individuals. Consequently, the thinning principles for air-polluted Norway spruce stands are in accordance with the thinning principles recommended for spruce stands endangered by snow and wind.

On the basis of the above-mentioned principles, thinning programmes were elaborated for the most endangered spruce stands differentiated on the level of danger by abiotic factors, air pollution, site conditions and some other factors. Proposed thinning programmes respect the positive shift of health condition on the prevailing forest area of the Czech Republic compared to the end of the eighties as well as new growth trends in the last 20 years (higher increment especially in young stands). Presented model programmes are based on the top height defined as the height of 200 thickest trees per hectare and they are compared with growth tables (ČERNÝ et al. 1996). Thinning programmes were drawn up using the results from the project *Silviculture in Ecotopes Disturbed by Human Activities* (SLODIČÁK, NOVÁK 2000, 2001).

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# Experiment s výchovou smrku Polom (východní Čechy) po 22 letech sledování


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**ABSTRAKT**: Vliv výchovy byl studován v mladém imisemi ovlivněném porostu smrku ztepilého na výzkumné řadě Polom v Orlických horách. Experiment byl založen v roce 1980 v patnáctileté smrkové mlazině vzniklé výsadbou v nepravidelném sponu s hustotou 3 500–4 000 sazenic na hektar v roce 1965. Výzkumná řada se nachází v nadmořské výšce 800 m v 6. smrko-bukovém vegetačním stupni. Na počátku experimentu se porost nacházel v pásmu ohrožení imisemi B. Experiment je založen na klasické srovnávací metodě, tj. porovnávání porostů s různým režimem výchovy (kontrola bez zásahu, režim se silnými a režim s velmi silnými podúrovňovými zásahy). Výsledky dlouhodobého experimentu potvrdily pozitivní efekt zkoumaných výchovných programů na růst a zdravotní stav smrkových porostů v počátečních fázích poškození imisemi a jejich odolnost vůči sněhovým polomům.

**Klíčová slova**: smrk ztepilý; imise; výchova; zdravotní stav; škody sněhem

Očekávaná regenerace většiny lesních ekosystémů v České republice po odsíření hlavních elektráren je pomalá a problémy se zdravotním stavem budou pravděpodobně pokračovat. Současně jsou smrkové porosty pod vlivem imisí v podhorských a horských polohách v nadmořských výškách 500–800 m ohrožovány sněhem a v nadmořských výškách nad 800 m námrazou. Výchova smrkových porostů v těchto lokalitách je proto orientována na zvýšení odolnosti vůči imisím a také vůči ostatním škodlivým faktorům – především sněhu a námraze.

Efekt výchovy byl studován od roku 1980 v mladých smrkových porostech pod vlivem imisí na experimentální sérii Polom v Orlických horách. Porost vznikl z výsadby čtyřletých obalovaných sazenic v roce 1965 v původní hustotě 3,5–4 tisíce jedinců na hektar. Experimentální řada leží na mírném (5%) svahu se SZ expozicí na kambizemi v nadmořské výšce 800 m (SLT 6K). Průměrná roční teplota dosahuje 5 °C, úhrn ročních srážek 1 000 mm. Dlouhodobá průměrná koncentrace $SO_2$ se v období sledování experimentu pohybovala kolem 30 μg/m$^3$.

Očekávaná životnost experimentálních porostů byla v době založení pokusu 40 let (pásmo ohrožení imisemi B). Experiment je založen na klasické srovnávací metodě, tj. srovnávají se porosty s různým režimem výchovy (kontrola bez zásahu, režim se silnými a režim s velmi silnými podúrovňovými zásahy). Série je tvořena třemi srovnávacími plochami o velikosti 40 × 25 m dělenými na 10 opakování (bloků) o velikosti 0,01 ha.

Vývoj a růst různě vychovávaných porostů (srovnávacích ploch 1, 2 a 3) je dlouhodobě sledován pomocí každoročního zjišťování počtu stromů ($N$) a výčetní kruhové základny ($G$), zdravotního stavu (průměrné olistění a počet zdravých stromů) a odolnosti vůči zlomům (štíhlostní kvocient horního stromového patra, tj. 200 nejsilnějších jedinců na hektar). Naměřená data byla vyhodnocována pomocí statistického softwaru UNISTAT® (vývoj počtu zdravých stromů regresní analýzou a ostatní data parametrickým *t*-testem).

Srovnávací plocha 1 je ponechána jako kontrolní, tj. bez úmyslných těžebních zásahů. Porost na srovnávací ploše 2 je vychováván podle programu navrženého pro porosty ohrožené abiotickými činiteli (CHROUST 1976) a na srovnávací ploše 3 je uplatňován výchovný režim založený na velmi silném zásahu s negativním výběrem v podúrovni doporučovaný TESAŘEM (1976) pro smrkové porosty pod vlivem imisí.

První experimentální zásahy na srovnávacích plochách 2 a 3 byly provedeny ve věku porostu 15 let (1980) negativním výběrem v podúrovni. Na srovnávací ploše 2 byl druhý zásah s negativním výběrem v podúrovni opakován po sedmi letech ve věku 22 let (1987) a třetí zásah s pozitivním výběrem v úrovni ve věku 33 let (1998). Na srovnávací ploše 3 byl druhý zásah negativním výběrem v podúrovni proveden až po 15 letech ve věku 30 let (1995). Síla zásahů a jejich načasování jsou zřejmé z obr. 1 a 2 a z tab. 1.

V průběhu sledování experimentu (1980–2002) byly porosty pětkrát poškozeny sněhem a jednou námrazou (sníh v letech 1986, 1988, 1998, 1999 a 2001, námraza v roce 1992). Počet stromů na kontrolní ploše 1 klesl v tomto období z původních 3 150 na 1 120 na hektar (o 64 %) hlavně v důsledku zmíněného poškození. Porosty s výchovou na plochách 2 a 3 byly poškozeny v mnohem menší míře převážně námrazou v roce 1992 a sněhovým polomem v roce 2001 (obr. 1 a 4).

Vliv sledovaných výchovných programů na odolnost experimentálních porostů vůči poškození sněhem byl shledán statisticky významným zvláště na variantě 3 s uvolněným zápojem (obr. 3). Oba výchovné programy – hlavně však program 3 – podpořily tloušťkový přírůst a tím zpomalily nárůst štíhlostního kvocientu dominantních stromů (200 nejsilnějších stromů na hektar) ve srovnání s porostem na kontrolní ploše 1 (finální hodnoty kvocientu na srovnávacích plochách 1, 2 a 3 dosáhly 90, 85 a 80). Rozdíly byly statisticky signifikantní na ploše 3 při všech revizích a na ploše 2 po prvním zásahu ve věku do 30 let (1995).

Na přírůstu výčetní kruhové základny všech tří sledovaných porostů nebyla zjištěna růstová deprese. Údaje o výčetní základně jsou srovnatelné s tabulkovými daty pro průměrné bonity.

Dynamický přírůst výčetní kruhové základny je v protikladu se zhoršujícím se zdravotním stavem sledovaných porostů. Průměrné olistění experimentálních porostů bylo na počátku sledování při první klasifikaci v roce 1982 90 % na všech třech srovnávacích plochách (rozdíly statisticky nevýznamné). V dalším období bylo zaznamenáno snižování olistění (pokračující defoliace) experimentálních porostů, které bylo nejvíce patrné na kontrolní ploše 1 (minimum 75 % v roce 1997). Od roku 1990 byly rozdíly v průměrném olistění mezi kontrolou a plochami 2 a 3 s výchovou kolem 5 % a byly statisticky signifikantní (obr. 5 a 6).

Vliv výchovy na růstové poměry sledovaných porostů vymizel 13 let po prvním výchovném zásahu v roce 1993, kdy zakmenění na plochách 2 a 3 s výchovou dosáhlo 96 a 97 % kontrolní plochy. Další vývoj zdravotního stavu (průměrné olistění, počet zdravých stromů) byl tedy podobný na všech třech srovnávacích plochách. Druhý slabší zásah na ploše 3 se již na zdravotním stavu sledovaného porostu neprojevil (obr. 7).

Na základě vyhodnocení dlouhodobého efektu silných podúrovňových zásahů ve smrkových porostech na sérii Polom v Orlických horách lze konstatovat:

– Ve sledovaných smrkových porostech série byl zjištěn velmi dobrý růst výčetní kruhové základny ve srovnání s růstovými modely (ČERNÝ et al. 1996). Silné podúrovňové zásahy dlouhodobě ovlivnily růst sledovaných smrkových porostů. Výčetní kruhová základna kontrolního porostu (bez výchovy) se za 22 let sledování zvýšila o 147 % (15.7 $m^2$), zatímco ve vychovávaných porostech 2 a 3 se za stejnou dobu zvýšila o 285 a 253 % (26,5 a 26,1 $m^2$).

– Byl doložen dlouhodobý pozitivní efekt silných podúrovňových zásahů na zvyšování odolnosti smrkových porostů vůči zlomům. Štíhlostní kvocient dominantních stromů (horního stromového patra) vykazoval příznivější (nižší) hodnoty v porostech s výchovou ve srovnání s porostem bez výchovy.

– Ve sledovaných porostech bylo zaznamenáno postupné zhoršování zdravotního stavu vyjádřené poklesem hodnot průměrného olistění. Velmi silné podúrovňové zásahy měly dlouhodobý příznivý efekt na vyšší olistění vychovávaných porostů ve srovnání s porosty bez výchovy.

Z uvedených závěrů vyplývá, že silné podúrovňové zásahy lze použít pro zlepšení zdravotního stavu a odolnosti vůči abiotickým činitelům v mladých smrkových porostech rostoucích ve specifických podmínkách horského prostředí (imise, škody sněhem, větrem a námrazou). S výchovou smrkových porostů pod vlivem imisí je třeba započít v mladém věku, kdy se porosty zapojují (TESAŘ 1976; SLODIČÁK 1988, 1992; CHROUST, SLODIČÁK 1989; SLODIČÁK, NOVÁK 2000, 2001) a první zásah by měl být velmi intenzivní. Tato strategie je ve shodě s preventivními opatřeními vůči škodám sněhem, větrem a námrazou, tj. pěstování mladých smrkových porostů ve volném zápoji (CHROUST 1980; PERSSON 1969; ABETZ 1976; KRAMER 1980; JOHANN 1980, 1981). Po vybudování individuální stability stromů se již intenzita výchovných zásahů snižuje a porosty jsou nadále pěstovány v plném zápoji.

Navrhované zásady výchovy smrkových porostů pod vlivem imisí respektují současné podmínky v lesních ekosystémech včetně nově zaznamenávaných růstových trendů (zvyšování přírůstu především mladých porostů).

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