Development of spruce (*Picea abies* [L.] Karst.) target (crop) trees in pole-stage stand with different initial spacing and tending regime

I. Štefančík

National Forest Centre – Forest Research Institute in Zvolen, Zvolen, Slovak Republic

Department of Silviculture, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, Prague, Czech Republic

ABSTRACT: This paper presents findings of a twenty-year investigation of silviculture-production in a 40-year-old afforested spruce pole-stage stand located in a mountain region. The stand was established by four different spacing models: (i) 1.5 × 1.0 m, (ii) 2.5 × 1.0 m, (iii) 2.5 × 1.5 m, and (iv) 2.5 × 2.5 m. Three alternatives were studied for each of these spacing models. These were: (i) geometrical (line) thinning, (ii) selective thinning and (iii) no tending. During the period of our research the above-mentioned stand was affected twice by a snow-break disaster. Promising and target trees in the stand were marked and selected at the beginning of the study. The development of the above-mentioned categories of trees was analysed in relation to the initial spacing of the stand, as well as to the method of tending. Based on the 20-year research period, we conclude that the most favourable results were obtained on plots that were established at a wider initial spacing and managed by selective thinning as opposed to the denser ones tended by geometrical thinning or without any tending.

Keywords: Norway spruce, target trees, promising trees, different spacing, different tending

Tending of forest stands is regarded as a crucial silvicultural measure, since it requires a long time period, more than a half of rotation cycle, as a rule. There are numerous papers dealing with the development of spruce stands managed by various thinning methods (Pařez 1972; Jurča, Chroust 1973; Mráček, Pařez 1986; Saniga 1996; Chroust 1997; Slodičák, Novák 2007; Slodičák et al. 2010). Similarly, many papers compare different ways of tending (line thinning, selective and combined thinning, Chroust 1988; Holodynski 1995; Saniga 1996). The results of our long-term research, together with the results obtained by these authors, allow us to conclude that the primary aim of stand tending should be improving the stability of treated stands. Stand stability is considered as a crucial parameter, especially in pure spruce stands – because further development of these stands may be endangered by applying inappropriate interventions (delayed and of low intensity).

It is necessary to support the stand stability just in the youngest growth phases (thicket, small-pole stage) by application of crown thinning with positive selection, where, as a rule, trees with the largest diameter and the highest vitality are released and free development of their crowns is ensured (Slodičák et al. 2010). This can be achieved by the method of target (promising) trees – consisting in the selection and marking of a required number of trees, followed by releasing their crowns by applying positive interventions. For spruce small pole-stage stands, about 300–400 target trees per hectare are generally recommended, spaced at 5–6 m (Abetz 1979; Štefančík 1984; Schober 1990; Spellmann, Nagel 1996). In the case of the promising tree method, the twofold number of promising trees is desirable. These trees represent the "stand skeleton" ensuring the favourable static stability of the stand, with the slenderness quotient values under 0.80. Moreover, these trees are also the main bearers of the quantitative production of spruce stands (Štefančík, Štefančík 2000). Lower numbers of target trees are an exception, like approximately 100 individuals per hectare in Belgic stands, established at an initial spacing of 2.0 × 2.5 m, i.e. counting 2,000 trees per hectare.

Together with the choice of the most favourable tending (thinning) method and the number of target trees, the estimation of the optimum initial density of plants under the given conditions is crucial for the rational management of spruce stands. An appropriate attention has been devoted to these issues equally abroad (Braastad 1970; Prokopjev 1983; Razin 1991; Nilsson 1994) as well as in the Czech Republic and in Slovakia. The initial spacing and/or density of the established stands affected the subsequent development of these stands not only quantitatively (Kramer et al. 1971; Kairiukštis, Malinauskas 2001), but they also imposed effects on mechanical properties of trees (Brüchert et al. 2000) and their quantitative production parameters (Braastad 1979).

The objective of this paper was to analyse the development of target (promising) trees and to assess the changes related to their initial spacing and to the tending methods used for the study period of 20 years.

MATERIAL AND METHODS

The study was conducted in a spruce (*Picea abies* [L.] Karst.), small pole-stage stand established on the series of permanent research plots (PRP) Biely Váh-Luksová, located in the area of the Biely Váh Forest District, Liptovský Hrádok Forest Enterprise. The PRPs were established with the purpose to find out the optimum number of plants per hectare in the initial stage of spruce stand development. The detailed description of the PRPs Biely Váh-Luksová is presented in Table 1.

The PRPs series consists of 12 partial plots, each of an area 0.09 ha. Four plots were treated by line (geometric) thinning, another four by selective thinning – free crown thinning according to methods proposed by Štefančík (1984) and four plots were left without tending (control). Although, the above-mentioned thinning method is not so common in the spruce stands (especially at a young stage), its application was chosen to enhance the static stability. It is a generally known fact that the stability of spruce stands has to be supported in the earliest stage. Consequently, the selection of target (promising) trees with suitable dimensional requirements as to height and diameter including appropriate spacing should be considered suitable from this point of view. These trees are the skeleton of the stand, representing the best static stability parameters.

The partial plots differed in the initial spacing (A, B, C, D) and/or in the initial number of trees in three replications representing three different thinning methods. The plots situated in the first (lower) row labelled as A_1, B_1, C_1 and D_1 were tended by geometric (line) interventions. In a small part of

Table 1. Basic characteristics of the series of permanent research plots (PRP) in the Biely Váh-Luksová locality

Characteristic	PRP Biely Váh-Luksová
Establishment of PRP	1972
Age of stand (years)	20 (in 1990)
Site index	32
Geomorphologic unit	Kozie Chrbty
Exposition	North
Altitude (m)	1,100
Inclination (%)	14
Parent rock	limestones, dolomites
Soil unit	Rendzina on slope deposits of limestones and dolomites
Forest altitudinal zone	6^{th} spruce-beech-fir
Ecological rank	B (fertile mesophilous)
Management complex of forest types	611 – fertile fir-beech spruce woods
Forest type group	*Abieto-Fagetum* (AF) higher tier
Forest type	6302 nitrifying low-herbaceous fir beech woods (higher tier)
Average annual temperature (°C)	5.0
Sum of average annual precipitation (mm·year^{-1})	1,140

plot D_1, pruning was realized during the first measurement in 1990, unlike in the other parts of this plot. The plots in the second (middle) row labelled as A_2, B_2, C_2 and D_2 were left without interventions as controls. Finally, the plots situated in the third (upper) row, labelled as A_3, B_3, C_3 and D_3, were treated by the method of selective thinning. The PRPs layout with the individual spacing variants and its replications are shown in Fig. 1.

From the establishment of the PRPs (1972) up to 1990, i.e. at the stand age of 20 years, no silvicultural measures were applied. Then, three thinning interventions (1990, 1996 and 2000) together with biometrical measurements were accomplished and the obtained results were published (Štefančík, Štefančík 2002). At the turn of 2002 and 2003, the PRPs were affected by a snow-break. A lot of trees were damaged and/or removed, consequently, no tending was realised during the subsequent measurement carried out in 2005. Due to another snow-break occurring later and with serious consequences, the intervention planned in 2010 was not realised.

All the trees were numbered and marked at 1.3 m above the ground – in order to measure their diameter (DBH). Since 1990, comprehensive biometrical measurements have been carried out on the PRPs, in accordance with the standard methods developed for the long-term research on silviculture-production problems in thinning. These characteristics were measured: diameter $d_{1.3}$, tree height, crown base height, crown size; and silvicultural evaluation was carried out, including the trunk and crown quality assessment. A special attention was paid to the tending of the trees of selective quality (target and promising trees) according to the methodology developed by Štefančík (1984).

Target (promising) trees are selected at a young stage (20–30 years) according to the following criteria: (1) satisfactory quality characteristics of stem and crown; (2) suitable dimensional requirements (diameter, height); (3) appropriate spacing in the stand. These trees should be visibly marked in the stand. They allow the forest manager to get a good orientation in marking further thinning. They are also a signal for those operating the logging process, to save them from damage, and if necessary, they become the object of rational protection against injury by game. In each replication the thinning of these trees must be comprehensively assessed in agreement with the criteria mentioned above.

The method of promising trees has been applied on 5 plots, and the method of target (crop) trees on 7 plots (Fig. 1).

The experimental data were processed by mathematical and statistical evaluation, using Microsoft Excel and QC Expert software. The statistical significance of differences was assessed by ANOVA analysis.

RESULTS AND DISCUSSION

The basic mensurational characteristics of target (crop) and promising trees are presented in

Method of crop trees 2.5 × 1.5 m Crop trees C_3	Method of crop trees 2.5 × 2.5 m Crop trees D_3	Method of promising trees 1.5 × 1.0 m Promising trees A_3	Method of promising trees 2.5 × 1.0 m Promising trees B_3
Without treatment 2.5 × 2.5 m Crop trees D_2	Without treatment 1.5 × 1.0 m Promising trees A_2	Without treatment 2.5 × 1.0 m Promising trees B_2	Without treatment 2.5 × 1.5 m Crop trees C_2
Geometric (line) treatment 1.5 × 1.0 m Crop trees A_1	Geometric (line) treatment 2.5 × 1.0 m Crop trees B_1	Geometric (line) treatment 2.5 × 1.5 m Crop trees C_1	Pruning in five interlines / Without treatment in six interlines 2.5 × 2.5 m Promising trees D_1

30 m

30 m

Fig. 1. Scheme of the series of the PRP Biely Váh-Luksová including the methods of their tending. A, B, C, D – alternatives of spacing, index 1, 2, 3 – replication of spacing and/or plot lines

Table 2. This category representing the qualitative production in commercial forests is also important for the static stability of the stand. Consequently, in silvicultural practice, the primary focus is on these trees. We can see that at the stand age of 30 years, that means before the first snow-break damage, the highest number of promising trees (PT) was found out on control plot B_2 (733 individuals·ha^{-1}), unlike on plot B_3 managed by selective tending (444 trees/·ha^{-1}). As for the target trees (TT), the highest number was registered on plots treated by selective tending – D_3 (422 trees·ha^{-1}) and the lowest on plots managed by geometrical (line) thinning (189 trees·ha^{-1}).

Another stand damage caused by a snow-break disaster registered during the second period of our research (2000–2010) affected also the promising and target trees, but with different intensities. Among the plots tended by the method of PT, the highest decrease was found out on A_2 and B_2 – with 32.7 and 19.6% trees remaining from the original number. These plots were established at the closest spacing, i.e. 1.5 × 1.0 m and 2.5 × 1.0 m, respectively. On the contrary, plots A_3 and B_3 established at the same (densest) spacing, but managed by selective thinning, showed the lowest damage. On these plots, 50% out of the initial number of PT remained after the snow-break disaster.

Among the plots treated by the TT method, the largest decrease, amounting to 47.1% of the initial target trees, was found on B_1 (geometrical thinning) with a spacing of 2.5 × 1.0 m. The lowest reduction related to the TTs in consequence of the snow-break disaster was registered on plot C_3 treated by selective thinning (spacing 2.5 × 1.5 m), where a 10% decrease was observed only.

The share of PTs and TTs in the main stand is an important silvicultural characteristic from the viewpoint of quality. This parameter exhibited the most favourable values on D_1 (64.3%) and D_3 (47.1%), i.e. on plots with the widest spacing (2.5 × 2.5 m), managed by geometrical and/or selective thinning. The same trend was also registered for the basal area and volume of the timber to the top of 7 cm o.b. Similar results were also reported by Prokopjev (1983), who obtained the best outcomes for qualitative production at the initial spacing of 3.0 × 1.5 m (2,200 individuals·ha^{-1}).

The presented results show that less severe snow-break damage to the development of PTs and TTs was suffered on the plots with wider spacing (2.5 × 2.5 m or 2.5 × 1.5 m). This fact is also in accordance with our assessment of the quantitative production for the same PRPs. These results show that the most damaged were the control plots (without tending) and the least damaged were the plots managed by selective thinning or by geometrical (line) interventions. It was also evident that almost in all cases the snow-break damage decreased with increasing initial spacing. As for the tending regime, the plots managed by selective and/or geometrical thinning exhibited the lowest damage, contrary to the control ones where the highest damage was registered (regardless of spacing).

The values in Table 2 show that at the stand age of 40 years, the number of TTs ranged from 89 to 356 individuals per hectare. It seems very important that the highest number of TTs was found out on the plots tended by selective thinning and the lowest number was on the plots managed by geometrical tending and on the control ones (without tending). The presented number of TTs could be considered as very low for their subsequent development – in comparison with the results published by other authors (Abetz 1979; Štefančík 1984; Schober 1990; Spellmann, Nagel 1996; Štefančík, Štefančík 2000; Slodičák, Novák 2007) recommending about 300–400 TTs per hectare. It is evident that the required number of TTs was reached only on two plots established at the closest and at the widest initial spacing, but managed by selective thinning (A_3 and D_3). Fewer than 400 TT individuals per hectare were also found by Slodičák and Novák (2007) on the IUFRO experimental plot CZ-Vítkov – only 360–380 individuals.

It is generally known that TTs represent not only the qualitative production of the stand, but also they are the "stand skeleton" ensuring favourable static stability with the slenderness quotient values under 0.80. Improvement of the static stability is especially important in young spruce stands. The static stability of PTs and TTs expressed by h_g/d_g ratio is depicted in Fig. 2. Numerous research results concerning this topic have confirmed that the static stability of spruce stands is desirable for trees with a stand age of 20–30 years, by the application of heavy thinning (Mráček, Pařez 1986; Slodičák 1987; Slodičák, Novák 2006, 2007; Slodičák et al. 2010). In the context of these findings, Saniga (1996) reported a positive effect of stand stability on the resistance to snow-break damage in a spruce pole-stage stand with a 2.0 × 1.0 m spacing, treated by geometrical thinning of 33% intensity. Similarly, Burschel (1981) pointed out an improvement of static stand stability along with a decreased risk of snow damage for the tree number lower than 2,000 individuals per hectare with a top height of 15–20 m. Improved stand stability obtained by the

Table 2. Development of the basic characteristics of promising and target (crop) trees

Plot	Type of tending (category of trees)	Age (year)	Number of trees (trees·ha^{-1})	Number of trees (% out of the main stand)	Basal area (m^2·ha^{-1})	Basal area (% out of the main stand)	Volume of the timber to the top of 7 cm over bark (m^3·ha^{-1})	Volume of the timber to the top of 7 cm over bark (% out of the main stand)
A_1	geometrical	20	–	–	–	–	–	–
		26	–	–	–	–	–	–
	(target)	30	278	26.9	6.96	40.5	48.55	44.2
		40	233	37.5	12.64	47.0	120.48	48.9
A_2	without tending	20	–	–	–	–	–	–
	(promising)	26	578	14.7	8.39	27.2	41.50	34.9
		30	578	18.0	11.50	31.5	71.70	35.6
	(target)	40	189	32.7	8.06	46.6	74.62	49.1
A_3	selective	20	711	18.0	2.97	31.7	4.23	56.1
	(promising)	26	611	21.6	6.89	37.4	30.73	47.8
		30	667	29.1	11.40	49.8	68.99	56.4
	(target)	40	333	45.4	11.86	54.9	104.00	56.6
B_1	geometrical	20	–	–	–	–	–	–
		26	–	–	–	–	–	–
	(target)	30	189	42.6	5.16	56.5	35.94	59.5
		40	89	40.1	6.14	49.5	60.66	51.1
B_2	without tending	20	–	–	–	–	–	–
	(promising)	26	756	28.1	10.58	44.6	51.09	52.3
		30	733	31.7	14.13	47.8	87.33	52.1
	(target)	40	144	28.2	6.18	36.9	57.04	38.4
B_3	selective	20	745	39.2	3.09	56.5	5.52	72.7
	(promising)	26	467	28.6	6.09	42.4	28.96	49.1
		30	444	29.0	9.09	45.6	57.11	49.6
	(target)	40	222	32.2	10.82	43.1	99.06	44.7
C_1	geometrical	20	–	–	–	–	–	–
		26	–	–	–	–	–	–
	(target)	30	289	35.2	7.64	46.6	54.07	49.8
		40	178	42.2	10.91	55.1	106.03	58.0
C_2	without tending	20	–	–	–	–	–	–
	(target)	26	267	14.7	3.52	22.6	16.63	26.5
		30	267	15.2	5.17	22.9	32.48	25.3
		40	133	28.5	6.63	38.6	63.02	40.3
C_3	selective	20	322	17.9	1.41	29.0	2.52	43.9
	(target)	26	322	18.9	4.70	28.6	23.12	33.6
		30	322	21.8	7.40	32.4	46.90	34.7
		40	289	32.5	13.08	40.3	118.38	41.3
D_1	geometrical	20	–	–	–	–	–	–
	(promising)	26	989	79.5	14.37	88.4	71.98	90.2
		30	544	81.7	12.00	93.3	81.46	95.5
	(target)	40	200	64.3	12.48	79.0	121.01	80.9
D_2	without tending	20	–	–	–	–	–	–
	(target)	26	267	21.3	4.46	29.8	22.47	33.1
		30	278	22.7	7.13	31.2	45.64	32.5
		40	233	30.4	10.58	37.9	99.6	39.2
D_3	selective	20	422	33.0	1.79	45.4	3.10	51.4
	(target)	26	489	40.4	6.43	50.7	30.47	55.2
		30	422	36.9	9.28	48.4	58.68	50.5
		40	356	47.1	15.32	56.2	138.80	57.7

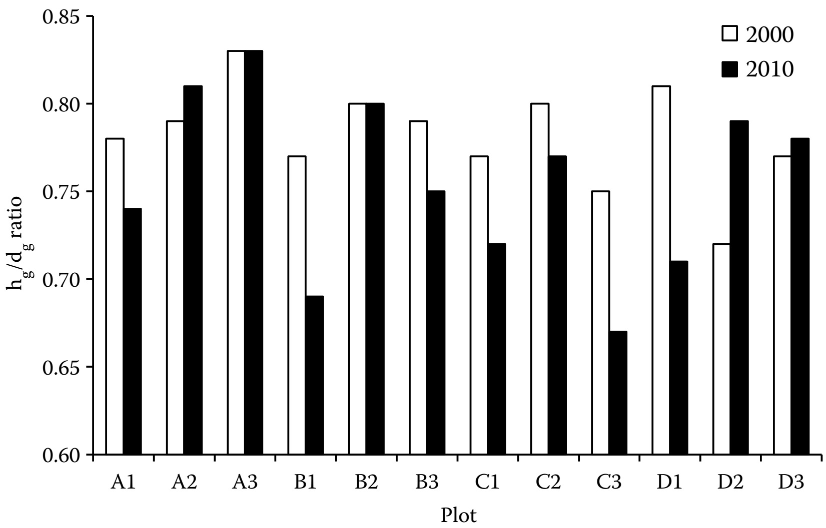

Fig. 2. The mean values of the h_g/d_g ratio of target (promising) trees

application of the method of target trees was also reported by Burschel et al. (1974) and Poleno et al. (2009).

After 10 years of tending and/or 20 years of the stand development (including two snow-break disasters), a decrease of h_g/d_g ratio was observed on the plots tended by geometrical and selective thinning (statistically significant at $\alpha = 0.05$ on plots B_1, D_1 and C_3). On the control plots (except for C_2 with the initial spacing of 2.5 × 1.5 m), the h_g/d_g ratio was found to increase (statistically insignificant). The same relation was also observed in the main stand on this PRP series. Positive effects of geometrical and combined thinning (geometrical + selective) on the resistance against snow damage of a spruce small pole-stage stand were also reported by Saniga (1996). Favourable results were obtained by Holodynski (1995), who assessed the effects of geometrical thinning in a 28-year-old small pole-stage stand with the initial spacing of 1.5 × 1.5 m. Higher values of slenderness quotient (from 1.04 to 1.16) in comparison with our data for the PRP series Turzovka–Semetéš at the stand age of 11 years were published by Piskun (1984). The author also found out that the slenderness quotient values increased with increasing stand density. The same trend was also confirmed by Nilsson (1994) in 30 years old spruce stands established at four different spacing variants (from 1.0 × 1.0 m to 2.5 × 2.5 m), with insignificant differences among the variants.

The values of the h_g/d_g ratio ranged from 0.67 to 0.83 at the stand age of 40 years. Similarly, at a wider spacing, the values of the h_g/d_g ratio decreased. As for the tending method, the most favourable results were obtained on plots managed by geometrical thinning. Small differences (not significant at $\alpha = 0.05$) between the control plots

Table 3. Mean annual diameter increment (i_d) with standard deviation ($s_{\bar{x}}$) in the investigated periods

Plot	Method of tending	i_d (1990–1999)		i_d (2000–2009)		i_d (1990–2009)	
		n	$\bar{x}$ (mm) ± $s_{\bar{x}}$	n	$\bar{x}$ (mm) ± $s_{\bar{x}}$	n	$\bar{x}$ (mm) ± $s_{\bar{x}}$
A_1	geometrical	25	9.68 ± 1.50	21	8.55 ± 1.40	21	9.15 ± 1.08
A_2	no tending	52	6.50 ± 1.44	17	5.67 ± 1.50	17	6.41 ± 1.12
A_3	selective	60	7.44 ± 1.28	30	6.33 ± 1.50	30	6.95 ± 1.15
B_1	geometrical	17	9.83 ± 1.69	8	10.51 ± 1.67	8	10.23 ± 0.97
B_2	no tending	66	6.82 ± 1.38	13	6.60 ± 1.71	13	6.89 ± 1.27
B_3	selective	40	8.66 ± 1.43	20	7.91 ± 2.25	20	8.45 ± 1.69
C_1	geometrical	26	9.52 ± 1.20	16	9.20 ± 0.80	16	9.43 ± 0.74
C_2	no tending	24	8.06 ± 1.14	12	8.26 ± 2.02	12	8.44 ± 1.45
C_3	selective	29	9.64 ± 1.23	26	6.69 ± 2.08	26	11.88 ± 1.73
D_1	geometrical	49	8.79 ± 2.31	18	8.85 ± 1.34	18	9.85 ± 1.28
D_2	no tending	25	9.95 ± 1.46	20	6.09 ± 1.21	20	7.91 ± 1.02
D_3	selective	38	9.53 ± 1.20	32	6.33 ± 1.48	32	8.07 ± 1.04

and the plots tended by selective thinning are also a consequence of the above-mentioned snow-break disasters releasing the crowns of target trees on the control plots.

The values of the mean periodic annual diameter increment (i_d) of target (promising) trees in the period before the snow-break disaster (1990–1999), in the years after the damage (2000–2009), and for the entire study period are presented in Table 3. The statistical significance of the differences between the plots (with the same initial spacing) in relation to the tending method and/or in relation to the spacing is shown in Tables 4 and 5. The differences due to the tending method (the same initial spacing) document (with a few exceptions) that the highest i_d values were obtained on the plots managed by geometrical (line) thinning, as opposed to the control plots with the lowest i_d. This applied to all three periods of comparison. The same relation was ascertained by the investigation of i_d of the main stand on these plots. These results are in accordance with the outcomes published by Chroust (1988) obtained by comparing the mean annual increment between a plot tended by geometrical thinning and a control one (without tending). The values reported by this author were similar or somewhat lower than our data from the PRPs Biely Váh-Luksová.

The analysis of the relation between i_d and spacing (with the same tending method) revealed that the plots tended by geometrical thinning during all the three study periods showed the highest values for the initial spacing of 2.5 × 1.5 m or 2.5 × 1.0 m (all differences were statistically insignificant). The control plots (without interventions) exhibited (except two plots) i_d values that increased with a wider spacing (statistically significant differences were found out only between the widest spacing and the two closest spacing variants in 1990–1999). As for the plots tended by selective thinning, no similar dependence occurred in the period of 2000–2009 after the snow-break disaster.

Table 4. Statistical significance of differences in i_d between the plots with the same initial spacing in relation to the method of tending

Plot	A_1–A_2	A_1–A_3	A_2–A_3	B_1–B_2	B_1–B_3	B_2–B_3
1990–1999	*	*	N	*	N	*
2000–2009	*	*	N	*	N	N
1990–2009	*	*	N	*	N	N
Plot	C_1–C_2	C_1–C_3	C_2–C_3	D_1–D_2	D_1–D_3	D_2–D_3
1990–1999	N	N	N	N	N	N
2000–2009	N	*	N	*	N	N
1990–2009	N	*	N	*	*	N

N – statistically insignificant difference ($P > 0.05$), * indicates statistically significant difference ($P < 0.05$)

Table 5. Statistical significance of differences in i_d between the plots with the same method of tending in relation to spacing

Plot	A_1–B_1	A_1–C_1	A_1–D_1	B_1–C_1	B_1–D_1	C_1–D_1
1990–1999	N	N	N	N	N	N
2000–2009	N	N	N	N	N	N
1990–2009	N	N	N	N	N	N
Plot	A_2–B_2	A_2–C_2	A_2–D_2	B_2–C_2	B_2–D_2	C_2–D_2
1990–1999	N	N	*	N	*	N
2000–2009	N	N	N	N	N	N
1990–2009	N	N	N	N	N	N
Plot	A_3–B_3	A_3–C_3	A_3–D_3	B_3–C_3	B_3–D_3	C_3–D_3
1990–1999	N	*	*	N	N	N
2000–2009	N	N	N	N	N	N
1990–2009	N	*	N	*	N	*

N – statistically insignificant difference ($P > 0.05$), * indicates statistically significant difference ($P < 0.05$)

The comparison of i_d among the investigated periods showed that almost on each plot, the diameter increment was found higher before the snow-break damage than in the subsequent period including the damage. Thus, the diameter increment in the target trees was influenced by the snow-break disaster. On the other hand, positive effects of the snow-break were observed in the main stand of this PRP series, because the values of i_d on the control plots in the period after disaster (2000–2009) were higher than the values before the snow-break damage in the two closest spacing variants (1.5 × 1.0 m and 2.5 × 1.0 m). The snow damage was the most intensive on the control plots, and so also their diameter increment in response to this damage.

CONCLUSION

Our 20-year investigation of the development of target (promising) trees in a 40-year-old spruce stand established at different spacing and affected by two snow-break disasters revealed different patterns of damage:

(1) Among the plots tended by the method of promising trees, the highest decrease in the trees concerned was found out on the control plots with the closest initial spacing. On the contrary, the lowest damage was measured on the plots tended by selective thinning (i.e. closest spacing).

(2) As for the plots tended by the TT method, the highest decrease was observed on plot B_1 (geometrical thinning) with a spacing of 2.5 × 1.0 m, where 47.1% of the initial TTs remained. The lowest reduction in the TTs due to the snow-break disaster was registered on plot C_3 tended by selective thinning (spacing of 2.5 × 1.5 m), where the decrease was found to be only 10%.

(3) Expressing the share of TTs out of the main stand according to the tree number, the best results were obtained on plots D_1 and D_3, i.e. on plots with the widest spacing (2.5 × 2.5 m) managed by geometrical and/or selective thinning. The same trend was also registered for the basal area and the timber volume up to the top of 7 cm o.b.

(4) The PTs and TTs developing on the plots with wider spacing (2.5 × 2.5 m or 2.5 × 1.5 m) suffered smaller snow-break damage. As for the tending regime, the plots managed by selective and/or geometrical thinning had the lowest degrees of damage, as opposed to the control plots with the most serious damage measured (regardless of the spacing).

(5) The highest numbers of TTs were found out on the plots tended by selective thinning and the lowest on the plots managed by geometrical thinning and on the control plots (without tending).

(6) After 10 years of tending and/or 20 years of the stand development (including two snow-break disasters) a drop in h_g/d_g ratio was found on the plots tended by geometrical and selective thinning, contrary to the control plots (except for C_2 with the initial spacing of 2.5 × 1.5 m) on which this ratio was found to increase. The values ranged from 0.67 to 0.83 at the stand age of 40 years.

(7) The snow-break disaster caused a decrease in the mean annual diameter increment in the target trees.

References

Abetz P. (1979): Brauchen wir „Durchforstungshilfen?" Schweizerische Zeitschrift für Forstwesen, ***130***: 945–963.

Braastad H. (1970): Et forbandsforsøk med gran. [A Spacing Experiment with Picea abies.] Meddelelser fra Det Norske Skogforsøksvesen, ***28***: 295–329.

Braastad H. (1979): Vekst og stabilitet i et forbandsforsøk med gran. [Growth and stability in a spacing experiment with *Picea abies*]. Meddelelser fra Norsk Institutt for Skogforskning, ***34***: 169–215.

Brüchert F., Becker G., Speck T. (2000): The mechanics of Norway spruce [*Picea abies* (L.) Karst.]: mechanical properties of standing trees from different thinning regimes. Forest Ecology and Management, ***135***: 45–62.

Burschel P., Franz F., Pechmann H., von Kroth W. (1974): I. Modern ideas on thinning, exemplified by models of Spruce stands. II. Advanced thinning methods and yield. III. Influence of thinning on wood quality. IV. Economic aspects of thinning. Forstarchiv, ***45***: 21–42.

Burschel P. (1981): Neue Erziehungs konzepte für Fichtenbestände. Allgemeine Forst-Zeitschrift, ***51/52/53***: 1386–1395.

Holodynski D. (1995): Schematische Erstdurchforstung in Fichtenbeständen. Allgemeine Forst-Zeitschrift, ***50***: 709–710.

Chroust L. (1988): Vliv selektivního, řadového a kombinovaného výchovného zásahu na smrkovou tyčkovinu. [Influence of selective, row and combined tending operations on a spruce pole stand.] Lesnícky časopis, ***34***: 37–49.

Chroust L. (1997): Ekologie výchovy lesních porostů. [The ecology of forest tending.] Opočno, VÚLHM: 275.

Jurča J., Chroust L. (1973): Racionalizace výchovy mladých lesních porostů. [Rationalization of Young Stand Tending.] Praha, Státní zemědělské nakladatelství: 239.

Kairiukštis L., Malinauskas A. (2001): The influence of initial density on spruce (*Picea abies* Karsten.) wood quality. Baltic Forestry, ***7***: 8–17.

Kramer H., Dong P.H., Rusack H.J. (1971): Untersuchung der Baumqualität in weitständig begründeten

Fichtenbeständen. Allgemeine Forst- und Jagdzeitung, ***142***: 33–46.

Mráček Z., Pařez J. (1986): Pěstování smrku. [Silviculture of spruce.] Praha, Státní zemědělské nakladatelství: 203.

Nilsson U. (1994): Development of growth and stand structure in *Picea abies* stands planted at different initial densities. Scandinavian Journal for Forest Research, ***9***: 135–142.

Pařez J. (1972): Vliv podúrovňové a úrovňové probírky na výši škod sněhem v porostech pokusných probírkových ploch v období 1959–1968. [Influence of thinning from below and crown thinning on snow damage extent in experimental thinning plots during the period of 1959–1968.] Lesnictví, ***18***: 143–154.

Piskun B. (1984): Začiatočná hustota a spon lesných kultúr v rastových podmienkach Slovenskej socialistickej republiky. [Initial density and spacing of forest plantations in the growth condition of Slovakia.] Vedecké práce VÚLH vo Zvolene, ***34***: 13–35.

Poleno Z., Vacek S., Podrázský V., Remeš J., Štefančík I., Mikeska M., Kobliha J., Kupka I., Malík V., Turčáni M., Dvořák J., Zatloukal V., Bílek L., Baláš M., Simon J. (2009): Pěstování lesů III – Praktické postupy pěstování lesů. [Silviculture III – Practical Methods in Silviculture.] Kostelec nad Černými lesy, Lesnická práce: 952.

Prokopjev M.N. (1983): Growth and yield of Norway spruce plantations of different initial density. Lesnoje Chozjajstvo, ***11***: 24–28. (in Russian)

Razin G.S. (1991): Patterns in the age dynamics of spruce plantations of different density. Lesnoje Chozjajstvo, ***9***: 40–42. (in Russian)

Saniga M. (1996): Vplyv rôznej sily a rôzneho druhu výberu na vybrané znaky kvantitatívnej štruktúry a stabilitu smrekovej žŕdkoviny. [The effect of thinning of different intensity and type on some traits of the qualitative structure and stability of a spruce small pole-stage stand.] Lesnictví-Forestry, ***42***: 254–260.

Schober R. (1990): Die Bedeutung des Umsetzens von Waldbäumen für Z-baum-Durchforstungen. Allgemeine Forst-Zeitschrift, ***45***: 824–828.

Slodičák M. (1987): Výchova mladých smrkových porostů ohrožených sněhem a její vliv na růst **a** statickou stabilitu stromů různých stromových tříd. [Tending of young spruce stands jeopardized by snow breaks and the influence of tending measures on the growth and static stability of trees belonging to various tree classes.] Lesnictví, ***33***: 1091–1106.

Slodičák M., Novák J. (2006): Silvicultural measures to increase the mechanical stability of pure secondary Norway spruce stands before conversion. Forest Ecology and Management, ***224***: 252–257.

Slodičák M., Novák J. (2007): Růst, struktura a statická stabilita smrkových porostů s různým režimem výchovy. [Growth, structure and static stability of Norway spruce stands with different thinning regimes.] Folia Forestalia Bohemica 3. Kostelec nad Černými lesy, Lesnická Práce: 128.

Slodičák M., Novák J., Štefančík I., Kamenský M. (2010): Silviculture measures and spruce stands conversion. In: Hlásny T., Sitková Z. (eds): Spruce Forests Decline in the Beskids. Zvolen, National Forest Centre – Forest Research Institute in Zvolen, Czech University of Life Sciences Prague: 145–155.

Spellmann H., Nagel J. (1996): Zur Durchforstung von Fichte und Buche. Allgemeine Forst- und Jagdzeitung, ***167***: 6–15.

Štefančík L. (1984): Freie Hochdurchforstung in ungepflegten Buchenstangenhölzern. Allgemeine Forst-Zeitung, ***95***: 106–110.

Štefančík I., Štefančík L. (2000): Vývoj borovicovo-smrekovej žrďoviny ovplyvnenej imisiami v oblasti stredného Spiša. [Development of pine-spruce pole-stage stand affected by air pollutants in the region of central Spiš.] Lesnícky časopis – Forestry Journal, ***46***: 393–412.

Štefančík I., Štefančík L. (2002): Výskum pestovno-produkčných otázok smrekových žrďovín založených pri rôznom východiskovom počte sadeníc. [Research on silviculture-production issues of spruce pole-stage stands established by different initial number of plants.] Folia-oecologica, ***29***: 109–132.

Received for publication May 31, 2012
Accepted after corrections October 5, 2012

Corresponding author:
Doc. Ing. Igor Štefančík, CSc., National Forest Centre – Forest Research Institute in Zvolen,
T. G. Masaryka 22, 960 92 Zvolen, Slovak Republic
e-mail: stefancik@nlcsk.org