Development of young substitute larch (*Larix decidua* Mill.) stands after first thinning

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ABSTRACT: European larch (*Larix decidua* Mill.) is one of the most important tree species in substitute stands of the Krušné hory Mts. (northern part of the Czech Republic). At present, young larch stands have dynamic height growth and their canopy is closing. Therefore, the proper forest treatment with respect to all functions of these stands is an urgent issue. The aim of the study is to recognise when it is possible to start with thinning and what types of thinning regimes are more suitable in larch stands with respect to their functions as substitute tree species stands. Research was conducted on experimental series Kalek established in a larch monoculture in 1999 (stand age of 12 years) at an elevation of 780 m above sea level in the category *Piceeto-Fagetum oligo-mesotrophicum – Calamagrostis villosa*. The presented analysis has two main parts: (a) effect of closing canopy on growth of larch – comparison of the groups of trees from border and inside rows and (b) effect of opening canopy on growth and development of young larch stands – comparison of two partial plots (500 m^2 each): the one without thinning and the other with thinning (negative selection mainly from above at the age of 13 years). Comparative analyses of trees from border and inside rows showed high growth dynamics of these young larch stands, and therefore the first thinning is necessary in this stage (by 15 years of age). In spite of air pollution, the growth of experimental stands is supernormal and exceeds the data from growth tables, but 60% of individuals showed some malformations, mostly one-sided or two-sided stem curvature. Five years after the first thinning we found a significantly lower *h/d* ratio of mean stem on the thinned plot in comparison with the plot without thinning. On the other hand, the applied thinning had no effect (five years after realisation) on the *h/d* ratio of dominant trees (200 thickest trees per hectare).

Keywords: substitute forest stands; European larch; thinning; Krušné hory Mts.; Czech Republic

The environment in the Krušné hory Mts. is damaged mainly due to careless economic development in the last decades, especially due to large-scale brown coal mining and burning in power plants. Forest ecosystems of this area suffered damage of different intensity or they were totally destroyed. During the 70's and the 80's, forest regeneration was aimed at the creation of substitute tree species (STS) stands, especially on the sites where the declining spruce monocultures could not be replaced by ecologically suitable tree species.

Currently, STS take up 33,000 ha of forestland, which is 52% of forestland of the eastern Krušné hory Mts. ridge. Birch (*Betula* sp.) and blue spruce (*Picea pungens* Engelm.) or mixtures of these two species cover the largest percentage (ca. 61%) of this area. European larch (*Larix decidua* Mill.) with ca. 14% of the area is another important species among STS. Other tree species such as European mountain ash (*Sorbus aucuparia* L.), European aspen (*Populus tremula* L.) and conifers (e.g. the pines *Pinus rotundata* Link. and *Pinus contorta* Loudon) occur to a lesser extent (Kubelka et al. 1992).

In the Czech Republic, European larch is an autochthonous species with relative air pollution tolerance (Šindelář 1965, 1978, 1988; Balcar 1998). Larch in the beech with spruce forest vegetation zone (6^{th} FVZ) is handled as target tree species and

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in the spruce with beech 7th FVZ as a transition from the target to the substitute tree species. As a rule, larch stands are not projected to stand reconstruction and stand conversion and, therefore, proper attention must be paid to their tending. Larch as light-demanding species needs timely and intensive thinning in the overstorey. Because of the insufficient cover of soil, it is important to create the rich understorey from birch or mountain ash (in 7th spruce with beech FVZ) or from beech (in 6th beech with spruce FVZ). With respect to various methods of regeneration, different development, density and various admixtures, the larch stands must be tended individually.

At present, young larch stands have dynamic height growth and the canopy is closing. The planting of larch stands as monocultures is atypical and traditionally not recommended. In spite of this, larch monocultures were created on immission clearings, and therefore the proper forest management with respect to all functions of STS stands is an urgent issue.

The aim of the experiments is to examine the effect of open canopy on growth and development of larch stands with respect to their functions as STS stands. Kalek experiment is one of the two thinning experimental series in European larch stands (5 comparative plots) which were established in the Krušné hory Mts. (Novák, Slodičák 2003).

MATERIAL AND METHODS

Kalek experimental series was established in 1999 to investigate the tending of young larch stands in Litvínov forest district. The stand is located in the 6th beech with spruce FVZ at an elevation of 780 m above sea level in the fresh, medium nutritive category 6S4 (*Piceeto-Fagetum oligo-mesotrophicum – Calamagrostis villosa*). The soil type was classified as Entic Podzol. Mean annual temperature is 6°C; the mean sum of precipitation is ca. 800 mm (for the period of 1961–1990). The co-ordinates of the series are 50°35´11´´N latitude and 13°21´11´´E longitude.

The experimental larch stand was established by line planting (with initial spacing 1 × 1.5 m – 6,667 trees per ha) after a mechanical raking of slash to rows. In 1996, when the larch stand was 9 years old, the rows were spread out and planted by Norway spruce. Therefore, alternating belts (width 15–20 m) of larch and spruce stands were created on the total area of 9.7 ha.

The present study is focused on two main problems:

a) **Effect of competition on growth and development of larch cultures**

The aim of this part of investigations was to recognise the time (period) when the growth of larches was significantly affected by the closing canopy. Therefore, the study is based on the comparison of biometrical parameters (dbh, height, *h/d* ratio) of two sets of trees (25 individuals each) from a border row and from an inside row. Three groups of trees were determined: d_{25} – all trees in the row, d_{20} – without 5 thinnest individuals, d_{10} – ten thickest individuals. We used the first row of the belt (border row) and an adjacent row from comparative plot 1 (inside row). All trees in rows were numbered and points for diameter measurement were labelled. Diameter at breast height and height of all trees have been measured annually since 1999.

b) **Effect of canopy opening on growth and development of young larch stands**

In this second part of investigations, we evaluated the effect of experimental thinning on biometrical parameters (dbh, height, *h/d* ratio) of larch stands.

In 1999, before a comparative analysis of plots was carried out, the health condition (foliage, game damage) and quality (stem curvature) of larch stand was evaluated. We used these classifications: (a) of health condition: 1 – healthy, 2 – moderately damaged, 3 – heavily damaged, (b) of game damage: 0 – no damage, 1 – damaged, (c) of stem quality: 1 – straight stem, 2 – one-sided curvature, 3 – two-sided curvature.

The experiment consists of two partial comparative plots (500 m^2 each): 1 – variant without thinning and 2 – variant with thinning. Due to the results of classification (stem quality and health condition), the thinning regime on plot 2 was planned as negative selection mainly from above. The first thinning started in 2000 (age of 13 years).

All trees on plots were numbered and points for diameter (d) measurement were labelled. Diameter at breast height of all trees and height of representative groups of trees from all tree classes have been measured annually since 2000 until now. Each comparative plot is divided into 5 partial blocks – replications (100 m^2 each) for the statistical evaluation.

All statistical analyses were performed in a statistical system UNISTAT® (version 5.1) using the significance confidence level of $p \leq 0.05$. All data on the mean stem – defined as the tree with mean diameter at breast height (diameter d, height h and quotient of slenderness h/d) and the data on dominant trees – defined as 200 thickest trees per hectare (diameter d_{200}, height h_{200} and quotient of slenderness h_{200}/d_{200}) were analysed by one-way ANOVA. The significance

Table 1. Growth characteristics of larch trees in connection with position in inside row or border row in 1999–2003 (age 12–16 years) in Kalek experiment. Analysed data sets: d_{25} all trees in row (n = 25), d_{20} without thin trees (n = 20), d_{10} only thick trees (n = 10)

Age (year)				12 (1999)			13 (2000)				14 (2001)				15 (2002)				16 (2003)			
Index				d (cm)	h (m)	h/d	d (cm)	id (cm)	h (m)	h/d	d (cm)	id (cm)	h (m)	h/d	d (cm)	id (cm)	h (m)	h/d	d (cm)	id (cm)	h (m)	h/d
All trees d_{25}	(n = 25)	inside row	mean	6.7	5.7	95	7.5	0.7	6.3	95	8.3	0.8	7.1	99	–	–	–	–	–	–	–	–
			S.D.	3.12	1.56	22.7	3.52	0.47	1.72	24.9	4.01	0.55	1.87	28.5	–	–	–	–	–	–	–	–
		border row	mean	6.7	5.6	98	8.0	1.3*	6.0	87	9.3	1.2*	6.7	83*	–	–	–	–	–	–	–	–
			S.D.	3.64	1.80	29.7	4.23	0.67	1.84	24.9	4.81	0.62	2.12	21.1	–	–	–	–	–	–	–	–
Without thin trees d_{20}	(n = 20)	inside row	mean	7.8	6.3	86	8.6	0.8	7	86	9.5	0.9	7.8	88	10.1	0.6	8.4	91	10.6	0.5	8.7	90
			S.D.	2.54	1.03	14.3	2.88	0.42	1.09	15.6	3.31	0.51	1.15	17.9	3.70	0.46	1.39	*18.3*	4.09	0.46	1.58	18.5
		border row	mean	7.8	6.2	86	9.4	1.6*	6.7	77	10.8	1.4*	7.5	75*	12.2	1.3*	8.1	72*	13.3	1.2*	8.6	70*
			S.D.	3.13	1.27	17.5	3.58	0.53	1.26	15.9	4.05	0.53	1.45	15.1	4.6	0.60	1.71	*14.1*	5.07	0.52	1.77	14.3
Only thick trees d_{10}	(n = 10)	inside row	mean	10.0	7.2	73	11.1	1.2	7.9	72	12.4	1.3	8.8	72	13.3	0.9	9.7	74	14.2	0.9	10.2	73
			S.D.	1.53	0.47	6.7	1.66	0.32	0.47	6.9	1.89	0.39	0.46	7.6	2.19	0.40	0.55	*8.4*	2.43	0.4	0.66	8.1
		border row	mean	10.4	7.3	72	12.4	1.9*	7.7	64*	14.2	1.8*	8.7	62*	15.9*	1.8*	9.5	61*	17.5*	1.6*	10.0	58*
			S.D.	2.12	0.61	8.7	2.33	0.36	0.58	7.6	2.48	0.23	0.60	6.9	2.73	0.35	0.69	6.2	3.00	0.34	0.70	6.2

d – diameter at breast height, id – diameter increment, h – height, h/d – quotient of slenderness, S.D. – standard deviation, *statistically significant differences between inside row and border row ($p \le 0.05$)

of the main effects or interactions was detected by ANOVA, multiple comparisons were carried out by Tukey's test. The diameter distribution of the experimental stands was analysed by Kolmogorov-Smirnov two sample tests.

RESULTS

Competition and growth

The effect of competition on growth and development of larch culture was investigated by comparison of biometric parameters (dbh, height, h/d ratio) of the groups of trees from border and inside rows. At the beginning of the experiment in 1999 (age of 12 years), the mean diameter of selected groups was statistically identical for both compared rows (d_{25} 6.7 cm, d_{20} 7.8 cm and d_{10} 10.0–10.4 cm, Table 1).

The following period of investigations was divided into two parts (1999–2001 and 2002–2003) because of mortality in the inside row. Therefore, the group of trees d_{25} (all trees in the row) has not been evaluated since 2001. In that year, mean diameter was higher (but statistically insignificantly) in the border row for all selected groups (d_{25} by 12%, d_{20} by 14% and d_{10} by 15%). Obvious differences were found in the last year of investigations (2003), when the mean diameter of group d_{20} was 10.6 cm in the inside row and 13.3 cm in the border row (statistically insignificant differences). On the other hand, the mean diameter of group d_{10} was significantly different in compared rows in that year (14.2 cm in the inside row and 17.5 cm in the border row) and thus similar results from the previous year (2002) were supported (Table 1).

Annual diameter increment of investigated trees in the period 2000–2003 (age of 13–16 years) varied in group d_{25} between 1.2 and 1.3 cm in border row and between 0.7 and 0.8 cm in inside row, in group d_{20} between 1.2 and 1.6 cm in border row and between 0.5 and 0.9 cm in inside row and in group d_{10} between 1.6 and 1.9 cm in border row and between 0.9 and 1.3 cm in inside row. In all cases, the diameter increment of trees was significantly higher in border row than in inside row (Table 1).

Development of tree height in the investigated groups was nearly the same (differences statistically insignificant) for both compared rows. In all cases, the mean height of groups of trees was higher (but not statistically significantly) in inside row than in border row, although mean height at the beginning of observations (1999, age of 12 years) was nearly identical for all investigated groups. In the last year of investigations (2003), the mean height in groups d_{20} and d_{10} was 8.6 m and 10.0 m in border row and 8.7 m and 10.2 m in inside row.

Better diameter increment of the trees from border row resulted in increased static stability (lower *h/d* ratio). At the beginning of experiment (1999), differences in *h/d* ratio values between the compared rows were statistically insignificant (for group d_{25} *h/d* = 95–98, d_{20} *h/d* = 86, d_{10} *h/d* = 72–73). The results show a similar trend for the groups ($d_{25,}$ d_{20} and d_{10}) during the period of observations: the *h/d* ratio of trees from the inside row increased (or was stable for group d_{10}), whereas the *h/d* ratio of trees from the border row continually decreased. Differences were statistically significant for group d_{25} and d_{20} from 2001 (age of 14 years) and for group d_{10} from 2000 (age of 13 years). In the last revision (2003), the values of *h/d* ratio in group d_{20} and d_{10} were 70 and 58 in border row and 90 and 73 in inside row.

Initial stem quality and health condition

In 1999, when the experiment started, the number of trees on both comparative plots was ca. 3,400 and basal area amounted to about 12 m^2 per hectare. At the same time, the health condition (foliage, game damage) and quality (stem curvature) of stands were evaluated. From the results, it can be concluded (Fig. 1):

– 22% of individuals showed moderate damage to assimilatory organs (health condition 2) and 10% of individuals, especially trees from lower diameter classes, were damaged heavily (health condition 3). Therefore, the trees with damage to assimilatory organs accounted for only 13% (10% moderate damage and 3% heavy damage) of total stand basal area.
– Game damage (bark browsing) was detected on 28% of individuals. Similarly like in the evaluation of health condition, especially trees from lower diameter classes (7 cm and less) were damaged. Individuals damaged by game accounted for 16% of total stand basal area.
– Only 39% of individuals showed straight stems (stem quality 1). One-sided curvature (stem quality 2) was detected in 14% of individuals. Individuals with two-sided stem curvature (stem quality 3) accounted for a larger portion of the number of trees (47%).

5-year development of stands after first thinning

Number of trees

Before the first experimental thinning (2000, age of 13 years), the number of trees on both compara-

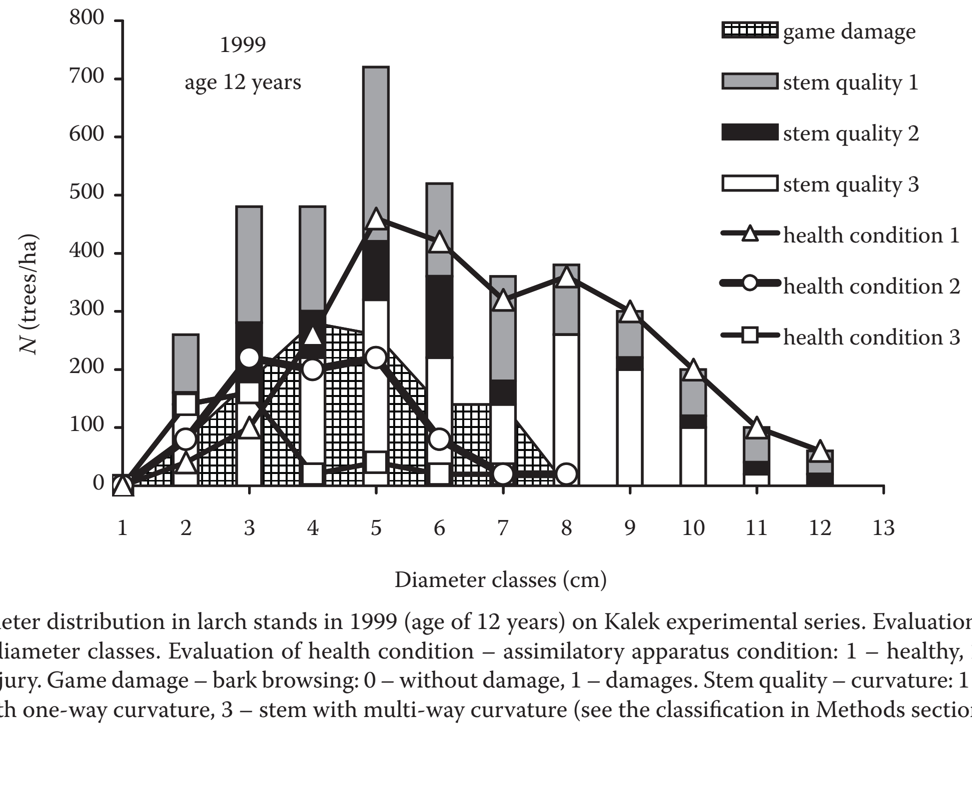


Fig. 1. Diameter distribution in larch stands in 1999 (age of 12 years) on Kalek experimental series. Evaluation of condition is marked in diameter classes. Evaluation of health condition – assimilatory apparatus condition: 1 – healthy, 2 – light injury, 3 – heavy injury. Game damage – bark browsing: 0 – without damage, 1 – damages. Stem quality – curvature: 1 – straight stem, 2 – stem with one-way curvature, 3 – stem with multi-way curvature (see the classification in Methods section)

Table 2. Basic data from Kalek experimental series in 2000–2005 (age 13–18 years)

Variants			N (trees/ha)		G (m²/ha)		d (cm)		h (m)		h/d		d_{200} (cm)		h_{200} (m)		h_{200}/d_{200}	
			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Age 13 years (2000)	before thinning	mean	3,400	3,420	14.29	14.32	7.3	7.3	6.6	6.6	91	92	12.3	12.3	8.3	8.5	67	69
		S.D.	463.7	414.7	2.876	2.615	0.47	1.19	0.21	0.55	2.9	7.0	0.85	0.97	0.20	0.25	2.9	3.2
	thinning	mean	–	1,800	–	6.54	–	6.8	–	6.4	–	94	–	–	–	–	–	–
		S.D.	–	458.3	–	2.666	–	2.25	–	1.54	–	4.9	–	–	–	–	–	–
	after thinning	mean	3,400	1,620	14.29	7.78	7.3	7.9	6.6	6.9	91	89	–	–	–	–	–	–
		S.D.	463.7	286.4	2.876	1.498	0.47	0.91	0.21	0.42	2.9	5.0	–	–	–	–	–	–
Salvage cutting (SC) 13–18 years			820	40	1.43	0.03	4.7	3.0	5.4	3.8	114	127	–	–	–	–	–	–
Age 18 years (2005)		mean	2,580	1,580*	24.69	17.19*	11.0	11.8	10.4	10.4	95	88*	17.7	17.6	12.2	12.2	69	70
		S.D.	164.0	249.0	2.883	2.968	0.57	0.94	0.22	0.37	2.9	3.7	1.27	1.91	0.24	0.42	3.5	4.6
Increment 13–18 years			–	–	11.83	9.44	3.7	4.5	3.8	3.8	+4	–4	5.4	5.3	3.9	3.7	+2	+1
Increment 13–18 years without SC			–	–	10.40	9.41	–	–	–	–	–	–	–	–	–	–	–	–

N – number of trees, G – basal area, d – diameter at breast height, h – mean height, h/d – quotient of slenderness, d_{200} – mean diameter of 200 thickest trees per 1 ha, h_{200} – height of 200 thickest trees per 1 ha, h_{200}/d_{200} – quotient of slenderness of 200 thickest trees per 1 ha, *statistically significant differences between variants ($p \leq 0.05$). Comparative variants: 1 – control plot without thinning, 2 – plot with thinning (negative selection mainly from above)

tive plots was ca. 3,400 (Table 2). Based on the results of classification (stem quality and health condition), negative selection mainly from above was chosen for the first thinning on plot 2. After the comparative analysis, 53% of the trees (46% of basal area) were removed.

During the next 5-year period without thinning, comparative stand 2 was not damaged and the number of trees per hectare decreased to 1,580 in 2005 as a result of mortality (age of 18 years). In the same period the number of trees on parallel control plot 1 decreased from initial 3,400 to 2,580 per ha (by 24%), mainly as a result of snow-break events in 2002 and 2004.

Basal area

The stand basal area before the first thinning on comparative plots 1 and 2 amounted to 14.29 and 14.32 m², respectively. Differences were not significant. The first experimental thinning decreased the basal area on comparative plot 2 to 7.78 m², i.e. to 54% of the control plot. Pronounced increment on plot 2 and several events of snow damage on plot 1 (removing 1.43 m²/ha) resulted in higher stocking on plot 2 (70% of the control plot) at the age of 18 years. Five years after the first thinning, the stand basal area on comparative plots 1 and 2 was 24.69 and 17.19 m², respectively (Table 2).

After including the basal area of all removed trees (i.e. including salvage cut), the basal area increment in the period of investigations was by 2.4 m² higher on control plot 1 compared with thinned plot 2 (11.83 m² on control plot 1 and 9.44 m² on plot 2). But on control plot, 1.43 m² of basal area (12% of increment) had to be removed during the period of investigations as salvage cut (breaks, dry trees, etc.), whereas salvage cut on thinned plot 2 amounted to only 0.03 m² (i.e. 3% of increment). When including the basal area of only intentionally removed trees (salvage cut excluded), the basal area increment in the period of investigations (age of 13–18 years) was 10.40 m² on control plot 1 and 9.41 m² on thinned comparative plot 2.

Static stability – quotient of slenderness

During the period of observations, diameter and height development was similar

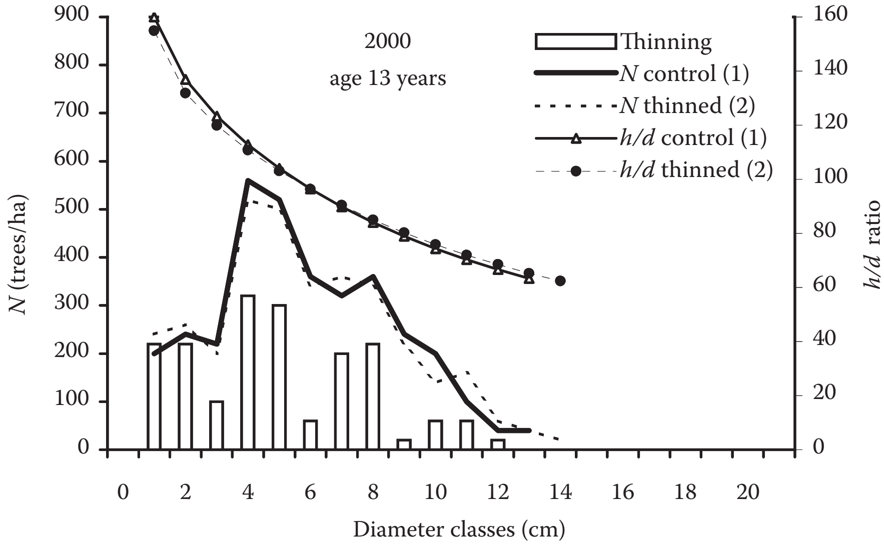
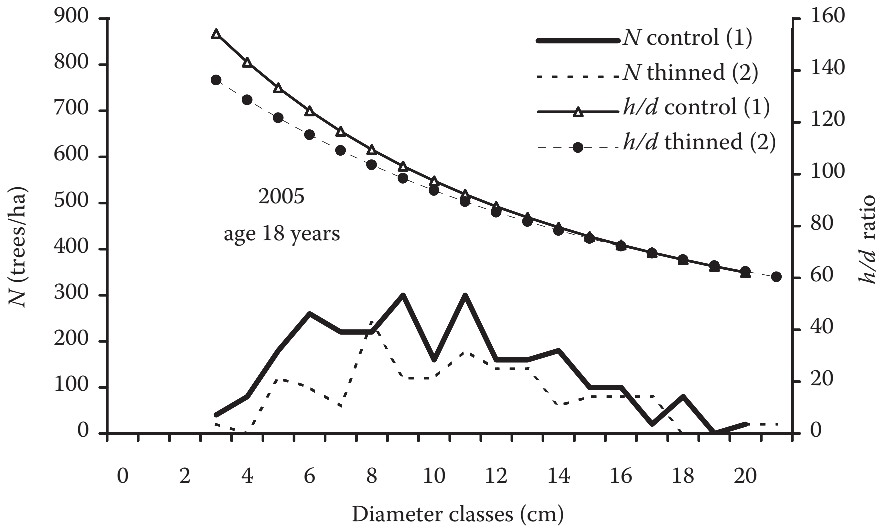


Fig. 2. Diameter distribution on comparative plots of Kalek experiment in 2000 (above) and 2005 (below) (age 13 and 18 years). Thinning on plot 2 (columns) and quotient of slenderness (*h/d*) are marked. 1 – control plot without thinning, 2 – plot with thinning



on both comparative plots (differences were not significant) primarily due to the type of thinning (negative selection), when undesirable trees were removed from all diameter classes (Fig. 2). Total height increment was identical on both plots (3.8 m) in this period (age of 13–18 years). However, total diameter increment of mean stem on thinned plot 2 (4.5 cm) was higher by 0.8 cm in comparison with control plot. Although the differences in diameter increment were not significant, an evidential effect of thinning on the *h/d* ratio of mean stem was found. At the beginning of investigations (age of 13 years), the quotient of slenderness (*h/d* ratio) of mean stem on comparative plots 1 and 2 had similar values 91 and 92 (differences were not significant). The applied thinning regime resulted in a decrease in the *h/d* ratio of mean stem on comparative plot 2 compared to the initially equal mean stem on control plot 1 without thinning (the final values at the age of 18 years on plot 1 and 2 were 95 and 88, respectively). Differences were found statistically significant (Table 2).

For the static stability of the whole stand, characteristics of dominant trees were more crucial. At the beginning of investigations (age of 13 years), the quotient of slenderness (*h/d* ratio) of initially equal 200 dominant trees on comparative plots 1 and 2 reached similar values 67 and 69 (Table 2). The effect of thinning on the *h/d* ratio of dominant trees was insignificant during the period of investigations. The final values at the age of 18 years on plot 1 and 3 were 69 and 70, respectively.

Stand structure – diameter distribution

Before the first experimental thinning at the stand age of 13 years (2000), the diameter distribution on both comparative plots was similar ranging from the classes 1–2 cm to 13–14 cm (Fig. 2). Differences were found statistically insignificant. *P*-value from the analysis by Kolmogorov-Smirnov two sample tests was 0.9995. The *h/d* ratio of particular classes on all three comparative plots ranged from relatively high values above 130 in trees with diameter below 2 cm to favourably low values below 70 in trees with diameter above 10 cm.

After the 5-year period of observations at the stand age of 18 years (2005), the diameter distribution in thinned stand 2 significantly differed from the distribution on control plot 1 (Fig. 2). *P*-value from the analysis by Kolmogorov-Smirnov two sample tests was 0.0471. One half of the remaining trees on control plot (1,300 out of total 2,580 per ha) was concentrated in diameter classes 9 cm and less with very unfavourable *h/d* ratios over 100. In thinned variant 2 only one third of the remaining individuals (34%) belonged to these diameter classes. On the other hand, we found 120 most stable trees per hectare with *h/d* ratio 70 and lower in both variants. These trees represented 8% in the thinned stand and only 5% out of the total number of individuals on the control plot.

DISCUSSION

As we mentioned in the introduction, larch is suitable for the establishment of substitute tree species stands in air pollution areas due to its relative air pollution tolerance (Šindelář 1994). Furthermore, larch (as substitute tree species) has additional advantages: compared with spruce, higher throughfall and solar radiation were found under larch stands in the vegetation period (Lang 1971). On the other hand, larch in the Czech-Moravian Uplands (ca. 600 m a.s.l.), affected the soil chemistry and organic matter cycles negatively (Podrázský, Ulbrichová 2004).

The planting of larch stands as monocultures is not traditionally recommended and practical foresters do not have adequate information about the management of such stands. Furthermore, neglected thinning and excessive density lead to unfavourable development of height growth of larch before the age of 10 years is reached (Šindelář 1974).

Larch monocultures established in the air-polluted areas have a primary function of substitute tree species stands. Therefore, stabilisation and preparations for the conversion of these stands belong to the main aims of forest management in this region.

Diameter distribution in the larch stand in our experiment was relatively wide (ca. from 2 to 21 cm). It corresponds with the results from lower altitudes (Kantor, Pařík 1998) where larch trees survived in the understorey for a relatively long time in spite of the fact that larch is considered as light-demanding species.

In our study the growth dynamics of trees from border and inside rows was compared and the trees from the border row showed significantly higher growth increments than the trees from the inside row. It means that the growth dynamics of these young larch stands is high and the first thinning should be carried out in this stage. Similar results were found for hybrid larch stands in Sweden (Ekö et al. 2004). Furthermore, the age of ten years as a time for the first thinning of larch stands to increase their stability was recommended by Vicena (1998). In this context, forest tending is important for stability in the following periods as well because omitting silvicultural measures may cause growth reduction (Klíma 1990).

Appropriate static stability of larch stands is one of the main preconditions for their survival in extreme conditions of the Krušné hory Mts. where breaks and leans of stems or crowns are frequent (Fabiánek et al. 1997). The analyses showed better diameter growth and better static characteristics (quotient of slenderness) of larch from the border row compared to trees from the inside row. Therefore, thinning at this age should result in the improved static stability of larch stand. It was confirmed by the results from Kalek experiment, where we found a significantly lower *h/d* ratio of mean stem on the thinned plot five years after the first thinning compared to the plot without thinning. On the other hand, the applied thinning did not have any effect on the *h/d* ratio of dominant trees (200 thickest trees per ha) five years after treatment.

Although substitute larch stands in the Krušné hory Mts. have primarily non-wood-producing functions, wood production cannot be omitted. European larch, as domestic tree species, belongs to the best productive species in the commercial forest (Petráš, Mecko 1994).

In spite of air pollution and location (780 m a.s.l.) of the experimental stands, diameter and height growth is very good and exceeds the data from growth tables. In 2005, the 18-years-old control stand reached the value of basal area 24.7 m^2/ha. Relevant basal area from the mensurational tables (ÚHÚL, VÚLHM 1990) is 18.0 m^2/ha (experimental stand was classified by mean height as site index 32 – mean height of main stand at the age of 100 years). Furthermore, the basal area of control stand from Kalek experiment is almost the same as the table basal area (24.8 m^2/ha) of the best 20-years-old larch stands in Switzerland (Marschall 1992). On the other hand, 60% of individuals showed some malformations, mostly one-sided or two-sided stem curvature. In addition, one result is important for the eventual wood production of these larch stands in future – we detected stem malformations in all diameter classes.

CONCLUSIONS

It can be concluded from the preliminary results of an experiment on the thinning of young larch cultures in an air polluted area of the Krušné hory Mts.:

– The canopy of larch stands that originated by the planting of ca. 6,500 plants per ha is closing in growing conditions of the 6^{th} beech with spruce forest vegetation zone at an elevation of 780 m approximately at the top height of 5–6 m (age of 10–12 years). In the period of canopy closure, the larch stands are deeply differentiated (dbh from 1 to 14 cm).
– Comparative analyses of the growth of trees from border and inside rows showed increased competition inside the stand already at the age of 15 years.
– In spite of air pollution, the growth of experimental stands is supernormal and exceeds the data from growth tables. At the same time, 60% of individuals showed some malformations, mostly one-sided or two-sided stem curvature.
– Responses of experimental larch stands to heavy thinning by negative selection were detected in the following vegetation periods. Five years after the first thinning we found a significantly lower *h/d* ratio of mean stem on the thinned plot compared to the plot without thinning. On the other hand, the applied thinning did not have any effect (five years after realisation) on the *h/d* ratio of dominant trees (200 thickest trees per ha).
– Five years after the first thinning, the diameter distribution of thinned stand was significantly different from the distribution on control plot 1. One half of the remaining trees in control plot was concentrated in diameter classes 9 cm and less with very unfavourable *h/d* ratios over 100. In thinned variant 2 only one third of the remaining individuals belonged to these diameter classes. On the other hand, we found 120 most stable trees per hectare with *h/d* ratio 70 and lower in both variants.

Recommendation to the practice

Growth dynamics of young substitute larch stands is high and the first thinning should be carried out at this stage (before the age of 15 years is reached, top height 5–6 m). Due to the common bad status of these stands (stem quality and health condition), we recommend negative selection mainly from above for the first thinning. On localities suitable for stand conversion, thinning can be connected with underplanting with shade-tolerant target tree species.

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Vývoj mladých náhradních porostů modřínu po prvních výchovných zásazích

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ABSTRAKT: Modřín evropský (*Larix decidua* Mill.) patří mezi nejdůležitější dřeviny náhradních porostů v Krušných horách. V současné době tyto porosty vykazují dynamický výškový růst a postupně se zapojují. V porostech je tak třeba začít provádět odpovídající pěstební opatření, respektující všechny funkce těchto porostů. Cílem práce bylo zjistit, kdy a jak je možné provést první výchovné zásahy s ohledem na hlavní funkci těchto porostů, tj. jako porostů náhradních dřevin. Výzkum probíhal na experimentální sérii Kalek, založené ve 12leté modřínové monokultuře v roce 1999 v nadmořské výšce 780 m na SLT 6S4 (*Piceeto-Fagetum oligo-mesotrophicum – Calamagrostis villosa*). Analýza je zaměřena na dva tematické okruhy: (a) vliv konkurence na růst a vývoj modřínových porostů – pro zjištění efektu postupného zapojování porostů byly srovnávány parametry stromů z okrajové a vnitřní řady a (b) vliv úmyslného uvolnění zápoje na růst a vývoj modřínových porostů – jsou porovnávány dvě varianty, každá o velikosti 500 m^2: 1 – kontrolní plocha bez zásahu a 2 – plocha se zásahem (negativní výběr převážně v úrovni ve věku 13 let). Srovnávací analýzou souboru stromů z vnitřní a okrajové řady byla zjištěna vysoká růstová dynamika sledovaných modřínových porostů. V odpovídajícím věku (do 15 let) je tak realizace prvních výchovných zásahů nezbytná. Přestože jsou sledované porosty lokalizovány v horské imisní oblasti, vykazují nadstandardní růst ve srovnání s tabulkovými údaji. Celkem 60 % jedinců však vykazuje tvarové vady, především jednostrannou a dvoustrannou křivost kmene. V porostu s výchovou byl pět let po zásahu zaznamenán průkazně nižší štíhlostní kvocient středního kmene ve srovnání s porostem bez výchovy. Efekt zásahu se však neprojevil na hodnotách štíhlostního kvocientu dominantních stromů (200 nejsilnějších jedinců na 1 ha).

Klíčová slova: porosty náhradních dřevin; modřín evropský; výchova lesních porostů; Krušné hory; Česká republika

Jednou z dřevin, které byly využívány k zalesňování rozsáhlých imisních holin v Krušných horách, je modřín evropský (*Larix decidua* Mill.). V současné době tyto porosty tvoří asi 14% podíl výměry porostů náhradních dřevin (PND) v Krušných horách. Cílem práce bylo zjistit, kdy je vhodné začít s výchovou modřínu a jaké výchovné zásahy jsou nejvhodnější ve vztahu k jejich funkci jako PND. Experiment Kalek patří ke dvěma experimentálním sériím (celkem pět srovnávacích ploch), založeným v modřínových porostech v Krušných horách.

Experiment Kalek byl založen v roce 1999 v tehdy 12letém náhradním porostu modřínu na LS Litvínov (zeměpisné souřadnice 50°35´11´´ sev. šířky, 13°21´11´´ vých. délky). Porost je lokalizován v nadmořské výšce 780 m na LT 6S4 (*Piceeto-Fagetum oligo-mesotrophicum – Calamagrostis villosa*) na kryptopodzolu. V období 1961 až 1990 se průměrná roční teplota vzduchu pohybovala kolem 6°C a roční suma srážek představovala 800 mm.

Sledovaný modřínový porost byl založen řadovou výsadbou (v původním sponu 1 × 1,5 m – 6 667 jedinců na 1 ha) po mechanizovaném shrnutí klestu do valů. V roce 1996, kdy byl modřínový porost devítiletý, byly rozpadající se valy rozhrnuty a zalesněny smrkem ztepilým. Takto vznikly střídající se pásy dvou dřevin (o šíři 15–20 m) na celkové ploše 9,7 ha.

Prezentovaná analýza je členěna na dvě části (témata):

(a) Vliv konkurence na růst a vývoj modřínových porostů. Pro sledování efektu postupného zapojování porostu bylo provedeno srovnání souborů (25 ks) stromů rostoucích v souvislé řadě na okraji porostu se souvislou řadou stromů, rostoucích uvnitř porostu na srovnávací ploše 1. Od roku 1999 byl každoročně odděleně hodnocen tloušťkový a výškový přírůst stromů v celých souborech (25 v každém souboru – d_{25}), po vyloučení slabých stromů (20 v každém souboru – d_{20}) a pouze u dominantních stromů (10 v každém souboru – d_{10}).

(b) Vliv úmyslného rozvolnění zápoje (výchovného zásahu) na růst a vývoj modřínových porostů. V této fázi byl sledován efekt výchovného zásahu na biometrické parametry (*d, h, h/d*) náhradních porostů modřínu. Před testováním srovnatelnosti vytyčených ploch bylo v roce 1999 provedeno hodnocení zdravotního stavu (olistění, poškození zvěří) a kvality (křivost kmene) modřínových porostů. Na experimentu jsou porovnávány dvě varianty, každá o velikosti 500 m^2: 1 – kontrolní plocha bez zásahu a 2 – plocha se zásahem. Na základě hodnocení zdravotního stavu a kvality kmenů byl na variantě 2 zvolen negativní výběr převážně v úrovni. Vlastní zásah byl proveden v roce 2000 ve věku porostu 13 let.

Všechny stromy na srovnávacích plochách jsou očíslovány a mají fixované měřiště výčetní tloušťky. Od roku 2000 se měří každoročně výčetní tloušťka všech stromů a výška reprezentativního souboru stromů (30 jedinců z každé varianty pro konstrukci výškové křivky). Obě srovnávací plochy jsou děleny na pět dílčích bloků – opakování (každý o velikosti 100 m^2) pro statistické vyhodnocení.

Statistické zpracování proběhlo v softwaru UNISTAT® (verze 5.1) s použitím hladiny významnosti $p \leq 0,05$. Všechny parametry středního kmene (tloušťka *d*, výška *h* a štíhlostní kvocient *h/d*) a parametry dominantních stromů, definovaných jako 200 nejsilnějších jedinců na 1 ha (tloušťka d_{200}, výška h_{200} a štíhlostní kvocient h_{200}/d_{200}), byly analyzovány metodou ANOVA (s následným mnohonásobným porovnáním pomocí Tukey testu). Tloušťkové struktury experimentálních porostů byly porovnávány pomocí Kolmogorov-Smirnov dvouvýběrového testu.

Na základě dosavadních výsledků experimentu s výchovou náhradních porostů modřínu v imisní oblasti Krušných hor lze formulovat následující závěry:

– Náhradní porosty modřínu s původní hustotou 6 500 stromů/ha se v podmínkách 6. LVS v nadmořské výšce 780 m zapojují při horní porostní výšce 5 až 6 m (věk 10 až 12 let). V této fázi jsou modřínové porosty již silně diferencovány (výčetní tloušťka od 1 do 14 cm, obr. 2).
– Srovnávací analýza prokázala zvyšující se konkurenci mezi jedinci uvnitř modřínového porostu. Ještě před dosažením 15 let věku byl zjištěn signifikantně vyšší tloušťkový přírůst stromů v okrajové řadě ve srovnání se stromy uvnitř porostu (tab. 1).
– Přesto, že jsou porosty lokalizovány v imisní oblasti, vykazují nadprůměrný růst přesahující tabulkové údaje (tab. 2). U většiny (60 %) jedinců však byly zjištěny deformace kmene (jednostranná a dvoustranná křivost, obr. 1).
– Byla zjištěna růstová reakce modřínových porostů na provedený výchovný zásah (negativní výběr převážně v úrovni). Pět let po provedení zásahu vykazoval štíhlostní kvocient středního kmene na zásahové ploše statisticky průkazně nižší hodnoty ve srovnání s kontrolní plochou bez zásahu. Na vývoji štíhlostního kvocientu dominantních stromů (200 nejsilnějších jedinců na 1 ha) se však efekt výchovy neprojevil (tab. 2).
– Pět let po provedení výchovného zásahu se tloušťková struktura vychovávaného porostu statisticky průkazně lišila od tloušťkové struktury porostu kontrolního (obr. 2). Polovina existujících jedinců na kontrolní ploše bez výchovy je koncentrována v tloušťkových stupních do 9 cm s velmi nepříznivým štíhlostním kvocientem na hodnotu 100. Ve vychovávaném porostu plochy 2 tvoří tyto tloušťkové stupně pouze třetina stromů. Na druhou stranu bylo zjištěno na obou variantách experimentu 120 nejstabilnějších jedinců na hektar s příznivým štíhlostním kvocientem 70 a méně.

Kvůli zjištěné vysoké dynamice růstu náhradních porostů modřínu doporučujeme v praxi provést první výchovné zásahy nejpozději do věku 15 let (optimálně při horní porostní výšce 5–6 m). Z důvodů obecně špatného stavu náhradních porostů modřínu (kvalita kmene, zdravotní stav) považujeme za vhodný negativní výběr převážně v úrovni. Na lokalitách určených k přeměně se nabízí spojit tyto zásahy již s podsadbou cílových dřevin.

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