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Importance of the first thinning in young mixed Norway spruce and European beech stands

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Abstract

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Experimental results from the first thinning in mixed stands are not broadly experienced by forestry practice. To extend the experience with the thinning of a mixed stand, we studied thinned and unthinned mixtures of Norway spruce with European beech on two study sites in the Czech Republic, which represented different conditions: Všeteč (age of 19–35 years) – originally beech dominated site at 440 m a.s.l. and Deštné (age of 17–33 years) – originally spruce with beech site at 990 m a.s.l. Spruce and beech were mixed individually or in small groups. As the for number of trees, mixtures were 35–54% beech and 46–65% spruce at a lower altitude and 7–30% beech and 70–93% spruce at a higher altitude. In the period 1997–2013, we observed annually: mortality, diameter at breast height of all trees and height of trees (minimum 30 individuals) that represented diameter distribution. Results showed that the growth and development of young mixed spruce/beech stands were positively influenced by the first pre-commercial thinning on both locations. The most pronounced effect of thinning consisted in a decreased amount of basal area of dead trees. On control plots, salvage cut accounted for 34 and 46%, while on thinned plots it reached only 7–8% (thinned from above) and 18% (thinned from below) of basal area periodic increment during the 16-year study period. In contrast, diameter distribution was still relatively wide (i.e. an important amount of thin trees was left) at the end of observations on all plots of both study sites. Thinned stands also showed the better static stability (expressed as an *h*/*d* ratio) of dominant spruces compared to unthinned stands on both locations. Additionally, thinning supported the spruce share at a lower altitude and the beech share at a higher altitude.

Keywords: pre-commercial thinning; diameter distribution; *h*/*d* ratio; skewness; kurtosis

Norway spruce is the most important (also due to its percentage representation) commercial tree species in Central Europe. In history, spruce was grown mainly as monoculture; this approach often resulted in a high risk of large-scale disturbances by abiotic and biotic harmful agents. According to current trends in European silviculture, mixed stands have been established more frequently over the last decades (Bravo-Oviedo et al. 2014). As a result of the new above-mentioned trends (Kelty 2006; Schütz et al. 2006; Ammer et al. 2008; Forrester, Pretzsch 2015; del Río et al. 2016; Metz et al. 2016; Pretzsch, Biber 2016), relatively large areas of young mixed stands are established annually and recommendations for the first (pre-commercial) thinning of these stands are required by forests practitioners (Fahlvik et al. 2005; Agestam et al. 2006; Hynynen et al. 2011).

One of the common mixtures for central European forests is based on Norway spruce and European

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beech. These mixtures can be established both artificially and naturally. Spruce has different ecological demands for successful development at a young stage (it needs open space for individual stability development) compared to beech (it needs closed canopy for stem quality development). It is known that the first thinning in young monocultures has an essential effect on stability of spruce (Persson 1972; Slodičák 1995; Cameron 2002) and quality of beech (Štefančík 2016).

Knowledge of thinning effects in young mixtures is not complete yet (Vettenranta, Miina 1999; Rytter, Werner 2007; Štefančík 2010; Prévost, Gauthier 2012; Dhar et al. 2015; Drössler et al. 2015). Therefore, the aim of the present work is to find the effect of the first thinning on growth, stability and maintenance of mixture in young mixed spruce-beech stands.

METHODS

We used both thinned and unthinned mixtures of Norway spruce with European beech on two study sites in the Czech Republic which represented different conditions: Všeteč – *Fagetum acidophilum* site at 440 m a.s.l., GPS position 49°13'46.000"N, 14°16'28.000"E, for more information see Novák and Slodičák (2009) and Deštné – *Piceeto-Fagetum acidophilum* site at 990 m a.s.l., GPS position 50°19'25.336"N, 16°21'24.538"E, for more information see Novák and Slodičák (2008). Observed stands originated from artificial regeneration, i.e. trees were planted on sites after clear-cutting. Spruce and beech were mixed individually or in small groups.

Všeteč experiment was established in a young 19-year-old stand and consists of three plots (0.1 ha each) with different thinning regimes: (*i*) without thinning, (*ii*) thinning from above, (*iii*) thinning from below. At the start of experiment, density (N) varied between 5,000 and 5,400 trees per hectare. Spruce accounted for 41–50% in species composition of the stand. Initial basal area (G) varied from 17 to 22 $m^2 \cdot ha^{-1}$ and 56–65% of G was spruce. The first thinning was done at the age of 21 years and totally 15 and 42% of N and 22 and 20% of G were removed by thinning from above (variant 2) and by thinning from below (variant 3), respectively. Ten years later, 31-year-old stands were thinned again and totally 17 and 37% of N and 22 and 20% of G were removed by thinning from above (variant 2) and by thinning from below (variant 3), respectively.

Deštné experiment was established in a young 16-year-old stand in the mountains and consists of two plots (0.05–0.09 ha) with different thinning regimes: (*i*) without thinning, (*ii*) thinning focused on the removal of trees (only spruces) from above, showing extremely high increment. At the start of experiment, N was about 3,500 trees per hectare. Spruce dominated in species composition of stands (70–93%). Initial G varied from 11 to 13 $m^2 \cdot ha^{-1}$ and spruce represented 66–98%. The first thinning was done at the age of 17 years and totally 43% of N and 62% of G were removed. Control plot was damaged by snow (stem breaks of spruce only) twice. Disturbances occurred in winter 2003/2004 at the age of 22 years (damaged 28% of N and 23% of G) and in winter 2005/2006 at the age of 24 years (damaged 31% of N and 26% of G).

We observed mortality, diameter at breast height and height in both experiments annually in the period 1997–2013, i.e. at the age of 19–35 and 17–33 years in Všeteč and Deštné experiments, respectively. The present work is focused on the evaluation of periodic stand basal area increment, characteristics of dominant trees, i.e. the thickest 200 individuals per hectare (diameter D_{200} and quotient of slenderness H/D_{200}), diameter structure and development of species composition in differently thinned young stands. Due to the experimental design (no replications), data were analysed only by descriptive statistical methods calculated using Microsoft Excel (Version 15.0.4911.1000, 2013) – arithmetical mean, maximum, minimum, skewness, kurtosis.

RESULTS

Salvage cut

The most pronounced effect of thinning consisted in reduced G of dead trees, which were removed as salvage cut. Periodic basal area increment was 16–21 $m^2 \cdot ha^{-1}$ in Všeteč experiment (age of 19–35 years) and 35–38 $m^2 \cdot ha^{-1}$ in Deštné experiment. On control plots, 34% (Všeteč) and 46% (Deštné) of G periodic increment had to be removed during the 16-year period of investigations as salvage cut, whereas salvage cut on thinned plots reached only 7% (Deštné, thinned), 8% (Všeteč, thinned from above) and 18% (Všeteč, thinned from below) of periodic increment (Fig. 1). Higher salvage cut was found in spruce-dominated (87–100%) patches compared to beech-dominated ones within the mixture.

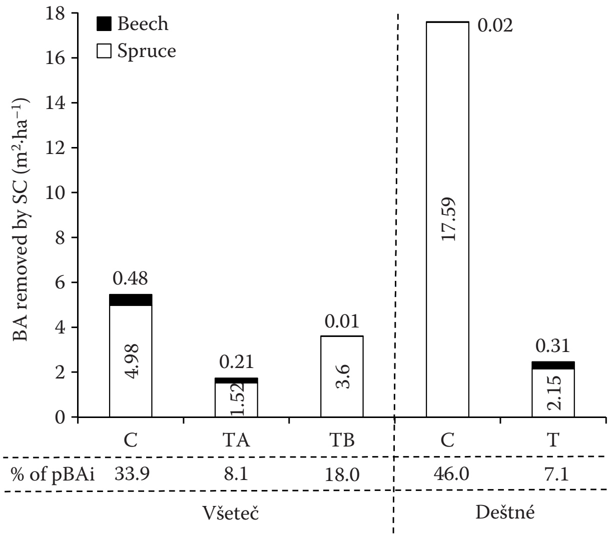

Fig. 1. Basal area (BA) removed by salvage cut (SC) during the period of observations in experiments Všeteč (age of 19–35 years) and Deštné (age of 17–33 years). Values below the *x*-axis indicate the percentage of periodic basal area increment (pBAi) removed by salvage cut

C – unthinned control, TA – thinned from above, TB – thinned from below, T – thinned (for more explanations see the chapter Methods)

Dominant trees

Characteristics of dominant trees (200 thickest spruces and beeches per hectare) were also influenced by thinning (Table 1). In Všeteč experiment, periodic diameter increment of dominant spruces (iD_{200}) was higher in thinned plots (71 and 53% in stands thinned from above and from below, respectively) compared to the control (37%). In beech, the highest periodic iD_{200} was found in stand thinned from below (73%), followed by control stand (55%) and stand thinned from above (33%). In Deštné mountain experiment, dominant spruces and beeches from thinned stand showed higher periodic iD_{200} (299 and 273%) compared to the control unthinned stand (130 and 100%).

Quotient of slenderness for dominant trees (H/D_{200} ratio) as a usual indicator of stem stability against snow damage was evaluated for spruces (Fig. 2), which are more vulnerable to snow breakage due to heavy snow load. On both locations, stability of dominant spruces was positively affected by thinning. On the location at a lower altitude (Všeteč), thinning resulted in an H/D_{200} ratio below the critical level 0.9 (thinning from above) and 1.0 (thinning from below). All dominant spruces exceeded the critical level (1.0) on the control plot. On the mountain location (Deštné), height increment of dominant spruces was lower and, consequently, the H/D_{200} ratio was below the level 0.7 (control stand) and 0.6 (thinned stand). Differences in the stability of control and thinned stands were confirmed by results of snow damage during the winters 2003/2004

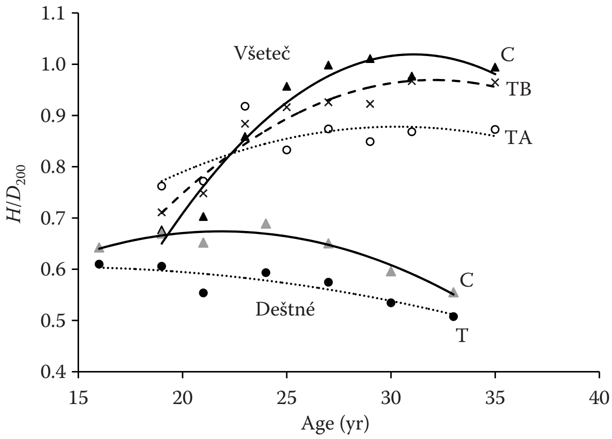

Fig. 2. Quotient of slenderness (H/D_{200}) of dominant (200 thickest individuals per hectare) spruces in Všeteč and Deštné experiments

C – unthinned control, TB – thinned from below, TA – thinned from above, T – thinned (for more explanations see the chapter Methods)

Table 1. Diameter (D_{200}) and periodic diameter increment (iD_{200}) for dominant trees (200 thickest trees per hectare) in Všeteč and Deštné experiments. Values are presented in the order (min) mean (max)

	Age of trees (yr)	Všeteč						Deštné			
		control		thinned from above		thinned from below		control		thinned	
		spruce	beech	spruce	beech	spruce	beech	spruce	beech	spruce	beech
D_{200} (cm)	19 (Všeteč), 17 (Deštné)	(12.6) 14.9 (22.8)	(10.7) 12.2 (15.7)	(10.9) 12.7 (15.8)	(9.6) 11.1 (16.3)	(11.8) 13.9 (21.9)	(9.7) 10.9 (13.1)	(10.3) 11.5 (13.4)	(1.2) 3.6 (7.6)	(9.8) 10.6 (12.0)	(2.6) 3.6 (4.5)
D_{200} (cm)	35 (Všeteč), 33 (Deštné)	(16.0) 20.4 (29.9)	(16.0) 18.9 (24.6)	(19.0) 21.8 (27.4)	(12.2) 14.7 (21.9)	(18.8) 21.3 (28.9)	(16.8) 18.8 (21.6)	(22.9) 26.5 (34.5)	(3.0) 7.2 (18.0)	(29.7) 31.6 (34.3)	(10.6) 13.4 (17.6)
iD_{200} (cm)		5.5	6.7	9.0	3.7	7.4	8.0	15.0	3.6	21.1	9.8
iD_{200} (%)		37	55	71	33	53	73	130	100	299	273

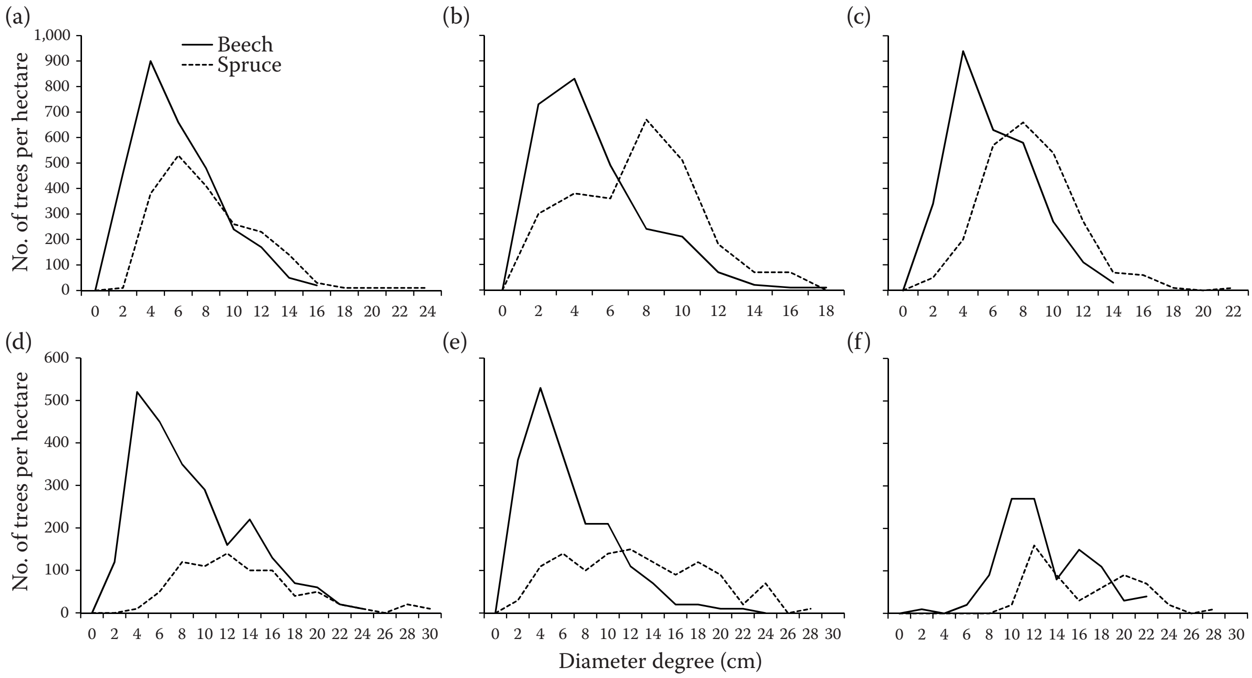

Fig. 3. Diameter distribution at two age stages – 19 (a, b, c) and 35 years (d, e, f) for beech and spruce trees in unthinned control (a, d), thinned from above (b, e), thinned from below (c, f) mixed stands of Všeteč experiment

and 2005/2006. In control stand unstable supressed spruces from lower diameter classes (mainly up to 12 cm) were damaged in comparison with thinned stand, where these thin trees were absent, i.e. no damage occurred.

DIAMETER STRUCTURE

Diameter structures ranged from 2 to 18 cm diameter class on all plots of Všeteč experiment (Fig. 3) before the first thinning at the age of 19 years. Positive values of skewness were found for diameter structure of both species (Table 2). It means right-tailed distribution. On the other hand, negative values of kurtosis, representing flatter distribution compared to normal distribution, were observed on all plots and for both species in the Všeteč experiment.

Sixteen years later (at the age of 35 years), diameter structures extended reflecting the presence of thicker trees, however thin beech trees with diameter up to 4 cm were still present (Fig. 3). We also found that the density of beech trees with 20 cm diameter and greater was the highest on control plot (90 trees per hectare) compared to plots thinned from above (20 trees per hectare) and thinned from below (70 trees per hectare). On the other hand, in the thickest spruce trees (20 cm diameter and greater) high densities were found on both thinned (190 trees per hectare) and control (110 trees per hectare) plots. Values of skewness for diameter structures were still positive (Table 2), i.e. distribution remained right-tailed. The only exception was beech on the plot thinned from above with negative skewness at the end of observation. Values of kurtosis remained negative on both control and thinned-from-above plots. On the contrary, kurtosis was changed to a positive value (spruce) or zero (beech) on the plot thinned from below.

In the mountain experiment (Deštné), diameter classes ranged from 2 to 14 cm before the first thin-

Table 2. Values of skewness and kurtosis for the diameter distribution of beech and spruce trees in stands of Všeteč and Deštné experiment at the age of 19 and 35 years and 17 and 33 years, respectively

	Age of trees (yr)	Všeteč						Deštné			
		control		thinned from above		thinned from below		control		thinned	
		spruce	beech	spruce	beech	spruce	beech	spruce	beech	spruce	beech
Skewness	19 (Všeteč),	0.79	0.55	0.38	0.87	0.89	0.51	1.26	1.91	1.28	1.26
Kurtosis	17 (Deštné)	−0.80	−0.64	−0.55	−0.83	−0.97	−0.54	1.26	3.68	2.16	1.73
Skewness	35 (Všeteč),	0.60	0.77	0.88	−0.52	1.35	1.06	0.72	0.94	1.50	0.04
Kurtosis	33 (Deštné)	−1.25	−0.54	−0.31	−1.14	1.49	0.00	−1.02	1.35	2.44	−1.51

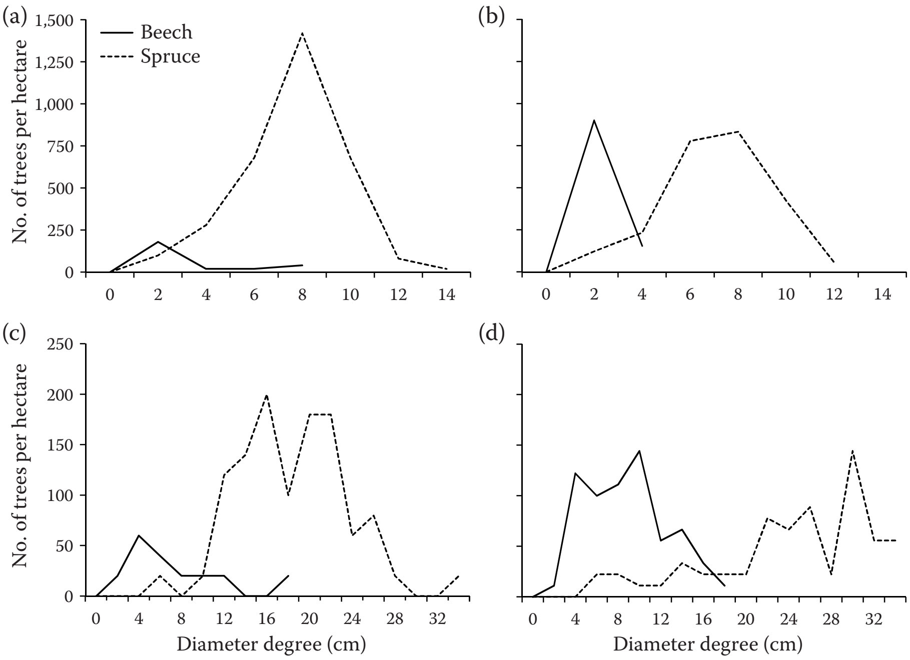

Fig. 4. Diameter distribution at two age stages – 17 (a, b) and 33 years (c, d) for beech and spruce trees in unthinned control (a, c), thinned (b, d) mixed stands of Deštné experiment

ning (at the age of 17 years) on both plots (Fig. 4). Positive values of skewness (mean right-tailed distribution) were found for diameter structure of both species (Table 2). Also (contrary to Všeteč experiment) positive values of kurtosis represented more tapered distribution compared to the normal one. It was observed on both plots and for both species at Deštné experiment.

Sixteen years later (at the age of 33 years) diameter structure also extended reflecting the presence of thicker trees, however, thin beech trees up to 4 cm were still present (Fig. 4). The maximum beech diameter did not exceed 20 cm on either plot. As for spruce, comparable densities of the thickest trees (diameter 20 cm and greater) were found on both control (540 trees per hectare) and thinned (533 trees per hectare) plots. This represents 79% of the total number of trees on thinned plot compared to only 47% on control plot.

Values of skewness for diameter structures remained still positive (Table 2) but lower compared to the state 16 years ago. Values of kurtosis remained positive for beech on control plot and for spruce on thinned plot. On the contrary, kurtosis was changed to negative values for spruce on control plot and for beech on thinned plot.

Development of mixture

The effect of thinning on the state and development of spruce/beech mixtures was analysed based on the proportion of both species in stand *N* and *G*. The lower-altitude experiment Všeteč is situated on a site naturally dominated by beech. Accordingly, this species increased continually its share (from 59 to 75% by *N* and from 44 to 60% by *G*) in unmanaged control stand (Fig. 5). In thinned stands, beech proportions were also higher at the end of observations compared to the start of experiment (except the basal area in stand thinned from above, where the beech share decreased by 3% during the observation), but the change was not so obvious.

In the mountain experiment Deštné, located on a site where spruce is a native tree species, thinning supported beech in the stand mixture from 30 to 50% by *N* and from 3 to 12% by *G* during the period of observation (Fig. 6). In control stand we found also a small increase of beech proportion from 8 to 14% by *N* and from 2 to 3% by *G*, but it was partly caused by two snow-damage events affecting spruce at the age of 22 and 24 years (see the chapter Methods).

DISCUSSION

The main purpose of pre-commercial thinning is to improve stand stability and maintain desirable species composition in the young mixture (Waskiewicz et al. 2013). The main effect of thinning in our experiments was reduced salvage cut on thinned plots compared to controls during the period of observation. In contrast, diameter distribution was still relatively wide (i.e. many thin trees were left) at the end of observations on all plots of both experiments. This was likely attributable to the low thinning intensity. In case of higher (40% of basal area removed) thinning intensity (Yücesan

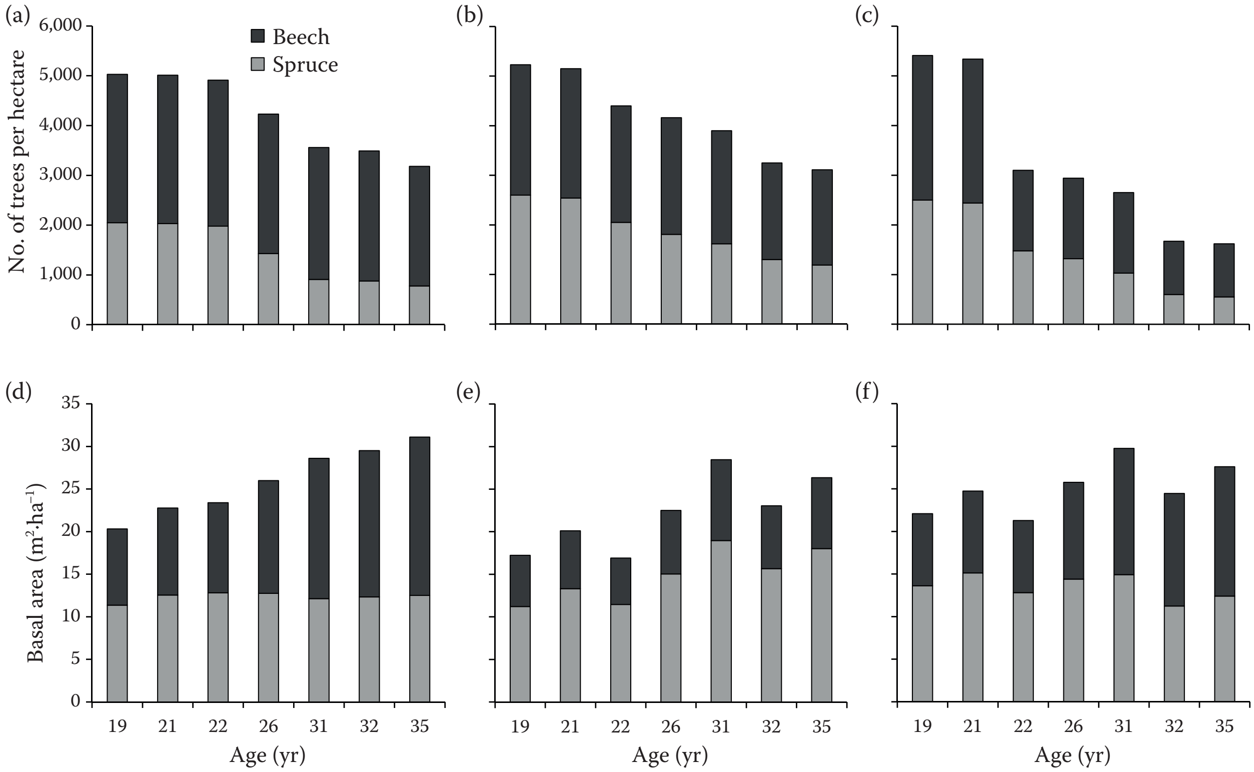

Fig. 5. Development of spruce/beech mixtures by number of trees (a, b, c) and basal area (d, e, f) in unthinned control (a, d), thinned from above (b, e), thinned from below (c, f) mixed stands in Všeteč experiment located in a site naturally dominated by beech

et al. 2015), the former rich diameter structure of beech stands was equalized.

Our results showed higher periodic diameter increment on thinned plots compared to controls; it supported partly the conclusions from mixed pine/spruce stands (Olson et al. 2012), aspen/fir stands (Prévost, Gauthier 2012) or birch/spruce stands (Hawkins et al. 2012). All above-mentioned studies found that pre-commercial thinning increased basal area increment. Consequently, higher di-

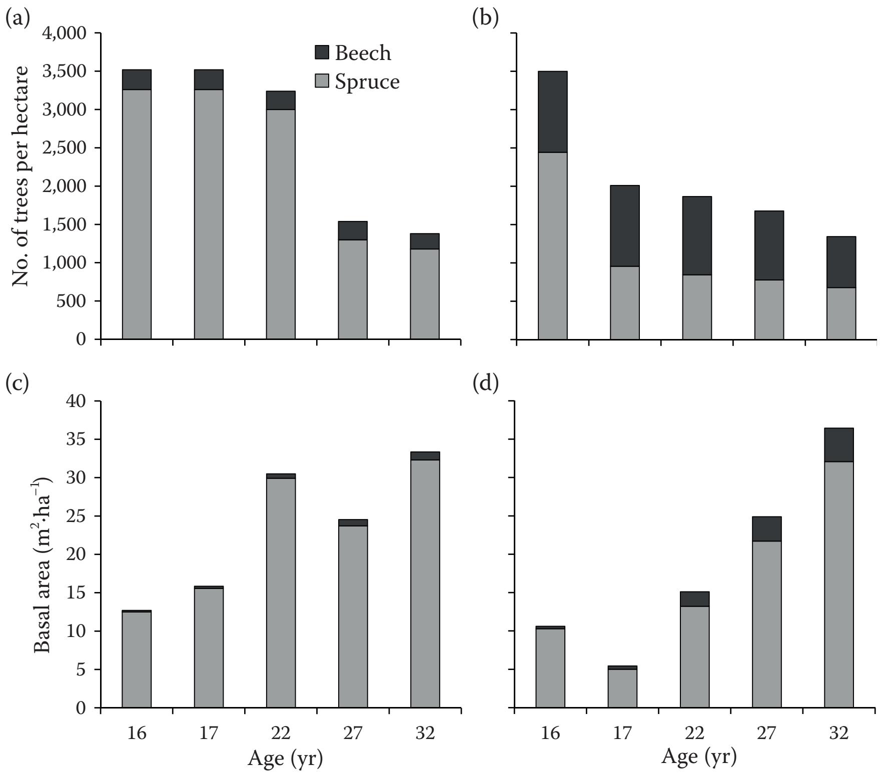

Fig. 6. Development of spruce/beech mixtures by number of trees (a, b) and basal area (c, d) in unthinned control (a, c), thinned (b, d) mixed stands in Deštné experiment located in a site naturally dominated by spruce

ameter increment contributed to higher individual stability (e.g. Konôpka et al. 2008). As in the monocultures, the intensive first thinning tended to diminish the risk also in mixtures (Eslami et al. 2013). The degree of damage in mixed stands derives essentially from the intrinsic stability (as observed in pure stands) of the species involved and their relative proportions (Colin et al. 2008). On the other hand, late intensive thinning (top height over 15 m) increases risks of windfall in spruce dominated stands (Wallentin, Nilsson 2014).

As for the diameter distribution, Fahlvik et al. (2011) found no significant influence of birch on the diameter development of Norway spruce in southern Sweden. Despite the simple experimental design, some trends showing the diameter distribution were found in our study. Diameter distribution of Norway spruce in mixtures showed lowering values of skewness and kurtosis on unthinned control plots in both experiments during the period of observations. On the other hand, the thinning increased these values for spruce in both experiments. In case of beech in mixture, results were not so clear, compared to spruce. Skewness and kurtosis of beech diameter distribution increased on both control and thinned-from-below plots in Všeteč experiment. During the same time, these values decreased on two plots thinned from above (both experiments). Our results are in accordance with Fahlvik et al. (2015), who reported a significant influence of the structure of mixed stands (Scots pine, Norway spruce and birch in Sweden) during pre-commercial thinning. On the other hand, Pach and Podlaski (2015) found that unmanaged mixed fir/beech stands showed more complex diameter structural diversity compared to managed mixtures. In our study, the above-mentioned trends need (dis)confirmation by subsequent research based on wider experimental material, because of non-replicated plots and relatively small initial proportion of beech in Deštné experiment (especially control plot).

In our study, thinnings supported the spruce share at a lower elevation and the beech share at a higher elevation. Similar results, i.e. an increase of broadleaves proportion in unmanaged stands, were observed in older natural mixtures of spruce/fir/beech (Štefančík, Kamenský 2006). Site conditions (poor vs. fertile sites) are important for biomass productivity of mixtures compared to monocultures (Pretzsch, Schütze 2014). A negative effect of beech on the pine growth was observed on unthinned plots by Primicia et al. (2016) in the western Spanish Pyrenees. Konôpka et al. (2016) found that the morphology of beech foliage is more plastic than that of spruce, i.e. possibly contributing to the competitive advantage of beech in locations where the two species co-occur. A higher proportion of broadleaves in mixtures can increase biodiversity and other non-wood forest services, though the stand volume increment is not benefitting. On the other hand, Hynynen et al. (2011) suggested that a small admixture of silver birch can be left in Scots pine dominated stand without major negative impacts on the amount of stem wood production.

Active management strategy at an early stage is essential also for the creation of mixed stands (Holmstrom et al. 2016). Spellmann, Nagel (1996) recommended early, more or less heavy crown thinning for spruce-beech mixtures according to today's tending targets. Mixtures can also be left as "self-thinning" stands (Cameron 2002). Instead of thinning, two species of different growth rates can be planted, which would support the "self-thinning" effect to leave the desired final crop.

Early thinning supported the growth of mixed stands in our study. We supposed that a new space created by thinning is essential for the growth of individual trees. Erickson et al. (2009) confirmed that the size of a neighbouring tree influenced growth more than the species identity.

According to natural processes, relative proportions in mixtures may change over time (Bravo-Oviedo et al. 2014). Our results indicated that the first thinning is an important silvicultural measure to maintain the future mixture.

Similar results were published by Waskiewicz et al. (2013) for a mixture of northern red oak/eastern white pine or by Neufeld et al. (2014) for a mixture of white spruce/aspen. Also Rytter and Werner (2007) confirmed the importance of early silvicultural measures (thinning) for young mixed broadleaved stands of birch/aspen/black alder/lime. Pre-commercial thinning is essential in mixed stands (study from spruce/fir stands) because of growth, yield and financial returns support (Bataineh et al. 2013).

CONCLUSIONS

The material we used for the presented analysis can be qualified as limited because of small dimensions, no replications and partly unbalanced mixture at the start of observations. However, some interesting trends about thinning effects in young spruce-beech mixtures were found.

Growth and development of young mixed spruce/beech stands were positively influenced by the first pre-commercial thinning on both study sites, i.e. naturally dominated by beech or spruce. The most pronounced effect of thinning consisted in a reduction of salvage cut (dead tree basal area). Thinned stands also showed the better static stability (lower *h*/*d* ratio) of dominant spruces compared to unthinned stands on both locations. Additionally, thinning supported the spruce share at a lower elevation and the beech share at higher elevation.

References

Agestam E., Karlsson M., Nilsson U. (2006): Mixed forests as a part of sustainable forestry in southern Sweden. Journal of Sustainable Forestry, 21: 101–117.

Ammer C., Bickel E., Kölling C. (2008): Converting Norway spruce stands with beech – a review of arguments and techniques. Austrian Journal of Forest Science, 125: 3–26.

Bataineh M.M., Wagner R.G., Olson M.G., Olson E.K. (2013): Midrotation response of ground vegetation to herbicide and precommercial thinning in the Acadian Forest of Maine, USA. Forest Ecology and Management, 313: 132–143.

Bravo-Oviedo A. et al. (2014): European mixed forests: Definition and research perspectives. Forest Systems, 23: 518–533.

Cameron A.D. (2002): Importance of early selective thinning in the development of long-term stand stability and improved log quality: A review. Forestry, 75: 25–35.

Colin F., Brunet Y., Vinkler I., Dhôte J.F. (2008): Résistance aux vents forts des peuplements forestiers, et notamment des mélanges d'espèces. Revue Forestiere Francaise, LX: 191–205.

del Río M., Pretzsch H., Alberdi I., Bielak K., Bravo F., Brunner A., Condés S., Ducey M.J., Fonseca T., von Lüpke N., Pach M., Peric S., Perot T., Souidi Z., Spathelf P., Sterba H., Tijardovic M., Tomé M., Vallet P., Bravo-Oviedo A. (2016): Characterization of the structure, dynamics, and productivity of mixed-species stands: review and perspectives. European Journal of Forest Research, 135: 23–49.

Dhar A., Wang J.R., Hawkins C.D.B. (2015): Interaction of trembling aspen and lodgepole pine in a young sub-boreal mixedwood stand in central British Columbia. Open Journal of Forestry, 5: 129–138.

Drössler L., Övergaard R., Ekö P.M., Gemmel P., Böhlenius H. (2015): Early development of pure and mixed tree species plantations in Snogeholm, southern Sweden. Scandinavian Journal of Forest Research, 30: 304–316.

Erickson H.E., Harrington C.A., Marshall D.D. (2009): Tree growth at stand and individual scales in two dual-species mixture experiments in southern Washington State, USA. Canadian Journal of Forest Research, 39: 1119–1132.

Eslami A., Jahanara M.R., Hashemi S.A. (2013): Effect of thinning on growth of *Acer velutinum* Boiss. in northern forests of Iran. Forest Science and Practice, 15: 320–324.

Fahlvik N., Ekö P.M., Petersson N. (2015): Effects of precommercial thinning strategies on stand structure and growth in a mixed even-aged stand of Scots pine, Norway spruce and birch in southern Sweden. Silva Fennica, 49: 1–17.

Fahlvik N., Agestam E., Ekö P.M., Linde M. (2011): Development of single-storied mixtures of Norway spruce and birch in southern Sweden. Scandinavian Journal of Forest Research, 26 (Suppl. No. 11): 36–45.

Fahlvik N., Agestam E., Nilsson U., Nystrom K. (2005): Simulating the influence of initial stand structure on the development of young mixtures of Norway spruce and birch. Forest Ecology and Management, 213: 297–311.

Forrester D.I., Pretzsch H. (2015): Tamm review: On the strength of evidence when comparing ecosystem functions of mixtures with monocultures. Forest Ecology and Management, 356: 41–53.

Hawkins C.D.B., Dhar A., Rogers B.J. (2012): How much birch (*Betula papyrifera*) is too much for maximizing spruce (*Picea glauca*) growth: A case study in boreal spruce plantation forests. Journal of Forest Science, 58: 314–327.

Holmstrom E., Hjelm K., Karlsson M., Nilsson U. (2016): Scenario analysis of planting density and pre-commercial thinning: Will the mixed forest have a chance? European Journal of Forest Research, 135: 885–895.

Hynynen J., Repola J., Mielikäinen K. (2011): The effects of species mixture on the growth and yield of mid-rotation mixed stands of Scots pine and silver birch. Forest Ecology and Management, 262: 1174–1183.

Kelty M.J. (2006): The role of species mixtures in plantation forestry. Forest Ecology and Management, 233: 195–204.

Konôpka B., Pajtík J., Marušák R., Bošeľa M., Lukac M. (2016): Specific leaf area and leaf area index in developing stands of *Fagus sylvatica* L. and *Picea abies* Karst. Forest Ecology and Management, 364: 52–59.

Konôpka J., Konôpka B., Nikolov C. (2008): Analysis of salvage timber felling according to injurious agents and forest regions. Forestry Journal, 54: 107–126.

Metz J., Annighofer P., Schall P., Zimmermann J., Kahl T., Schulze E.D., Ammer C. (2016): Site adapted admixed tree species reduce drought susceptibility of mature European beech. Global Change Biology, 22: 903–920.

Neufeld B.A., Morris D.M., Luckai N., Reid D.E.B, Bell F.W., Shahi C., Meyer W.L., Adhikary S. (2014): The influence of competition and species mixture on plantation-grown white spruce: Growth and foliar nutrient response after 20 years. The Forestry Chronicle, 90: 70–79.

Novák J., Slodičák M. (2008): Quantity and quality of litterfall in young European beech (*Fagus silvatica* L.) stands in localities naturally dominated by broadleaves. Austrian Journal of Forest Science, 125: 67–78.

Novák J., Slodičák M. (2009): Thinning experiment in the spruce and beech mixed stands on the locality naturally dominated by beech – growth, litter-fall and humus. Journal of Forest Science, 55: 224–233.

Olson M.G., Wagner R.G., Brissette J.C. (2012): Forty years of spruce-fir stand development following herbicide application and precommercial thinning in central Maine, USA. Canadian Journal of Forest Research, 42: 1–11.

Pach M., Podlaski R. (2015): Tree diameter structural diversity in Central European forests with *Abies alba* and *Fagus sylvatica*: Managed versus unmanaged forest stands. Ecological Research, 30: 367–384.

Persson P. (1972): Stand Treatment and Damage by Wind and Snow – Survey of Younger Thinning Experiments. Stockholm, Department of Forest Yield Research: 205. (in Swedish with English summary)

Pretzsch H., Biber P. (2016): Tree species mixing can increase maximum stand density. Canadian Journal of Forest Research, 46: 1179–1193.

Pretzsch H., Schütze G. (2014): Size-structure dynamics of mixed versus pure forest stands. Forest Systems, 23: 560–572.

Prévost M., Gauthier M.M. (2012): Precommercial thinning increases growth of overstory aspen and understory balsam fir in a boreal mixedwood stand. Forest Ecology and Management, 278: 17–26.

Primicia I., Artázcoz R., Imbert J.B., Puertas F., Traver M.C., Castillo F.J. (2016): Influence of thinning intensity and canopy type on Scots pine stand and growth dynamics in a mixed managed forest. Forest Systems, 25: e057.

Rytter L., Werner M. (2007): Influence of early thinning in broadleaved stands on development of remaining stems. Scandinavian Journal of Forest Research, 22: 198–210.

Schütz J.P., Gotz M., Schmid W., Mandallaz D. (2006): Vulnerability of spruce (*Picea abies*) and beech (*Fagus sylvatica*) forest stands to storms and consequences for silviculture. European Journal of Forest Research, 125: 291–302.

Slodičák M. (1995): Thinning regime in stands of Norway spruce subjected to snow and wind damage. In: Coutts M.P., Grace J. (eds): Wind and Trees. Cambridge, Cambridge University Press: 436–447.

Spellmann H., Nagel J. (1996): Aspects concerning the thinning of Norway spruce and beech. Allgemeine Forst- und Jagdzeitung, 167: 6–15.

Štefančík I. (2010): Vplyv výchovy a poškodenia snehom na zmeny drevinového zloženia, porastovej výstavby, kvalitatívnej a kvantitatívnej produkcie zmiešanej smrekovo-jedlovo-bukovej žrďoviny na výskumnej ploche Stará píla. Lesnícky časopis – Forestry Journal, 56: 129–154.

Štefančík I. (2016): Porovnanie kvalitatívnej produkcie bukových porastov s rozdielnym manažmentom. Zprávy lesnického výzkumu, 61: 247–253.

Štefančík I., Kamenský M. (2006): Natural change of tree species composition in mixed spruce, fir and beech stands under conditions of climate change. Lesnícky časopis – Forestry Journal, 52: 61–73.

Vettenranta J., Miina J. (1999): Optimizing thinnings and rotation of Scots pine and Norway spruce mixtures. Silva Fennica, 33: 73–84.

Wallentin C., Nilsson U. (2014): Storm and snow damage in a Norway spruce thinning experiment in southern Sweden. Forestry, 87: 229–238.

Waskiewicz J., Kenefic L., Weiskittel A., Seymour R. (2013): Species mixture effects in northern red oak-eastern white pine stands in Maine, USA. Forest Ecology and Management, 298: 71–81.

Yücesan Z., Özçelik S., Oktan E. (2015): Effects of thinning on stand structure and tree stability in an afforested oriental beech (*Fagus orientalis* Lipsky) stand in northeast Turkey. Journal of Forest Research, 26: 123–129.

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