Transformation of even-aged spruce stands at the School Forest Enterprise Kostelec nad Černými lesy: Structure and final cutting of mature stand

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ABSTRACT: This paper deals with the transformation of pure even-aged forest stands to mixed and more uneven-aged stands on an example of selected even-aged Norway spruce stands in the School Forest Enterprise (SFE) in Kostelec nad Černými lesy. A forest stand where individual tree felling was used as the main method of forest stand regeneration was chosen as a conversion example. The main criterion of tree maturity is the culmination of mean volume increment of a single tree. The analyses confirmed a very high variability in the growth potential of individual trees. The potential and actual increment was strongly influenced by the stand position of tree and by crown release. These results show a high potential level of tree growth even at the age of 120 years. From 30% to 9% of all trees on particular experimental plots achieved felling maturity.

Keywords: even-aged stand; uneven-aged stand; single tree selection; final felling criteria; mean and current increment

Even-aged monoculture forest stands with a dominant position of Norway spruce (*Picea abies* [L.]) and Scotch pine (*Pinus sylvestris* [L.]) constitute the main part of forests in the Czech Republic. The proportion of both species is still distinctly different from the natural state and it amounts to more than 70%. The originally mainly broadleaved and mixed forests were replaced by coniferous plantations since the late 18th century. This change was a response to the results of an uncontrolled system of selective management which was practised in Europe till the second half of the 18th century. This selective system (without an assessment of taken quantity of wood) was missing any criteria of sustainability and it frequently led to the devastation of forests (Poleno 2000).

This implemented fundamental change brought some positive effects – higher growth rate, financial benefit for more valuable timber, sustainability of management on the basis of age and area. On the other hand, some negative impacts such as a decrease in ecological and static stability of forest ecosystems, an increase in snow, wind and biotic damage and in consequence a high portion of salvage cutting, negative impact of needle monoculture cultivation on the environmental conditions, were criticised for a long time. Mainly for these reasons there were efforts to change even-aged forest management towards alternative silviculture – "Dauerwald" – Möller (1921), "Arbeitsgemeinschaft für Naturgemässe Waldwirtschaft" – Dannecker (1951), "Vorratspflege" – Rubner (1939), Heger and Schönbach (1962) – in the forest management history. The idea of selection forest and selection management system played an uncommon role in this process. This concept was inosculated into the modern forest management history more than 100 years (Poleno 1996).

Also in recent years, the alternative systems of forest management have become more and more popular. The transformation of even-aged pure spruce or pine forest stands into forest stands with more complex stand structure is a key topic of forest management in many countries. Not only in the countries of Central Europe (Kenk, Guehne 2001; Reininger 1992; Sterba, Zingg 2001; Schütz

2001; Grassi et al. 2003) but also in North America (O'Hara 2001; Buongiorno 2001; Nyland 2003; Bergeron, Harley 1997) and in the countries of the boreal zone (Lähde et al. 1999). There are variant target estates of forests and different ways of achieving this point because they are influenced by site and forest conditions, former use of land and requirements of social community. It is possible to find various names describing a new model of forest management on the natural base, i.e. "ecologically oriented silviculture" (Frivold 1992), "ecologically sound silviculture" (Poleno 1993, 1994), "close-to-nature forestry" (Mlinšek 1996), "diversity oriented silviculture" (Lähde et al. 1999), "nature oriented silviculture" (Koch, Skovsgaard 1999) and others.

In contrast to implicit environmental advantages of this diversity oriented silviculture, some mainly economic constraints and risks of transformation were mentioned mainly in Central Europe in the last years (Knoke, Pluszyk 2001; Knoke et al. 2001; Hanewinkel 2001).

The efforts aimed at rational forest management in the Czech Republic are commensurate in many aspects with fundamentals of close-to-nature forest management which emerged in the 19th century. The main representatives of this forest movement contrary to schematic establishment of coniferous monocultures were K. Liebich and A. Tichý (Poleno 1996). The first practical forester, who realised close-to-nature forest management in the territory of the Czech Republic, was Hugo Konias – director of the Forest Estate Opočno. He conducted the conversion of spruce and pine monocultures to mixed stands since 1924 and later also the conversion of a forest managed under systems involving coupes to the selection forest (Konias 1950). The other protagonists and successors of selection forest management in the Czech Republic were Zakopal (1981), Polanský (1960, 1961) and Kratochvíl (1970). The knowledge of conversion to selection forest could be applied to other management systems, especially to a shelterwood system. Thanks to its variability this management system can be used on a large scale in the forest conditions of the Czech Republic. After 1945, the shelterwood system was applied on a relatively large area of Czech forests. This system is characterised by elimination of clear cuttings, natural regeneration, relatively long-term regeneration period and sequential conversion of coniferous monocultures into mixed stands. At that time the theory of shelterwood system was investigated in detail by Čížek and Stone (1963) and Poleno (1967).

However, in the 70s and 80s of the 20th century there was a significant decrease in practical implementation of shelterwood and selection management and a distinct increase in clear cutting application. The interest in the ideas of close-to-nature forest management was revived in the Czech Republic only several years ago. Researchers focused their attention on the evaluation of conversion to selection (uneven-aged) forest (Truhlář 1995; Šach 1996; Souček 2002; Tesař et al. 2004) and also on the optimisation of individual tree felling (Poleno 1999, 2000).

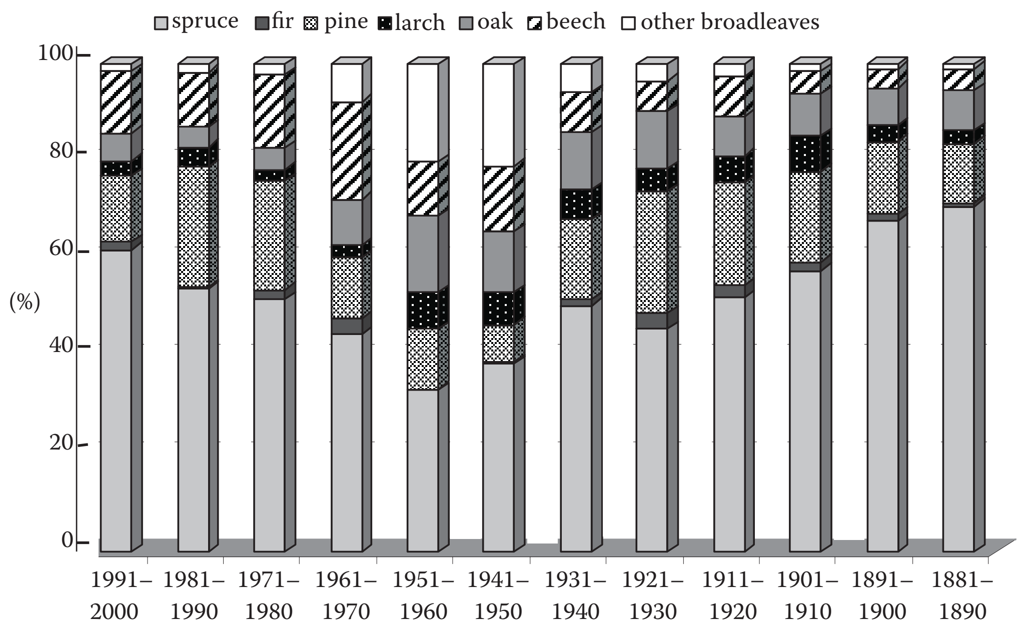

Fig. 1. Relative tree species composition according to age classes (Forest Management Plan for 2001–2010)

Table 1. Tree species composition in the SFE Kostelec nad Černými lesy in the period 1961–2001 and target species composition at the beginning of conversion

Species	Year			Long-range goal of conversion
	1961	1981	2001	
Norway spruce	46.9	45.8	49.8	22
Silver fir	2.8	1.9	1.6	13
Scots pine	24.4	22.8	18.2	26
European larch	3.1	4.4	4.4	5
Other conifers	0.4	0.5	0.3	–
Conifers in total	77.6	75.4	74.3	66
Sessile oak	8.6	9.7	8.9	15
European beech	5.5	6.8	11.7	18
European hornbeam	2.5	2.0	1.1	
Maple	0.6	0.6	0.6	
European ash	0.6	0.8	0.5	
Common birch	1.7	1.6	0.8	1
Black alder	0.8	1.0	1.0	
Linden	1.2	0.8	0.8	
Other broadleaves	0.9	1.3	0.3	
Broadleaves in total	22.4	24.6	25.7	34

Conversion of spruce monocultures in the School Forest Enterprise Kostelec nad Černými lesy

The School Forest Enterprise in Kostelec nad Černými lesy (SFE) is a facility of the Czech University of Agriculture in Prague (CUA). It was established in 1935 in the former Liechtenstein estate. The present situation of the forest estate of CUA is a result of the restitution process after 1989 and implementation of University Act No. 111/98.

SFE is located about 25–50 km south-east of Prague and it is a part of the geomorphologic system Středočeská pahorkatina, which passes to the Polabí geomorphologic system in the north. The forest stands belong to the Natural Forest Region Středočeská pahorkatina (99%) and Polabí (1%). The altitude of SFE ranges between 210 and 528 m above sea level and forest stands cover about 7,000 ha today.

SFE can be considered in many aspects as a typical example of management system development in the Czech Republic in the 20th century. The conversion of the spruce even-aged monocultures in the SFE territory started at the beginning of the 20th century. This process was accelerated after SFE foundation and forest management was importantly influenced by the Faculty of Forestry. The main person, who conducted this conversion process, was Josef Sigmond – the first professor of silviculture at the Faculty of Forestry in Prague. He accomplished systematic wide conversion through small-scale gap felling and shelterwood group regeneration. The followers of Prof. Sigmond continued the conversion by the method of differentiated regeneration. Tending of young stands (the first and the second age class) was focused on the benefits of admixture target species. A regeneration treatment was the core of the transformation process. Forest stands were divided into several categories according to the applicability of natural regeneration.

A large scale of this ambitious conversion plan and, on the other hand, not very successful results are evident from the comparison of the target tree species composition and the tree species composition in 1961, 1981, 2001 (Table 1). The process of the conversion is also well documented in Fig. 1, showing the tree species composition according to the age classes. In this graph it is possible to see a time period of Norway spruce elimination at forest regeneration (1941–1960) and a period of silver fir increase at artificial regeneration (1961–1970). For example, in 1971 silver fir plantations at the age 1–10 years covered 56.2 ha of forest land (Šrámek et al. 1985).

At the present time, several forest stands in the SFE territory, the conversion of which was initiated a few decades ago, are evaluated. This paper presents selected results of the even-aged spruce stand conversion into the forest stand with more irregular stand structure in the territory of the School Forest Enterprise in Kostelec nad Černými lesy. The forest stand where individual tree felling is used as the main method of forest stand regeneration is chosen as a conversion example. The definition of maturity is based on the increment criterion according to Poleno's idea (Poleno 1999, 2000); the main criterion is the culmination of average volume or basal area increment of a single tree. The main purpose of our research was to evaluate stand structure, current and mean increment of each tree and natural regeneration influenced by this management system.

MATERIAL AND METHOD

Site conditions

A research area (forest stand 11 C_{12}) is located in the Jevany forest district of SFE. This stand was chosen by Prof. Poleno as a part of the management method demonstration and teaching objects. The experimental plots are situated on a moderate slope at the altitude of 400–420 m above sea level. The mineral bedrock is granodiorite (so-called Říčanská žula) covered by Luvisol, in some parts with transition to Pseudogley. The slope has the north exposition with a good groundwater regime for the main part of the year. Soils have good nutrition levels and sufficient buffering capacity. The production conditions for forest trees can be evaluated as good or very good.

Climatic conditions can be described as the semi-humid climate. The average annual temperature is 7.6°C, average annual precipitation is 665 mm and Lang's rain factor is 87.6 (according to the Meteorological Station of Czech Hydrometeorological Institute in Ondřejov, the average values for the period 1961–2000).

The phytocoenological unit of research plots belongs to *Querceto-Abietinum* (forest type 401, management complex of stands 461) while a smaller part of the plots is classified as *Querceto-Fagetum* (forest type 3K3, management complex of stands 421).

This stand is a part of the National Nature Reserve Voděradské bučiny, near to its north-western border (above the Švýcar and Jan ponds, which were built on the Jevanský potok creek).

Species composition and forest management system

Nowadays, the stand age is 119 years and the present area is 7.36 ha. Natural species composition (according to the Czech typological system), present species composition of the stand (according to the management plan for 2001–2010) and target species composition (defined by Prof. Poleno) are shown in Table 2.

The forest stand regeneration started 35 years ago, when the large (more than 10 ha) mainly Norway spruce even-aged forest stand was divided by narrow strip felling followed by oak and beech planting. Natural regeneration started from the central part of the stand as a result of shelterwood and salvage cutting. The main species were Norway spruce, European larch and Scots pine. The opening for the growing young trees in a triangle design (so-called Eberhard's regeneration cut) was created step by step.

The rest of the stand area (about 7 ha) is regenerated by single tree selection followed by natural regeneration by all species of mature stand. There are differences in regeneration due to different age and different microclimatic conditions. The conditions are also favourable for silver fir regeneration due to slow development of regeneration cut giving to young silver firs competitive advantages. Silver fir is one of the most important species because it was one of the dominant species in the natural species composition of NPR Voděradské bučiny.

Last regeneration cuttings were done in this stand in 1998 and 2002.

Table 2. Tree species composition of experimental forest stand 11 C_{12}

Tree species	Natural species composition	Present species composition	Target species composition
Norway spruce (*Picea abies* [L.] Karst.)	0–2	84	50
Silver fir (*Abies alba* Mill.)	30–45	3	10
Scots pine (*Pinus sylvestris* L.)	0–5	7	–
European larch (*Larix decidua* Mill.)	–	1	10
Sessile oak (*Quercus petraea* [Matt.] Liebl.)	30–45	–	10
European beech (*Fagus sylvatica* L.)	10–25	–	20
Other species	±10	–	–

Research plots and methods

Three permanent research plots (PRP) for structural and increment analyses of the parent stand are situated in the parts of the forest stand with different phases of regeneration and with different stand and canopy density; their area is 9,430 m^2. The research project started in 1996, with the aim to consider practical feasibility of the increment criterion of individual tree felling maturity (POLENO 1999, 2000). The following measurements were done on each plot:

- diameter at breast height (measured with calliper to the nearest 1 mm),
- height (measured with Blumme-Leiss standard hypsometer to the nearest 0.5 m),
- crown height (m),
- crown space (m^2) was detected with equipment that is based on the refraction of the image in a looking glass (embedded under an angle 45°),
- crown volume (m^3),
- stem position (ordinates x, y were measured with theodolite),
- diameter increment and increment on basal area of each tree were determined by analyses of increment cores. Six samples were taken for full stem analyses.

On the basis of data from these measurements the following characteristics were analysed:

- height structure (2000),
- diameter structure and its development in the period 1996–2001.

The spatial arrangement (tree spatial distribution) and its development in the period 1996–2001 were evaluated by a standard method of point structural analyses that is based on the indices of CLARK and EVANS (1954), HOPKINS and SKELLAM (1954) and PIELOU and MOUNTFORD (1959, 1961).

The impact of the regeneration system on the stand structure was always investigated.

The evaluation of increment vitality and growth space efficiency of particular stand components (tree and diameter classes) was done for each plot. The modified Konšel's tree classification and diameter classes in a 2 cm interval were used.

Current annual increment of particular trees was calculated as a periodic annual increment (for the last 5 years). The detection of artificial form factor, form height and basal area were essential parameters of volume assignment of individual trees. The form height was determined once over the evaluation period (in 2000). It was estimated through the volume of large wood (> 7 cm d.o.b.) that was assessed according to Grundner-Schwappach's volume tables in 2000 (on the basis of tree diameter and height). This form height is considered constantly for a short time period (KORF 1972; EBERT 1994).

The basal area was calculated from diameter at breast height (at the end of the period, 2001) and on the basis of diameter increment over the evaluation period (in 1997) that was measured on increment cores and deducted from the measured diameter in 2001. Diameter at breast height (measured overbark – $d_{1.3}$) was converted to the underbark diameter ($d_{1.3}$) by the reciprocal value of Šmelko's bark coefficient k (ŠMELKO 2000).

The volume of large wood was calculated at the beginning (1997) and at the end of the period (2001) by means of the formula:

$$v = f_{1.3} \times h \times g_{1.3}$$

The current annual volume increment was determined from the equation

$$C.a.i. = \frac{(v_{2001} - v_{1997})}{5}$$

The development of volume and basal area and their mean and current annual increments were evaluated by a mathematical model using Korf's function (KORF 1972):

$$y = A \times e^{\frac{k}{(1-n)t^{n-1}}} = A \times e^{\varphi(t)}$$

The current increment was calculated as the first derivation of Korf's function:

$$f'(t) = A \times e^{\frac{k}{(1-n)t^{n-1}}} \times \frac{k}{t^n}$$

The mean increment is the ratio of the growth function and the age of tree:

$$\eta = \frac{f(t)}{t}$$

The culmination of the mean volume (basal area) increment of individual trees is the basic point of time arrangement of final cutting for this regeneration system. A felling maturity is achieved when current and mean increments are equal:

$$f'(t_2) = \frac{f(t_2)}{t_2}$$

The statistical evaluation of the stand component increment was done by analysis of variance (ANOVA), by multiple comparison (Scheffe). Regression analyses were used for the curve fitting of the relation between volume and basal area increments and selective characteristics of the trees (the polynomial and the power function were calculated by the least

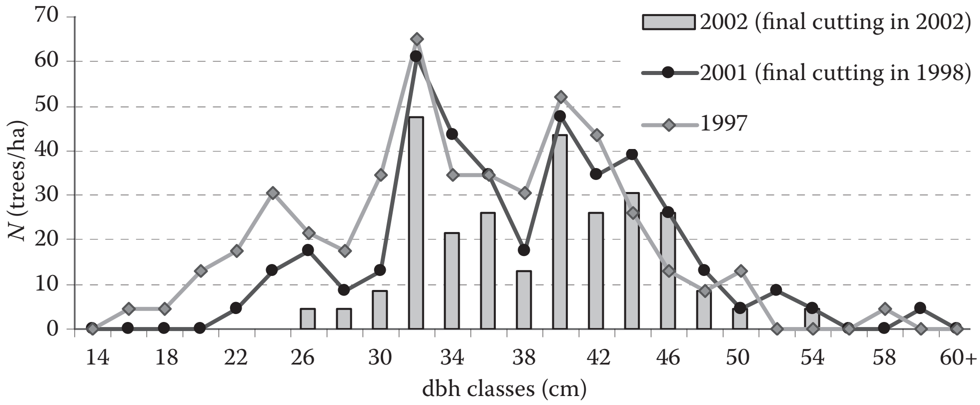

Fig. 2. dbh distribution on experimental plot 1 and its changes in the period 1997–2002

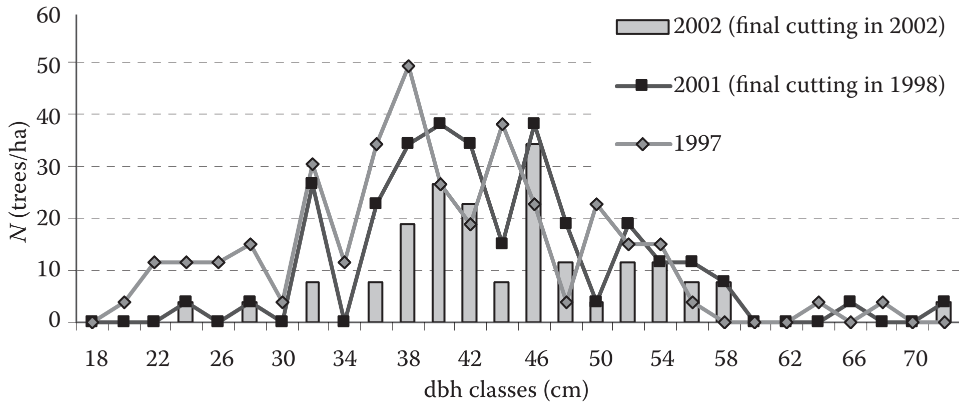

Fig. 3. dbh distribution on experimental plot 2 and its changes in the period 1997–2002

squares method using statistical software SPSS and S-PLUS).

RESULTS AND DISCUSSION

Structure and mensurational data of mature stand

The mature stand (No. $11C_{12}$) is a typical even-aged stand with dominant position of Norway spruce. The tree species composition is far from the natural state (Table 2) and the proportion of other species (larch, pine and fir) is only about 10%. This state is a result of Norway spruce propagation and planting in the SFE territory in the second half of the 19th century (Šrámek 1985).

Figs. 2–4 show dbh distribution on each experimental plot and its changes in the period 1996–2004 (these changes are due to diameter increment and they are also influenced by final cutting). The height structure and the tree distribution into tree classes also confirm the even-aged stand.

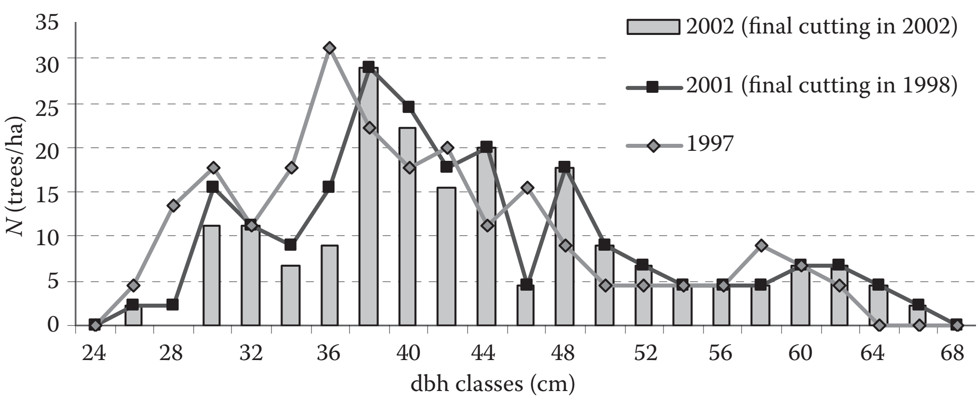

Fig. 4. dbh distribution on experimental plot 3 and its changes in the period 1997–2002

Table 3. Basic mensurational data on the experimental plots

Mensurational data	Year	Permanent research plots (PRP)		
		PRP 1	PRP 2	PRP 3
Number of trees per ha	1997	469	357	229
	2001	395	296	218
Canopy	2001	0.78	0.70	0.61
Stand density	1997	0.988	0.867	0.586
	2001	0.956	0.864	0.622
Mean diameter dbh (cm)	1997	35.64	39.55	40.55
	2001	38.35	43.21	42.87
Mean height *h* (m)	2000	31.4	34.4	32.7
Dominant height (m)	2000	34.7	38	36.3
Mean crown cover (m^2)	2001	19.4	22.8	27.3
Mean crown volume (m^3)	2001	83.9	109.9	147.3
Volume per ha (m^3)	1997	701.6	727.8	469.8
	2001	687.5	711.4	498.3

The spatial arrangement of trees, evaluated by the indexes, corresponds to the regular distribution of the trees. The indexes are as follows: Clark-Evans $R > 1$, Hopkins-Skellam $A < 0.5$, Pielou-Mountford $a < 1$. This type of distribution is emphasized with decreasing tree number (in the course of final cutting). The spatial structure is quite different from selection forests and forests with group spatial tree distribution (Pretzsch 1998).

General information about basic mensurational data of the experimental plots is given in Table 3. The relatively high site production of this stand (fertile soil, good water regimes) is evident from mean dbh, mean height, dominant height and volume stock. The volume stocks are 688, 711 and 488 m^3 per hectare, with relatively open canopy (0.78, 0.70 and 0.61, respectively). The positive effect of the open stand increment is apparent from the stand density calculation, which involved comparison of actual and table values. The stand density is distinctly higher than the canopy degree (0.96, 0.86 and 0.62).

Different stand densities of these experimental plots are reflected in the crown development. Statistically significant differences were confirmed between the mean crown cover and the mean crown volume of particular plots. The largest crowns were documented on PRP 3, on the plot with mostly open canopy (27.3 m^2 and 147.3 m^3) while the trees on PRP 1, on the plot with relatively closed stand, had the smallest crowns (19.4 m^2; 83.9 m^3). The release of the trees was accelerated by crown development and it influenced the tree growth potential (compare mean dbh, height and volume on particular plots).

Volume increment

A distinct emphasis was laid on the evaluation of current and mean volume increment (and also of basal area increment) of each tree because it is a basis for individual tree felling maturity assessment according to Poleno's idea. The information about the volume stand increment was of course also ascertained.

Stand volume increment

The current annual volume increment of a stand is importantly influenced by site quality, stand density

Table 4. Current annual volume increment of stands on the permanent research plots (PRP)

PRP	Stand density	Canopy	*N* (trees/ha)	CI_{volume} (m^3/ha)	CI_{volume} (m^3/tree)	Mean crown cover (m^2)
1	0.96	0.78	395	7.68	0.01943 a	19.4 a
2	0.85	0.70	296	8.53	0.02884 b	22.8 b
3	0.62	0.61	218	8.39	0.03847 c	27.3 c

CI_{volume} – current annual volume increment. Different symbols (a, b, c) in the same column indicate statistically significant differences between plots

Table 5. Average value of current annual volume increment according to diameter classes

Diameter class (4 cm)	Current annual volume increment (m^3)		
	PRP 1	PRP 2	PRP 3
22	0.0025		
26	0.0062	0.0085	0.0110
30	0.0141 a	0.0085 a	0.0109 a
34	0.0140 a	0.0111 a	0.0237 b
38	0.0203 a	0.0222 a	0.0303 b
42	0.0253 a	0.0305 a, b	0.0373 b
46	0.0348 a	0.0352 a	0.0438 a
50	0.0441 a, b	0.0276 a	0.0555 b
54	0.0551 a	0.0399 a	0.0604 a
58		0.0597 a	0.0637 a
62			0.0645
66		0.0413	0.1406
74		0.1379	

Different symbols (a, b, c) in the same row indicate statistically significant differences between plots

(number of trees per hectare) and by the individual growth potential of each tree. In this case, the decrease in the tree number was balanced by the strong enhancement of individual tree growth. The release of trees was followed by crown development that finally brought the strong light increment. Therefore, the current annual volume increment of experimental plot 1 was lower than the increment of plot 2 and 3, in spite of higher tree numbers (Table 4). The individual tree growth was more important for the stand production. However, it is valid only for a certain level of the stand canopy density. The comparison of plot 2 and 3 shows that a too high decrease in the tree number must be connected with the stand increment decline (Assmann 1961). Although the current annual volume increment of mean trees was the highest on PRP 3 (0.038 m^3), being statistically significantly different from the other plots (0.029 m^3 on PRP 2 and 0.019 m^3 on PRP 1), the current annual volume increment of PRP 3 was already lower than that on plot 2 (8.39 m^3/year/ha and 8.53 m^3/year/ha).

These results are also affected by differences in the site quality between these research plots although these plots are situated very close to each other (they are located in the transect and the distance between the border of the neighbouring plots is only 20 m).

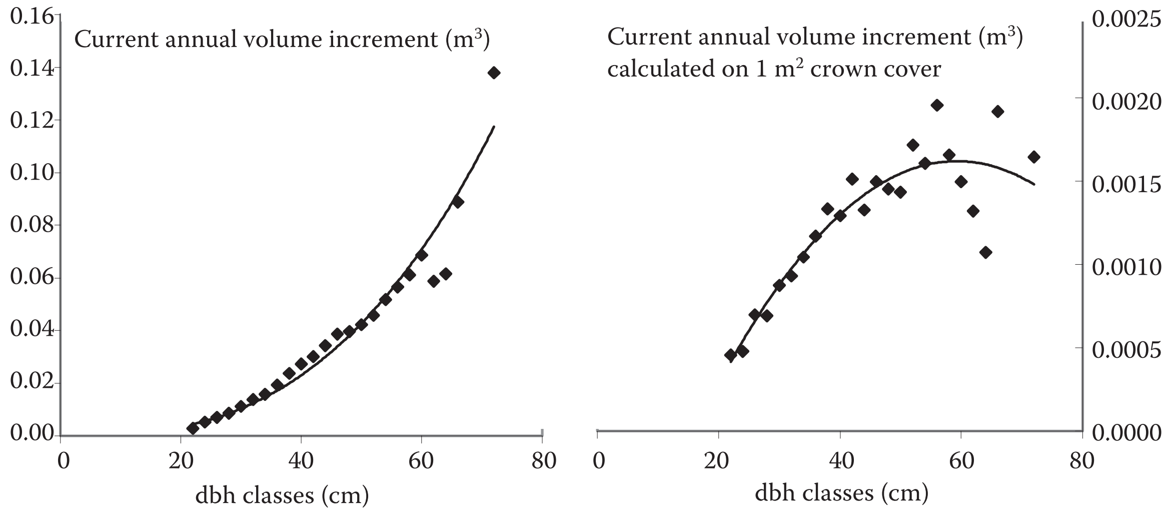

Fig. 5. Dependence of current annual volume increment on dbh classes (average value for each dbh class)

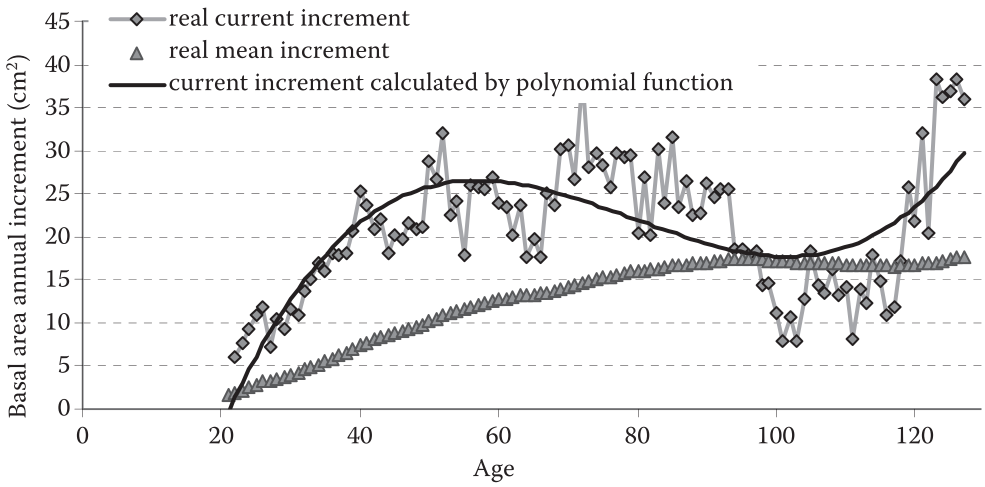

Fig. 6. Development of basal area increment of tree No. 89 (PRP 3). Silver fir, tree class 2a, dbh = 56.3 cm, height = 33 m

Volume increment of individual trees and evaluation of felling maturity

The effect of light increment and the impact of tree release were also investigated for diameter classes. The differences between current annual volume increments in the same diameter classes of particular plots were tested by analysis of variance. The tree release and the increment increase were statistically confirmed between plot 3 (with distinct open canopy) and the others in diameter classes 34 and 38, partly also in classes 42 (between PRP 3 and 1) and 50 (between PRP 3 and 2, Table 5). The tree release considerable affected the annual increment of mainly intermediate trees with the mean diameter. The positive increment response after tree release was described also by Poleno (1969a,b) and Schmitt (1994).

The evaluation of the growth vitality of individual trees showed that the thickest trees had the absolutely highest current annual volume increment. The correlation between diameter and volume increment was constantly positive and it was expressed by the power function and this relation was statistically confirmed (on the basis of *t*-test, Fig. 5). The same result was also found by Poleno (1969a,b). On the other hand, Schmitt (1994) stated that this positive dependence diminished with dbh increase. After 65 cm of dbh, the curve is oblate and after 70 cm Schmitt observed a hint of the inflection point. Kadlus (2001) registered a typical "S" form of growth curve with the important deceleration of increasing trend of the function at larger diameters.

This trend was not so clear when production effectiveness was evaluated in relation to the growth space of individual trees (growth efficiency). The production effectiveness was investigated by means of the relationship between tree diameter and current annual volume increment calculated per m²

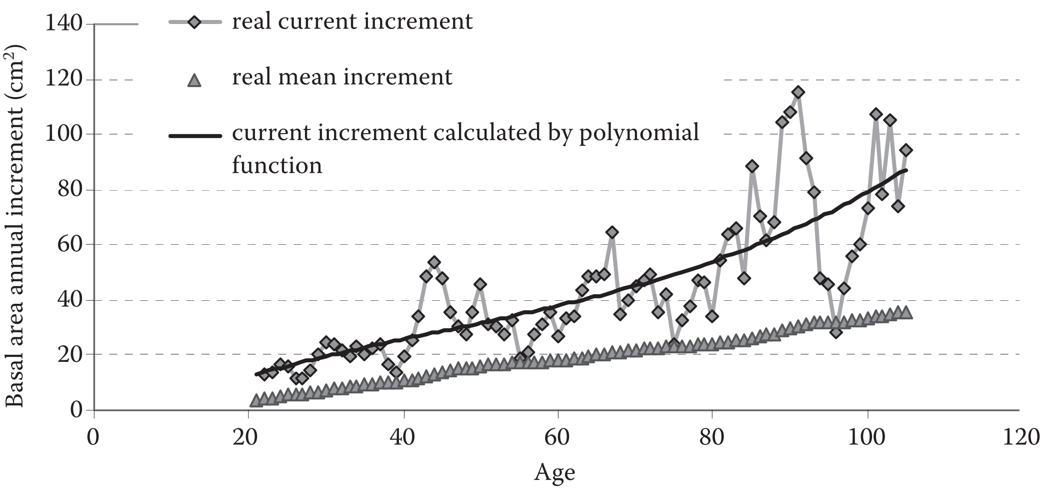

Fig. 7. Development of basal area increment of tree No. 19 (PRP 2). Norway spruce, tree class 1, dbh = 72.1 cm, height = 37 m

Table 6. Percentage of the felling maturity trees according to tree classes and species

Experimental plot	Species	Tree classes according to Konšel's classification						Proportion of all trees
		1	2a	2b	3+	3–	4	
1	Norway spruce	8.3	0	20.8	23.8	87.5	80	27.2
	Scots pine	100	–	–	–	0	100	75
	European larch	50	–	100	–	–	–	66.7
	Total	27.8	0	26.9	23.8	77.8	83.3	31.9
2	Norway spruce	12.5	23.5	47.1	10	87.5	100	32.9
	Silver fir	–	0	–	–	100	–	50
	Total	12.5	22.2	47.1	10	88.9	100	33.3
3	Norway spruce	0	0	4.2	0	33.3	100	6.3
	Silver fir	0	0	0	0	100	100	28.6
	Total	0	0	3.8	0	45.5	100	9.2

It means the proportion of felling maturity trees out of all trees of particular species and tree classes
– the species did not have any tree in tree classes

of crown cover. Because the biggest trees have of course large crowns, their high absolute growth potential is significantly reduced by a large growth space (crown cover). In spite of it, the positive correlation between tree diameter and current annual volume increment calculated per m^2 of crown cover was detected up to approximately 60 cm of dbh. After that we can see a turnover (expressed by a polynomial function), but further course of this relationship is not quite clear. In this case, the diameter of about 60 cm seems to be a maximum of growth efficiency (Fig. 5).

For example Badoux (in Assmann 1961) described the diameter of maximum increment efficiency from the growth space aspect, for Norway spruce at 50 to 75 cm, for silver fir at 70–100 cm (it was investigated in the selection forest), Poleno (1969a,b) did not find this inflection point (probably due to younger spruce stand).

The assessment of current and mean volume increments (and also basal area increments) of individual trees was carried by tree-ring analyses of increment cores and by full stem analyses. The analyses confirmed very high variability in the growth potential of individual trees, on the other hand, the dependence between trees size and social status of trees was found. The potential and actual increment is strongly influenced by the stand position of the tree and by crown release. This conclusion shows a high potential level of tree growth even at the age of 120 years (Fig. 7). The percentage of felling of mature trees also depends on the species (Table 6).

On PRP 1 (plot with closed canopy), 32% of all trees (28.5% of total volume) were after the culmination of mean volume increment. While in the case of Norway spruce 27.2% of all spruce trees were after the culmination and 72% out of them were suppressed trees, 75% of all pine trees and 67% of all larch trees were after the culmination and among them dominant or co-dominant trees prevailed (67% in the case of pine and 100% in the case of larch). It confirmed an assumption that Scots pine and European larch are light-demanding species with fast growth at young age and sooner increment culmination.

On PRP 2, partly similar results like on PRP 1 were detected. 33% of all trees (29.8% of total volume) were after the mean volume culmination. But contrary to the first plot, 64% of spruce trees after culmination were dominant trees, especially co-dominant trees (tree class 2b according to Konšel).

The results from PRP 3 were quite different from the others. Only 9.2% of all tress (5.7% of total volume) were after the mean volume increment culmination. 6.3% of all spruce trees reached felling maturity and a prevailing part consisted of suppressed trees (80%); on the other hand a relatively high portion of silver fir trees after increment culmination was found (28.6% of all fir trees, which were suppressed trees). It is caused by the long-term damage of this tree species. But recently, distinct revitalisation and growth acceleration of silver fir were detected. This is evident from increment analyses of silver fir trees (Fig. 6). A relatively low portion of trees after increment culmination on this plot is a result of considerable tree (crown) release. It shows the long-term high production potential of individual trees of Norway spruce and silver fir in the Central European conditions. Considering this high growth potential,

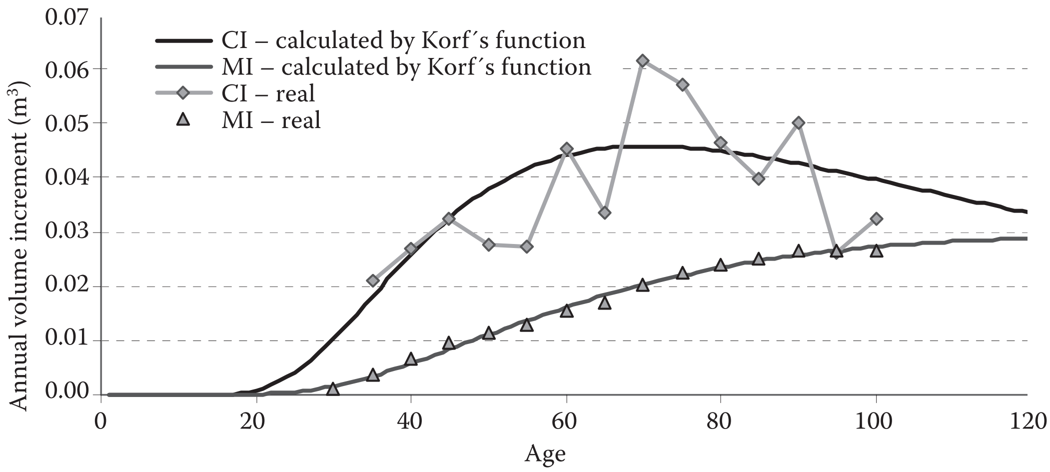

Fig. 8. Development of volume increment of tree No. 20 (PRP 2). Norway spruce, tree class 2b, dbh = 51.4 cm, height = 36.7 m, the time of increment culmination is calculated as 135 years (CI – current increment, MI – mean increment)

this type of regeneration cuts could be under way in the following decades in the stand creating the rich interior stand structure, after recruitment of advanced regeneration. These results correspond with data from other authors (Guttenberg 1915; Poleno 1999; Schmitt 1994), they also document the high growth potential of individual trees at the age above 100 years and a relative low portion of trees after the increment culmination.

The analyses method has some constraints of its practical application. One problem of this regeneration system seems to be to consider if a depression of the current annual volume increment under the mean increment is permanent. The increment analyses often showed an important current increment variability and its fluctuation in the course of tree lifetime, and its important increase mainly in the last decades (Fig. 6). Partly, it is probably due to growth responses to thinning and release cutting. It corresponds with Schmitt (1994), who described four culminations of mean increment in one tree during its lifetime. A new phenomenon of the growth increase in European forests also plays an important role (Spiecker et al. 1996; Röhle 1999; Šrámek et al. 2002). This trend complicates the use of model estimation of felling maturity by Korf's growth function as well as by growth functions of other authors, for example of Chappmann-Richardson. Uncommonly high volume increment at the age over 100 years very often caused that the time of felling maturity of individual trees was calculated at unreasonable tree age. But Korf's growth function was successfully used for felling maturity estimation of trees relatively near or on the border of culmination (Fig. 8).

The second problem of this felling maturity concept application in practical forest management is time consumption of its identification. Only two methods are available: repetitive diameter and height measurement of all trees or increment analyses of increment cores.

CONCLUSION

This paper describes the results of research focused on the evaluation of conversion of even-aged nearly pure Norway spruce stand in the School Forest Enterprise in Kostelec nad Černými lesy. This conversion is done by differentiated regeneration that started 30 years ago. The change in the tree species composition is ensured by combined artificial and natural regeneration. Greater size and age diversification of the future forest stand will be achieved by the long-term final cutting. The final cutting is based on an individual tree selection. The culmination of mean annual volume increment is the main criterion of individual tree felling maturity according to Poleno's idea. The regeneration process of the mature stand is evaluated on three permanent experimental plots with different level of canopy opening and different advanced regeneration development.

The current annual volume increment of a stand is importantly influenced by stand density (number of trees per hectare) and by the individual growth potential of each tree. The release of trees on PRP 2 and 3 was followed by crown development that finally brought the strong light increment. But the excessive decline of stand density was connected with stand increment decrease (comparison of PRP 2 and PRP 3).

The tree-ring analyses of all trees provided information about the still very high current annual increment level of individual trees. The thickest trees had the absolutely highest current annual volume increment of all trees. The dependence between tree diameter and current increment permanently increased. Production effectiveness was investigated on the basis of the relationship between tree diameter and current annual volume increment calculated per one m^2 of crown cover. After approximately 60 cm of dbh a turnover in the positive trend was detected.

On the basis of evaluation of felling maturity, a relatively low number of trees was achieved by the mean annual volume increment culmination point. They are mostly trees of light-demanding species (Scots pine and European larch) and suppressed trees of shade tolerant species (Norway spruce and silver fir). The tree release seems to be an important factor influenced by the growth vitality of individual trees. It is documented by a very low number of trees after the increment culmination on PRP 3 – only about 9% of all trees, opposite to approximately 30% on PRP 1 and PRP 2.

These results indicate that this kind of felling maturity definition will probably lead to the long-term regeneration and consequently to the more diversify forest stand.

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Přeměna stejnověkých smrkových porostů na Školním lesním podniku v Kostelci nad Černými lesy: struktura a mýtní těžba mateřského porostu

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ABSTRAKT: Práce se zabývá transformací stejnověkých nesmíšených jehličnatých porostů na porosty smíšené a více různověké na příkladu Školního lesního podniku v Kostelci nad Černými lesy. Příspěvek hodnotí průběh obnovy vybraného porostu, při které se mýtní těžba realizuje výběrem jednotlivých stromů. Hlavním kritériem mýtní zralosti je kulminace průměrného objemového přírůstu jednotlivých stromů. Provedené analýzy potvrdily vysokou variabilitu v růstovém potenciálu jednotlivých stromů, který je dominantně ovlivněný postavením stromů a uvolněním jejich korun. Výsledky dokládají vysokou růstovou potenci jednotlivých stromů i ve věku 120 let. Na jednotlivých výzkumných plochách byl zjištěn podíl mýtně zralých stromů od 30 do 9 %.

Klíčová slova: stejnověký porost; nestejnověký porost; těžba jednotlivých stromů; kritéria mýtní těžby; průměrný a běžný přírůst

Příspěvek se zabývá přeměnou stejnověkých smrkových monokultur na území Školního lesního podniku v Kostelci a podrobněji hodnotí průběh obnovy vybraného porostu, kde je uplatňován specifický způsob mýtní těžby. Ten je založen na myšlence prof. Polena a spočívá v tom, že se obnova porostu děje výhradně těžbou jednotlivých stromů, ke které dochází v době kulminace jejich průměrného objemového přírůstu, případně průměrného přírůstu na výčetní kruhové základně (Poleno 1999, 2000). K této kulminaci dochází právě v době, kdy se oba základní přírůsty – přírůst průměrný a přírůst běžný – rovnají. Ve zkoumaném porostu byly na trvalých výzkumných plochách (TVP) u všech stromů zjištěny jejich přírůstové poměry, tj. byl zjištěn průběh běžného a vypočteny hodnoty průměrného objemového přírůstu a přírůstu na výčetní kruhové základně. K tomuto stanovení byla použita metoda vývrtová a metoda plných kmenových analýz vzorníků. Pro standardizaci letokruhových řad a pro možnou predikci dosažení doby kulminace průměrného přírůstu byla použita Korfova růstová funkce a polynom 3. stupně. Cílem šetření bylo vyhodnotit probíhající obnovu z pohledu struktury mateřského i následného porostu (druhová, věková a prostorová struktura), zjistit přírůstovou vitalitu jednotlivých stromů a posoudit jejich mýtní zralost. Výsledky určily další postup obnovy porostu. Důležitým cílem výzkumu bylo také posouzení možnosti praktické realizace tohoto obnovního způsobu.

Provedené analýzy potvrdily poměrně značnou variabilitu v růstovém potenciálu jednotlivých stromů. Běžný objemový přírůst stromů mateřského porostu je významně ovlivněn zakmeněním porostu (počtem stromů na jednotku plochy). Snížené zakmenění se projevilo výraznějším uvolněním a následným rozvojem korun s akcelerací světlostního přírůstu (TVP 2 a 3 ve srovnání s TVP 1). Růstová schopnost jednotlivých stromů byla také významně ovlivněna jejich cenotickým postavením v porostu a druhem dřeviny. Nejtlustší stromy, což byly zároveň stromy nadúrovňové a úrovňové, vykazovaly dosud nejvyšší absolutní běžný objemový přírůst. Závislost mezi výčetní tloušťkou stromů a běžným objemovým přírůstem byla trvale rostoucí. Efektivita tvorby dřeva byla zkoumána prostřednictvím běžného objemového přírůstu přepočítaného na 1 m^2 plochy korunové projekce. Zde již nebyla závislost mezi výčetní tloušťkou a tímto ukazatelem efektivnosti tak těsná a přibližně u výčetní tloušťky 60 cm byl zjištěn v pozitivním trendu bod obratu (obr. 5). Z hodnocení mýtní zralosti jednotlivých stromů vyplynulo, že jen relativně malý počet stromů je již po kulminaci průměrného objemového přírůstu. Do kategorie mýtně zralých stromů spadal především značný podíl stromů světlomilných dřevin (borovice lesní a modřín opadavý) a podúrovňové stromy (stromové třídy 3, 4 a 5) stinných dřevin (smrk ztepilý a jedle bělokorá). Jak již bylo uvedeno, uvolnění korun stromů snížením hustoty porostu je velmi důležitý činitel ovlivňující růstovou vitalitu jednotlivých stromů. To je také doloženo velice malým podílem stromů po kulminaci průměrného objemového přírůstu (pouze asi 9 %) na TVP 3 (plocha s nejnižším zakmeněním) ve srovnání s TVP 1 a 2 (zde bylo po kulminaci asi 30 % stromů).

Zjištěné výsledky indikují, že zkoumaný způsob obnovy porostu pravděpodobně povede k velmi dlouhé obnovní době (ta trvá v současné době již 30 let), což se projeví ve výrazně věkově, prostorově i druhově diverzifikovaném následném porostu.

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