Response of European beech radial growth to shelterwood cutting

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Abstract

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There were investigated possibilities of varying cutting intensities and cycles optimization within shelterwood system applied in beech stands growing in a suitable site conditions. The study was based on dendrochronological analysis of increments on radial discs taken from three different stem heights from sample trees representing the means for individual tree classes, selected on sample plots differing in cutting intensity (residual stocking 0.3–0.5–0.7 and control plot 0.9). The decrease in the stand density due to the cutting induced a significant radial growth increase in the sample trees, even in the advanced age (100 years). The decrease in stand stocking by 0.1 was reflected in a linear radial growth enhancement by on average 17%. The subdominant trees were best responding to the release (radial growth enhancement up to 200% after the heavy cut), followed by co-dominant and dominant trees (enhancement app. 45% and 25%). The period of the positive increment response depends on the cutting intensity, e.g. trees on the plot after heavy cut (stocking 0.3) showed a positive increment response over the whole 8 (7)-year period after the intervention across the whole stand profile, but trees on the plot after light cut (stocking 0.7) subjected to a light cut showed an increased increment only for 2–3 years, and no response was found in the subdominant trees.

Key words

annual ring index, dendrochronology, *Fagus sylvatica*, stand density, tree ring analysis

Introduction

Shelterwood regeneration is the most common and long-term applied method for natural regeneration of forest stands Central Europe (Gayer, 1898). The method is very suitable for regeneration of shade-tolerant species. The release of the main canopy layer and the decreased stand density has a considerable improving effect on increments and fertility in the residual trees and, at the same time, they support the regeneration and growth of the seedlings (Nyland 2003; Agestam et al., 2003; Pastur et al., 2000).

From the stand production view, the shelterwood regeneration is connected with losses in the volume increment of mature stands because even the higher increment in the residual trees cannot outweigh the losses due to the lower production base (Assmann, 1970). On the other hand, the higher light increment in the superior trees of the mature stand can considerably increase the value of production and, in such a way, minimise or even completely compensate losses in the volume production and the higher cost demands on the felling (Ashton et al., 2001; Korpeľ et al., 1991).

Another possibility how to shorten the rotation period is to shorten the regeneration period by increasing the intensity of the initial (preparation and seed) shelterwood cuttings. An ideal intensity of the initial cutting should ensure regeneration and optimum growing conditions for the young stand, and simultaneously induce the maximum light growth response in the residual mature trees – up to the successive release cutting. The period required for the shelter removal depends on the ecological and biological demands of the regenerated species. Saniga (2007) recommends releasing of the seedlings 3–5 years after the application of a moderate seed cutting (the intensity should not exceed the critical stocking of 0.6–0.7 according to Assmann, 1970).

In general, from the long-term production experiments it is known that the more intensive is the cutting intervention, the bigger and longer increment reaction of the parent stand can be expected – thanks to the lowered competitions for light, water and nutrients (Assmann, 1970; Peterson et al., 1997). Shelterwood cuttings, thinnings, respectively every reduction of the stand density change the way of its vertical distribution along the stem. In general, the highest diameter increment is allocated in low parts of the stem and decreases with increasing height up to a certain distance from the ground at which it reaches its minimum. Then it increases up to the crown base. In some species (beech, oak) it decreases again upwards the crown (Wenk et. al., 1990). The released trees show a tendency to shift the increment creation to the lower stem part – to the more extent the higher H/D ratio they have (Abetz, 1988). The values of the diameter increment along the stem are varying in dependence on the tree age, social status and site quality (Šmelko, 1982).

The absence of details about the changes in increments caused by a strong density reduction of mature stands results in practical absence of an exact recommendation for reaching a maximum yield from the parent stand in the last phases of its lifetime (Holgén et al., 2003). This has also been reflected in the lack of recommendation under what conditions and how is it possible to increase the intensity of the initial shelterwood cutting in such a way as to lower the risk of decreased production quality of the mature trees and to lower the overall costs connected with the stand regeneration. Quantification of the radial increment responses in a beech stand growing in good site conditions corresponding to the different intensities of the initial shelterwood cuttings and study of the influence of the tree social status on the radial growth responses in different stem parts was the principal objective of the presented study.

Area description

The study was conducted in the Western Carpathians – Kremnické vrchy Mts, Central Slovakia (48°38' N, 19°04' E). The subject was a mature beech stand with the mean age of 100 years at the establishment of experiment. The exposure is west, slope inclination up to 20º, altitude 470 m a.s.l., mean annual temperature 8.2 °C, mean temperature in the vegetation period 14.9 °C, mean annual precipitation sum 664 mm, mean precipitation sum in the vegetation period 370 mm. Before the research, the stand had been managed according to the common forestry practice. Over the 30 years preceding the research (1986) the stand was subjected three times to thinning treatments. The dominant tree species at the locality is common beech (80–95%); fir, oak and hornbeam are admixed species. The detailed site description can be found in Bublinec and Dubová (2003), Kellerová (2003, 2009), Kuklová et al. (2005), Schieber et al. (2009), Janík (2009), Mihál et al. (2009). The influence of different cutting intensity on the radial growth was studied on 4 permanent sampling plots, distinguished by the stocking, i.e. by the ratio between the actual and maximum stand basal area defined for the corresponding site quality and stand age (Assmann, 1970). The data of the Slovak yield table for beech were taken as the reference for stocking of 1.0. In February 1989 an initial shelterwood cutting of different intensity was executed. The original stocking of the stand with the value of 0.9 was changed after the cutting into: 0.3 on the plot H (heavy cut), 0.5 on the plot M (medium cut) and 0.7 on the plot L (light cut). The control plot

Table 1. Main characteristics of beech stands on research plots after cutting (1989) and sampling (1996) (H, High intensity cutting; M, Medium; L, Low and C, Control)

Plot	Year	Density stems [ha^{-1}]	Height [m]	DBH[a] [cm]	Volume[b] [m^3 ha^{-1}]	Stand density
H	1989	160	27.7	32.0	193.7	0.3
	1996	160	29.3	37.5	280.2	0.4
M	1989	243	26.9	31.3	256.8	0.5
	1996	229	28.6	35.4	353.4	0.6
L	1989	397	25.4	29.4	398.9	0.7
	1996	363	28.2	32.7	497.1	0.8
C	1989	700	23.6	25.3	571.2	0.9
	1996	633	26.3	26.6	619.8	0.9

[a]the mean diameter at breast height, [b]volume of large wood (>7 cm d.o.b. – diameter outside the bark).

C was left without intervention, with the original stocking of 0.9. The cutting was primarily focused on the admixed species, dying and ill trees and trees of a very low quality. The development of the basic stand variables after the cutting in February 1989 compared with the corresponding data from 1996 (sampling) is summarised in Table 1.

Methods

Experimental design

The diameter increment in beech trees after the application of a shelterwood cutting was analysed through a dendrochronological analysis performed on 12 sample trees. The selection of the trees was based on the dendrometric measurements of 316 beech trees from sample stands, each 0.35 ha in area. On each plot was selected a tree representing the mean for the given tree class. The tree classes were determined according to the Kraft´s classification system: dominant trees – with very well developed and large crowns, co-dominant trees – with well developed crowns; forming the main canopy level, subdominant trees – with irregularly developed, small crowns suppressed on one or several sides. The fallen sample trees were subjected to the detailed dendrometric measurements (Table 2). The stems were divided into three equal parts and radial discs were taken from the mid of medium and upper stem parts. From the lower parts, the discs were taken at a height of 1.3 m. Eventually, 36 radial discs were obtained. Annual radial increments were measured by a Digitalpositiometer in 4 selected directions, with an accuracy of 0.01 mm. The first direction was chosen randomly and second, third and fourth were obtained by 90 degrees rotation. All ring width series were cross-dated and synchronized with the help of pointer years within the system DAS (Dendrochronological Analysis System, Janíček, 1994). After the validation, individual tree ring series from the data for 4 radii were averaged. Finally, we obtained synchronized diagrams of tree rings for 12 sample trees at three different heights on stems, visualized on Fig. 1.

Quantification of changes in radial increment

Dendrochronological studies quantifying the influence of discrete events on the radial growth are based on the comparison of the tree ring widths before and after the beginning of presence of a specified controlled factor. In general, the quantification process consists of three phases (Cook and Kariukstis, 1990; Šmelko and Ďurský, 1999).

1. The first is the standardization of the original tree rings: where RW_t is the measured width of the annual ring at the age t, and A_t is the width of an annual ring expected for a given age, site quality, stand density and social position. The purpose of the standardisation is to eliminate the dimensional differences between the compared time periods, caused by the natural physiological growth processes closely related to the tree age (age trend) and tree social status.
2. Filtering from annual ring indexes the portion of variability caused by climate conditions and weather (Piovesan et al, 2003; Kucbel et al. 2009) in the years preceding and following the relevant

Table 2. Biometric characteristics of sample trees (H, M, L, C see Table 1)

Plot	Social status	Height (m)	DBH* (cm)	Crown length (m)	Crown projection (m^2)	Age (yr)
H	dominant	32.5	40.8	16.6	67.9	112
	co-dominant	27.1	30.2	12.1	45.7	100
	subdominant	19.6	20.2	13.5	52.1	98
M	dominant	29.3	42.3	14.0	76.8	97
	co-dominant	29.2	31.5	13.5	69.9	100
	subdominant	20.2	16.2	18.0	28.2	97
L	dominant	31.5	40.4	18.7	92.5	107
	co-dominant	29.7	29.4	12.3	73.0	99
	subdominant	24.9	19.0	18.6	33.7	97
C	dominant	31.3	39.8	17.0	68.1	98
	co-dominant	29.6	27.6	14.5	64.9	99
	subdominant	22.7	17.6	17.3	26.2	99

*diameter at breast height.

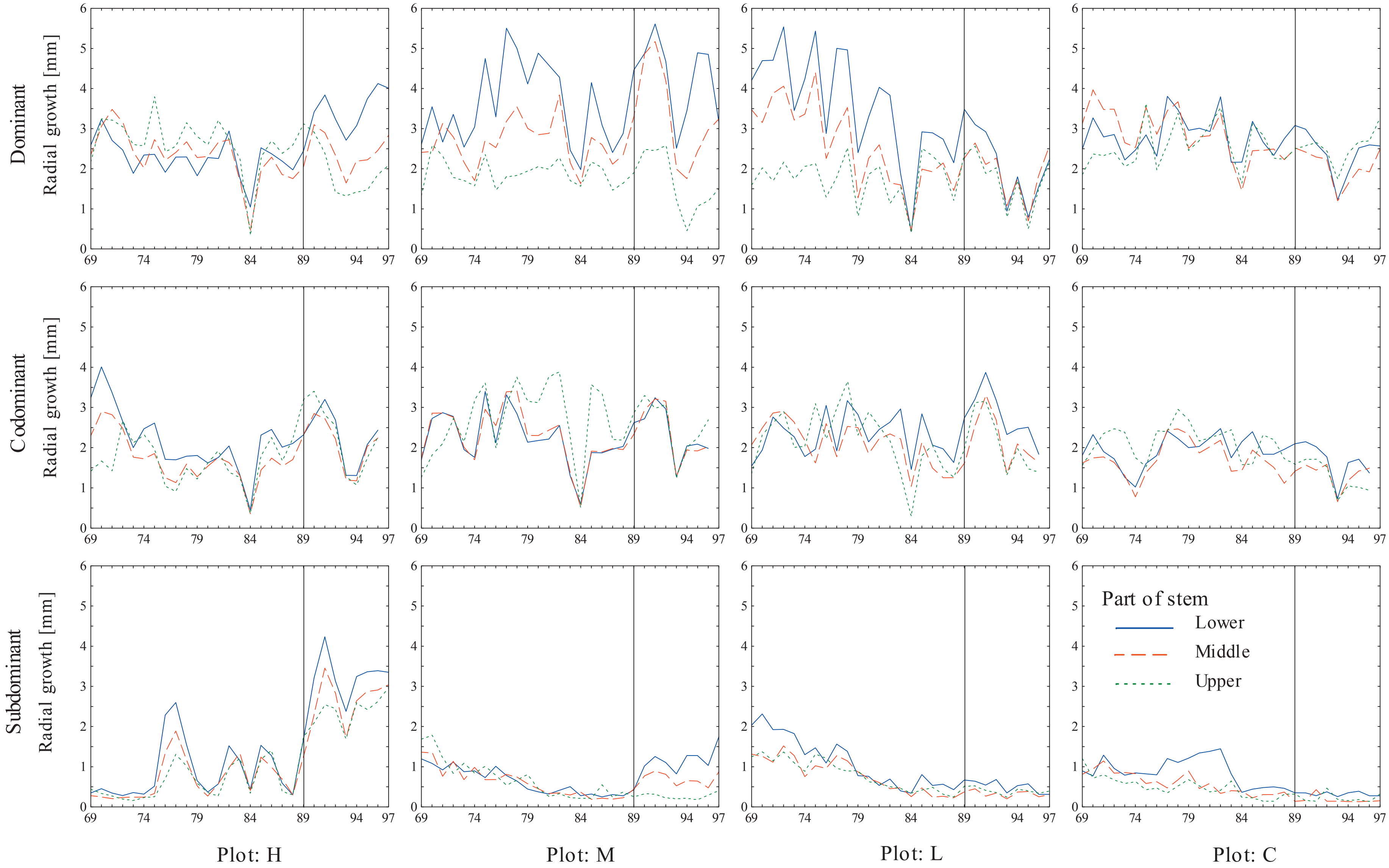

Fig. 1. Individual tree ring series stratified according to cutting intensity (H, M, L, C see Table 1) and social status, in year 1969–1997. Vertical line marks the year of cutting intervention.

event (Šmelko et al., 1992; Schweingruber, 1993). One possibility is to design a dendroclimatic model reflecting the connections between the selected climatic variables (air temperature, precipitation amount, soil water content) and annual ring indexes obtained in the first stage, and then to provide the primary and the model annual ring indexes with double indexing. More simple and more frequently used solution is a calculation of the mean values for the individual annual ring indexes over sufficiently long time periods before and after the event (Šmelko and Ďurský, 1999). The compared periods should not be shorter than 5 years (to ensure "smoothing" between the years with better and worse climate conditions; Gruber, 2002) and the most important condition for calculation of the simple means is a random fluctuation of climate effects in the compared periods.

3. The third phase is the classification of relative increment changes *CH%* based on the double indexing:

$$CH\% = \left(\frac{\overline{RWI}_{t>t_0}}{\overline{RWI}_{t<t_0}} - 1 \right) \cdot 100$$

where $\overline{RWI}_{t>t_0}$ is the mean annual ring index in the studied period and $\overline{RWI}_{t<t_0}$ is the mean annual ring index in the reference period preceding the relevant event at an age t_0.

The studied period after the cutting intervention in 1989 comprises 7 or 8 years, depending on the time when the relevant sample tree was cut (1996 or 1997). The corresponding reference period consists of 20 or 30 years before the cutting (according to the available length of the annual ring series). It is 3–5 times longer then the studied period, so as to obtain reliable estimates of the exponential smoothing parameters.

The method of simple non-seasonal exponential smoothing was used for standardization of the annual ring series and the derivation of annual ring indexes, because of relatively short time series and requirement to eliminate the combined age-increment trend in the different social groups. Parameters for the exponential smoothing were obtained by using the method of the network searching involving six optimization criteria – mean error, mean absolute error, sum of error squares, mean square error, mean relative error and mean absolute relative error.

The quantification of relative changes in the radial increment was made by using the method of double indexing; the statistical significance of the changes in increments between the studied and reference periods was tested using the *t*-test. More detailed analysis of interactions between the studied factors was done using the Duncan´s test. All analyses were conducted in the program Statistica (Tulsa, OK); modules Basic statistics, Time series analysis and ANOVA.

Results

Regardless the cutting intensity, each intervention caused a significant increase in radial increments (Table 3A). Significant increases of increments ($P \leq 0.05$) were recorded almost in all social groups and at all selected positions on the stem (Tables 3B, C). The biggest positive increment response was recorded on the plot H (stocking reduction to 0.3) where the increments increased almost 2 times, on average (Table 3A). On the plots M and L (stocking reduction to 0.5 and 0.7), a linear decrease of positive increment response with decreasing cutting intensity was also recorded. An increment increase on the plot M was 64.6% and on the plot L 19.4%. In the case of the control plot C (without intervention), we expected that the relative change in radial increments would not significantly differ from 0. Nevertheless, there occurred a significant ~10% decrease that can be related to very unfavourable, dry wetter in years 1992 and 1993. Moreover, the higher competition pressure caused worsening of tree social status of subdominant trees that showed lesser increments in comparison with the expected age trend.

Analysis of the sample tree increment responses on the plots subjected to cutting intervention (H, M, L) according to the tree social groups (Table 3B) shows that each social group had a statistically significant positive increment response to cutting interventions. The worse is the tree social status the more significant is its positive increment response. The increments in subdominant trees after the cutting were more than two times higher (109.1%). On the contrary, the smallest increments were recorded in the dominant trees (24.6%), for which the release meant only 4× smaller benefit. The mean increase of increments in co-dominant trees was 42.7% – app. two times more than in the dominant tress, on the other hand, only one half compared to the subdominant trees.

The analysis of radial increments according to the cutting intensity and tree social groups in their interaction (Table 4A, Fig. 2) showed that the increments significantly increased in all social groups on the plots H and M. The most significant response was observed in the suppressed subdominant trees that increased their increments by 199.7 and 138.4%, respectively. From the practical viewpoint, however, the increase by 24.5 and 20.6% in dominant and the increase by 60.0 and 22.2%, in co-dominant trees is much more important – both concentrated in the lower stem parts. On the plot L we can observe a significantly positive increase in increments on the dominant and co-dominant sample trees (28.8 and 43.7%, respectively). However, we did not observe a positive impact of the cutting on the subdominant sample tree in which the increments decreased by 8.6%. This decrease is comparable to the sample trees on the control plot C, in general showing decreases up to 13.7%, caused primarily by adverse climate conditions in the years 1992 and 1993.

Table 3. Changes in radial growth on annual ring indexes before and after cutting: cutting intensity (A), social status (B), different stem part (C)

Treatment		Number of annual ring indexes		Mean annual ring index		Relative change [%]
		before cutting	after cutting	before cutting	after cutting	
A	Cutting intensity (Plot)					
	high (H)	229	69	1.039	2.057	**98.0***
	medium (M)	259	69	1.033	1.700	**64.6**
	low (L)	259	69	1.043	1.245	**19.6**
	control (C)	259	69	1.030	0.932	**–9.5**
B	Social status					
	dominant	239	72	1.010	1.258	**24.6**
	codominant	229	63	1.003	1.431	**42.7**
	subdominant	279	72	1.092	2.283	**109.1**
C	Stem part					
	lower	269	69	1.061	1.974	**86.1**
	middle	259	69	1.046	1.659	**58.6**
	upper	219	69	1.002	1.368	**36.5**

*Bold letters represent statisticaly significant differences in annual ring indexes before and after cutting (P ≤ 0.05).

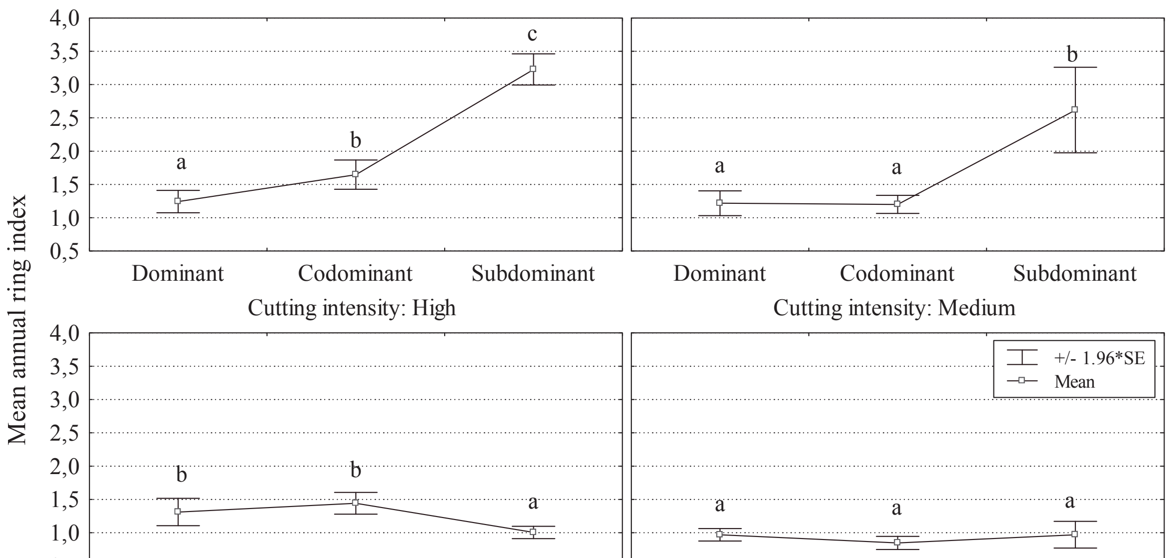

Fig. 2. Differences in mean annual ring indexes among different cutting intensity (H, M, L, C see Table 1) and social status. Different letters indicate statistically significant differences between the means; Duncan's test applied ($P \leq 0.05$).

Increment responses in dominant and co-dominant trees growing on the plots H, M and L are rather similar (Table 4), which means, that they are not close connected with the intensity of the cutting. A significant difference between the values of annual ring indexes in dominant and co-dominant trees on the plots subjected to cutting (H, M and L) was only found on the plot H (Fig. 2). Nevertheless, there are considerable differences between the lengths of enhancement increment period (Fig. 1). On the plots M and H were observed annual ring indexes considerably exceeding a value of one even after the growth depression in 1993, and they increased up to the end of the studied 7 or 8-year period after the cutting. This period of a higher increment was found through the whole stand profile, in all social groups. However, on the plot L we only detected a short 3 year period of positive increment reactions and, after the growth depression in 1993, the increment magnitude has not significantly over-passed the common age trend. The increment increase has not encompassed the whole stand profile, only dominant and co-dominant trees. On the other hand, the increment response in the first three years following the cutting was considerable. In spite of the fact that the increase proceeded for only a short time (three years), the impact of the annual rings in 1990-92 caused that the mean indexes of annual rings over the whole studied 7 (8)-year period are comparable with the mean indexes of the sample trees grown on the plots subjected to a heavier cutting treatment.

The evaluation of increment response corresponding to the individual stem parts is similar to evaluation according to the social groups: a statistically significant positive increment response to the cutting was observed in each stem part (Table 3C). The magnitude of increment enhancement decreased with increasing position on the stem; the differences between the enhancements were statistically significant. The highest positive response was identified in the lower stem parts (up to 86.1%), lower in the medium parts (58.6%) and the lowest in the upper parts (36.5%).

Interesting results were obtained after an analysis of the radial increment response according to the social groups and individual stem parts in their interaction (Table 4B). The most significant positive increment response was observed in lower parts of the subdominant trees (an increase up to 2.5 times), what well corresponds to the knowledge about the most pronounced increment response in suppressed subdominant trees and lower stem parts. In a similar manner, dominant trees also allocate the major part of their increments in the medium and lower stem parts; on the other hand, the upper parts remain without any substantial impact by the cutting intervention. Interesting situation is in the category of co-dominant trees, which show the increment uniformly distributed in all stem parts.

The interactions between the cutting intensity and the stem parts are not unambiguous (Table 4C), in spite of the expectations that the higher cutting intensity would shift the positive increment response to lower stem parts as it was observed on the plot M and partially L. There are contrary changes in increment allocation along the stem, in the plot C.

Discussion

The radial growth responses to the shelterwood cuttings of different intensity were evidently positive, in spite of the higher age of beech trees (100 years). Releasing of the tree crowns connected with a higher light supply and lowered competition for water and nutrients was reflected in a statistically significant increase in width of the annual rings in the years after the cutting treatment. Significant changes were recorded regardless the cutting intensity, almost in all social classes and stem parts. This effect has been known for a long time and it is described in the silviculture literature as light increment (Assmann, 1970; Nyland, 2002). Within the shelterwood system, it is applied in order to support the increments of the most quality trees in the mature stand over the regeneration period (Korpeľ et al., 1991; Schütz, 1999). The purpose is to reach a higher production value and, in such a way, to outweigh the higher expenses connected with the shelterwood cutting compared to clear-cut management (Holgén et. al., 2003).

Information about the magnitude of positive increment changes in mature stands is quite scarce. Certain information can be drawn from long-term dendrochronological reconstructions of growth history in the individual trees; however, commonly without an exact specification of the stand density or degree of the crown release and without any information about the cause of this release (Biondi, 1993; Nowacki and Abrams, 1997; Tokár and Krekulová, 2005). From the similar studies, we can mention the work Holgén et al. (2003), who recorded on the dominant trees in 140 year old spruce stands app. 40–48% increment enhancement as the response to the two types of shelterwood cutting (so called light and dense shelterwood cutting reducing the basal area of the mature stand to 50% and 75%, respectively). Latham and Tappeiner (2002) report that old co-dominant conifers (age ranging 158–650 years) in the Oregon area increased their radial increments after a lighter shelterwood cutting by 10% in 68% of cases and more than 50% in 30% of cases. Nowacki and Abrams (1997) detected an app. 25% increase in increments in the ancient oaks. Bebber et al. (2004) found for *Pinus strobus* L. a mean positive increment response up to 60% over the period of 9 years after shelterwood cutting, from which more than one half of the trees showed the responses over 100%, which is considered as a big increment response in the dendrochronology according to Lorimer and Frelich (1989).

The results of our research revealed a linear dependence between the positive increment responses and the cutting intensity. The stocking reduction by 0.1 (10%) induced a mean increase in the radial increment by about 17.5%. Increases in the radial increments occurred immediately the next year after the intervention (1990, Fig. 1). No negative effect (cutting shock) due to the sudden change in light conditions was detected (North et al., 1996). Equally, it has not been detected even time-delayed increment response triggered by the supposed transition period necessary for adaptation to the new microclimatic conditions; not even in the suppressed subdominant trees (Holgén et al., 2003; Latham and Tappeiner 2002; Shifley, 2004). The duration of positive increment response is also dependent on the cutting intensity. The plots H and M subjected to heavy and medium cuttings showed positive increment responses over the whole 8-year period after the intervention (except unfavourable years 1993 and 1994).

Table 4. Changes in radial growth (annual rings and ring indexes) before and after cutting, dependent on cutting intensity and social status (A); social status and different parts of stem (B); part of stem and cutting intensity (C)

Treatment			Number of annual rings		Mean annual ring (mm)		Standard deviation		Mean annual ring index		Relative change [%]
			before cutting	after cutting	before cutting	after cutting	before cutting	after cutting	before cutting	after cutting	by ring index
A	Cutting intensity	Social status									
	high (H)	dominant	73	24	2.404	2.614	0.568	0.854	0.998	1.243	**24.5***
		codominant	63	21	1.876	2.161	0.688	0.714	1.030	1.648	**60.0**
		subdominant	93	24	0.671	2.813	0.500	0.581	1.077	3.228	**199.7**
	medium (M)	dominant	83	24	2.665	3.069	0.890	1.511	1.011	1.219	**20.6**
		codominant	83	21	2.585	2.396	0.744	0.683	0.982	1.200	**22.2**
		subdominant	93	24	0.868	0.724	0.521	0.423	1.098	2.618	**138.4**
	low (L)	dominant	83	24	2.799	1.827	1.171	0.729	1.018	1.311	**28.8**
		codominant	83	21	2.202	2.367	0.591	0.744	1.004	1.443	**43.7**
		subdominant	93	24	1,080	0.402	0.525	0.126	1.100	1.005	–8.6
	control (C)	dominant	83	24	2.814	2.308	0.605	0.504	1.010	0.969	–4.1
		codominant	83	21	1.798	1.399	0.473	0.421	0.981	0.847	**–13.7**
		subdominant	93	24	0.878	0.239	0.532	0.109	1.090	0.970	–11.0
B.	Social status	Part of stem									
	dominant	lower	93	24	2.917	3.022	0.953	1.185	1.045	1.493	**42.9**
		middle	83	24	2.759	2.421	0.764	0.954	0.985	1.292	**31.2**
		upper	63	24	2.219	1.921	0.659	0.714	0.990	0.989	–0.1
	codominant	lower	83	21	2.012	2.246	0.615	0.738	1.009	1.394	**38.2**
		middle	83	21	1.980	1.990	0.598	0.711	0.982	1.458	**48.5**
		upper	63	21	2.173	2.006	0.770	0.824	1.023	1.440	**40.8**
	subdominant	lower	93	24	0.909	1.323	0.479	1.233	1.123	2.963	**163.8**
		middle	93	24	0.773	0.983	0.417	1.073	1.157	2.203	**90.4**
		upper	93	24	0.942	0.827	0.672	0.960	0.995	1.684	**69.2**
C.	Part of stem	Cutting intensity									
	lower	high (H)	23	83	1.713	0.903	3.055	0.777	1.120	2.320	**107.1**
	middle		23	73	1.427	0.909	2.432	0.592	1.103	2.011	**82.3**
	upper		23	73	1.504	1.039	2.149	0.632	0.882	1.839	**108.5**
	lower	medium (M)	23	93	1.970	1.237	2.604	1.500	1.006	2.344	**133.0**
	middle		23	93	1.901	0.962	2.120	1.402	1.028	1.704	**65.8**
	upper		23	73	1.772	0.958	1.422	1.099	1.074	1.051	–2.1
	lower	low (L)	23	93	2.279	1.235	1.700	1.134	1.062	1.257	**18.4**
	middle		23	93	1.997	1.045	1.433	0.993	1.018	1.262	**24.0**
	upper		23	73	1.6015	0.770	1.354	0.940	1.050	1.215	15.7
	lower	control (C)	23	93	1.790	0.861	1.422	0.960	1.000	0.822	**–17.8**
	middle		23	93	1.821	1.080	1.172	0.851	1.032	0.959	–7.1
	upper		23	73	1.769	0.936	1.341	1.051	1.064	1.016	–4.5

*Bold letters represent statisticaly significant differences in annual ring indexes before and after cutting ($P \leq 0.05$).

This result well corresponds to the knowledge in literature. Korpeľ et al. (1991) reports that the influence of a release maintains quite long, in fir and beech trees up to 30 years. Shifley (2004) reports a similar value – up to 20 years for oak stands. On plot L with low cutting intensity was the period of increased increment only 2–3 years; a similar response in the dominant and co-dominant trees was also found in the longitudinal increments on branches of the studied sample trees (Barna, 1999, 2000).

The magnitude of positive increment responses has been considerably influenced by the tree social status (Table 3, 4). In the category of dominant and co-dominant trees, there were no significant differences in the size of positive increment responses. Regardless the cutting intensity, the magnitude of positive increment response was ~25% in dominant trees and ~45% in co-dominant trees. According to the knowledge from the literature, the individual tree increment increases with the increasing growing space, until a certain saturation point is reached. After having exceeded this limit, there is no change in tree increment, the tree is provided with maximum usable energy supply (Utschig, 2002). This fact has been confirmed in the case of dominant and co-dominant trees. The crown releasing in dominant and co-dominant trees led to a rapid exceeding of the saturation point; consequently, there was no additional advantage for the trees growing on the plots M and H that show the positive growth responses comparable to the responses in trees growing on the plot L.

On the other hand, in the case of slight intervention into canopy, as it was the light shelterwood cutting on the plot L or any thinning from above not exceeding the critical stocking (for beech 0.6–0.7), there is no increment response in the subdominant trees. Dhote (1994) found that even after a removal of a lot of large, dominant trees by heavy thinning from above, there was no improvement of growing conditions for the subdominant trees (primarily light supply). Consequently, he concludes that the vertical structure of beech – a species with very dense foliage – is not very sensitive to cutting treatments, in terms of differentiation according to light availability. That is the probable reason to why most silvicultural instructions recommend to begin a shelterwood regeneration with a total removal of the subdominant trees (Nyland, 2003). Subdominant trees do not seem to respond to release of the upper tree layer – because the usually recommended reduction of stand density in the initial phases of shelterwood regeneration should not exceed the critical stocking (Korpeľ et al., 1991).

Analysis of the increment allocation along the stem revealed that the bigger increments were created on the lower stem parts, namely on the plots with a higher cutting intensity and in the dominant and subdominant trees (Fig. 1). On the plot L with a low cut, the trees did not show any significant changes in allocation of the increased increments along the stem. That corresponds to the observations made by Korpeľ et al. (1991) and Saniga (2000) according whom a lighter shelterwood cutting has no significant impact on the stem taper. Increased increments in the lower stem parts in the trees strong loaded by wind and by their own crown mass, after a sudden release, were frequently observed (Mitchell, 2000; Šmelko, 1982). In such cases, the trees respond to the growing space not only through increased increments; but also, according to the mechanical theory of the stem shape because of an increase of the mechanical stability, it puts them in the lower stem parts (Brüchert et al., 2000; Holgén et al., 2003). Both facts were well observable on the plots H and M treated with a heavier cutting. Overall, the significant changes in the stem shape are possible even in the advanced tree age. The cuttings could significantly deteriorate the stem taper. This fact can cause an overestimation of the tree volume and growing stock in the mature stand in later phases of the shelterwood cutting, what is especially important for the dominant trees that are the main production carriers in later phases of the shelterwood regeneration (Wenk et al., 1990).

Specific results were obtained in the category of co-dominant trees with increments distributed uniformly along the stem. Co-dominant trees are a transition social group from the viewpoint of success in competitions for the growing space. In comparison with the subdominant trees, they are able to gain a sufficient growing space and to allocate the increased increments in the lower stem parts, as required by the tree stability; on the other hand, the measure of crown suppression is considerably higher in comparison with the most successful dominant trees. Consequently, a cutting intervention into the canopy releases relatively suppressed crowns, substantially enhances their leaf area and causes remarkably enhanced increments in the crown, i.e. upper stem parts. Increased increments need not be allocated in the lower stem parts because the overstory trees can statically support each other.

Conclusions

Research on the radial increment response in the model beech stand to the different intensities of the initial shelterwood cuttings and study of the influence of the tree social status on the radial growth responses in different stem parts was the main intention of the presented study.

Dendrochronological analysis of the radial growth responses indicates that after the application of the classic seed cut of a low intensity (plot L, residual stocking 0.7), effect of the increased increments was evident only on the dominant and co-dominant trees and for three years.

The high initial cutting (plot H, residual stocking 0.3) fully maximises effects of the light increment –

increased increments were observed in all social groups and they proceeded over the whole period after the cutting (7–8 years).

Effect of the light increments on the plot M (residual stocking 0.5) has been maximised. It has been proceeding over the whole period after the intervention. The light increments in the dominant and co-dominant trees are comparable with the plot H and, unlike on the plot L, an increased increment creation is also evident in the subdominant trees. Number of the trees with the highest production is considerably higher than on the plot H (Table 1); consequently, it is possible to suppose a much higher increase in the total production value. The felling costs are comparable to the plot H because a stronger preparation cutting enables the concentration of regeneration cuttings into two phases (required by the regeneration success).

The study results present possibility to increase initial cutting intensity within the shelterwood regeneration in the unmixed even-aged beech stands in order to increase radial increments. Based on the obtained results, for mature beech stands growing in the mentioned natural conditions, we can recommend the shortened two-phase shelterwood system with heavier seed cutting. The application of the mentioned regeneration strategy should meet all silvicultural targets connected with regeneration and survival of young stands and it also enables maximisation of the production value for mature stands.

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Odozva radiálnych prírastkov u buka na intenzitu clonného rubu

Súhrn

Štúdia bola založená na dendrochronologickej analýze radiálnych prírastkov na kotúčových výrezoch, odobratých z 3 častí kmeňa (horná, stredná, dolná) vzorníkov. Bukové vzorníky, ktoré reprezentovali stredné kmene stromových tried boli spílené a analyzované 8 (7) rokov po aplikácií clonného rubu rôznej intenzity (plochy: H – silný ťažbovo-obnovný zásah, zakmenenie 0,3; M – stredný, 0,5; L – mierny, 0,7 a C – kontrolná plocha, bez zásahu, 0,9). Pokles hustoty porastu vyvolal signifikantné zväčšenia radiálnych prírastkov bukových stromov aj vo vyššom fyzickom veku (priem. 100 rokov), a to vo všetkých sociálnych skupinách a vo všetkých výškach na kmeni. Zníženie zakmenenia o 0,1 prinieslo lineárne zväčšenie radiálneho prírastku priemerne o 17 %. Vplyv sily zásahu najlepšie dokumentovali podúrovňové stromy, ktoré zareagovali na presvetlenie najvýraznejšie (zväčšenie prírastkov až do 200 %). Pri predrastavých stromoch sa zväčšenia prírastkov pohybovali okolo 25 % a pri úrovňových 45 %. Prírastky sa vo zvýšenej miere ukladali v spodných častiach kmeňov, najmä na plochách po silnejších zásahoch a pri nadúrovňových a podúrovňových stromoch. Dĺžka trvania kladných prírastkových reakcií bola závislá od sily ťažbového zásahu, napr. na ploche so zakmenením 0,3 (H) trvali kladné prírastkové reakcie celé 8 (7)-ročné obdobie po zásahu, v celom porastovom profile, ale na ploche so zakmenením 0,7 (L) trvalo obdobie zvýšeného prírastku iba 2–3 roky a rast podúrovňových stromov nebol ovplyvnený vôbec.

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