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Changes in trends of the height growth of spruce and pine derived from continuous measurements in forest management plans of Kostelec nad Černými lesy and on pilot research plots in the Czech Republic

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ABSTRACT: In changing growth conditions, methodical procedures should concentrate on the investigation of processes currently under way in forests. Many studies have shown that present models of forest growth parameters differ from previous surveys as far as for instance the height is concerned. Causes of these phenomena have not been satisfactorily explained although various hypotheses are investigated. In our study, we present partial results of the investigation of height growth within a sixty-five-year period, based on the analysis of data obtained from seven forest management plans in the management-plan area of Kostelec nad Černými lesy (Kostelec n. Č. l.) and continuous measurements on pilot research plots in the period of 1965–1994. The comparison of mean height growth curves obtained by the curve fitting of the values of empirical data signifies by their different course and increasing kurtosis a dependence on the calendar year when the measure was taken. It signifies an increasing height growth trend of both species in the given area.

Keywords: spruce; pine; mean stand height; height growth trends; current and mean height increment; stand age; year; forest vegetation zones; forest management plan (FMP); pilot research plots (PRP)

The trend of growth development of European tree species has shown substantial differences in the last decades, and it is confirmed by a number of authors who based their studies on measurements on research plots, e.g. SCHMIDT (1969), PRETZSCH (1985), SEQUENS (1985). When registering real increment, it was not confirmed that the forest always grew in the same way. Therefore, some authors recommend that the increment should be dealt with not only as the function of stand age but also as the function of an increment at the particular moment and thus the increment should be seen as the function of the stand age and year (KOUBA 1985).

For the above-mentioned reasons, the methodical procedures of determination of forest stand values should rather aim at investigations of their current development in the forest. A number of studies showed that the present forest growth models differed from previous observations as far as for instance the height is concerned. Causes of these phenomena have not been satisfactorily explained; nevertheless, various hypotheses are investigated. These findings, though, were found useful in methodical procedures of the construction of yield tables of the CR (ČERNÝ et al. 1996).

In the study, there is a graphical and numerical comparison of the results of stand-height-growth investigations of our principal conifers, spruce and pine. Differences in height-growth trends of both tree species growing in similar natural conditions were viewed from the aspect of stand age and year of measurement. The authors made use of quite a large database of the long-term series of continuous measurements of mean stand height, which follows the previous research (SEQUENS 1985, 1994). The existing empirical data on the mean stand height were complemented by heights of spruce and pine from FMP Kostelec n. Č. l. 2001 in the area of the Training Forest Enterprise Kostelec n. Č. l. and furthermore by continuous measurements of both tree species on pilot research plots (PRP) founded by Lesprojekt in the whole CR. The research was carried out in the framework of the Grant of Prof. Jan Kouba, called *Methods of Optimal Management of Forest Development and Production in Variable growth Environment and Economic and Ecological Risks* (No. 526/01/0922) and the Grant called *Modeling of Forest Development and Production Using Mathematica Programme* by CIGA CUA.

EMPIRICAL MATERIAL AND METHODOLOGY OF ITS PROCESSING

Height data from a time series of FMPs in the Training Forest Enterprise in Kostelec n. Č. l.

The data on mean stand heights were taken from forest management books of forest management plans from the years 1936, 1952, 1961, 1971, 1981, 1991 and 2001 for the area of the Training Forest Enterprise Kostelec

Table 1. Number of measurements of mean stand heights of pine and spruce in age classes according to particular FMP of Kostelec n. Č. l.

Age class	Pine/Spruce															
	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*
	10		20		30		40		50		60		70		80	
FMP 1936	0	*0*	0	*0*	1	*50*	1	*72*	0	*51*	2	*66*	17	*29*	11	*21*
1952	0	*6*	5	*11*	18	*43*	13	*75*	8	*75*	5	*68*	7	*86*	19	*39*
1961	0	*0*	2	*12*	13	*39*	22	*42*	16	*70*	17	*96*	9	*88*	16	*76*
1971	17	*40*	17	*24*	9	*45*	25	*71*	34	*77*	17	*92*	28	*163*	28	*133*
1981	60	*117*	17	*45*	3	*21*	5	*36*	17	*43*	19	*32*	12	*47*	24	*69*
1991	114	*145*	61	*131*	28	*67*	10	*28*	6	*42*	18	*41*	15	*42*	13	*46*
2001	38	*87*	63	*105*	59	*101*	17	*51*	12	*28*	2	*23*	8	*29*	10	*27*

Age class	Pine/Spruce															
	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*
	90		100		110		120		130		140		150		160		Total	
FMP 1936	10	*27*	4	*8*	2	*0*	3	*2*	3	*0*	1	*0*	0	*0*	0	*0*	55	*326*
1952	16	*26*	13	*24*	12	*10*	4	*9*	2	*1*	0	*0*	0	*0*	2	*0*	124	*473*
1961	35	*30*	14	*21*	17	*20*	7	*10*	2	*2*	1	*0*	0	*0*	1	*0*	172	*507*
1971	28	*90*	45	*45*	22	*29*	23	*25*	11	*12*	4	*1*	6	*2*	0	*0*	314	*849*
1981	11	*84*	15	*63*	23	*18*	17	*17*	12	*11*	6	*3*	0	*0*	1	*0*	242	*606*
1991	22	*73*	16	*78*	15	*65*	23	*21*	8	*13*	7	*3*	2	*0*	2	*0*	360	*795*
2001	9	*28*	8	*35*	5	*42*	4	*40*	14	*9*	6	*5*	2	*2*	0	*0*	257	*612*
															Total		1,524	*4,168*

n. Č. l. Forest management plans are regularly updated in ten-year periods. World War II caused the longer period between 1936 and 1952. The management-plan area of Kostelec n. Č. l. is situated on the boundary line of two climatically different forest regions of the Středočeská pahorkatina Hills and Polabí lowland. Its forest veg-

Table 2. Number of measurements of mean stand heights of pine and spruce in age classes according to selected pilot research plots founded by Lesprojekt

Age class	65–74		75–84		85–94		Total 65–94	
	PI	*SP*	PI	*SP*	PI	*SP*	PI	*SP*
10	0	*0*	0	*0*	0	*0*	0	
20	1	*1*	0	*0*	0	*0*	1	*1*
30	2	*0*	1	*2*	0	*0*	3	*2*
40	7	*17*	3	*3*	1	*1*	11	*21*
50	28	*21*	14	*20*	2	*4*	44	*45*
60	32	*38*	34	*32*	15	*17*	81	*87*
70	31	*56*	33	*52*	35	*31*	99	*139*
80	36	*56*	40	*72*	39	*45*	115	*173*
90	29	*27*	40	*73*	39	*66*	108	*166*
100	20	*8*	33	*29*	42	*64*	95	*101*
110	7	*4*	21	*10*	32	*26*	60	*40*
120	1		8	*4*	19	*8*	28	*12*
130	1		1		6	*3*	8	*3*
140	2		1		1		4	
150			2		1		3	
160					2		2	
	197	*228*	231	*297*	234	*265*	662	*790*

Table 3. Parameters of Korf's growth function for curve fitting of the stand heights from FMP

Year of measurement	Pine			Spruce		
	A	*k*	*n*	*A*	*k*	*n*
1936	28.92	275.272	2.43157	*50.21*	*35.110*	*1.87403*
1952	34.86	21.658	1.86112	*36.66*	*77.242*	*2.11397*
1961	78.98	2.713	1.37697	*41.27*	*18.982*	*1.81896*
1971	32.82	16.428	1.84646	*34.77*	*48.144*	*2.05985*
1981	28.86	25.854	1.99458	*36.35*	*63.936*	*2.12503*
1991	36.00	9.506	1.72905	*46.30*	*13.007*	*1.75737*
2001	35.35	11.749	1.79452	*54.92*	*11.094*	*1.69922*

Table 4. Parameters of Korf's growth function for curve fitting of the stand heights from PRP

Measurement	Pine			Spruce		
	A	*k*	*n*	*A*	*K*	*n*
65–74	25.64	13.842	1.88383	*25.29*	*28.821*	*2.08263*
75–84	24.84	44.753	2.20074	*25.16*	*1,982.290*	*3.10644*
85–94	25.40	62.656	2.30262	*26.73*	*102,869.934*	*4.01177*

etation zones are as follows: 3rd oak-beech – 53.8%, 4th beech – 24.2% and 2nd beech-oak – 21%. Mean stand heights in the forest management plan were measured to the nearest 1 m. Spruce and pine stands with the following parameters were selected for monitoring: the stand area of spruce and pine ≥ 0.5 ha, spruce representation ≥ 85%, pine representation ≥ 80%, spruce stand density ≥ 8, pine stand density ≥ 7. Areas larger than 0.5 ha ensure the elimination of stand residues or groups of trees unduly influenced by neighbouring stands. Representation of 85% or 80% diminishes competition of tree species within the stand. Stand density 8 or 7 eliminates the stands thinned by occasional felling. Lower percentage for pine was set in accordance with its relatively lower representation in the forest management-plan area. Numbers of the acquired data on mean stand heights are presented in Table 1 and they stand for 4,168 spruce measurements and 1,524 pine measurements.

Height data from continuous measurements of spruce and pine pilot research plots (PRP)

The database of height measurements was supplemented by data from continuously measured (in five-year periods) research plots. The owner, Department of Public Administration and Game Keeping of the Ministry of Agriculture, permitted utilization of these valuable empirical data for research. The plots were founded and continuously measured in the years 1965–1994 and they served as a source of data necessary for the construction of yield tables for our natural conditions.

At present, and after a thorough review, these plots serve for monitoring of the forest stand situation. To compare height measurements from pilot research plots and continuous measurements from forest management plans of Kostelec n. Č. l., only data from the 2nd, 3rd and 4th forest vegetation zone in the area of the Training Forest Enterprise Kostelec n. Č. l. were used. The results of this selection (Table 2) divided according to the years of measurement (1965–1974, 1975–1984 and 1985–1994) and age class encompass 790 spruce measurements and 662 pine measurements in all.

Curve fitting of the empirical data

Real stand height data on both tree species from the above-mentioned empirical material were fitted in age dependence by Korf's growth function:

$$y\,(t) = A \exp\left(\frac{k}{1-n}\ t^{1-n}\right)$$

This growth function was devised in 1939 (KORF 1939) and has been successfully used in this country as well as abroad for modelling the height growth of forest stands (HALAJ, ŘEHÁK 1987; ZEIDE 1993; KIVISTE 2002). When using mean growth of many stem analyses of various tree species in various locations, the Korf's function turned out to be far more precise than any other growth function (ZEIDE 1993).

The current height increment was calculated as the first derivative of the presented growth function

$$y'(t) = A \exp\left(\frac{k}{1-n}\ t^{1-n}\right)\frac{k}{t^n}$$

The mean increment was calculated by the equation

$$i\,(t) = \frac{y\,(t)}{t}$$

The parameters of growth functions for particular cases are presented in Tables 3 and 4.

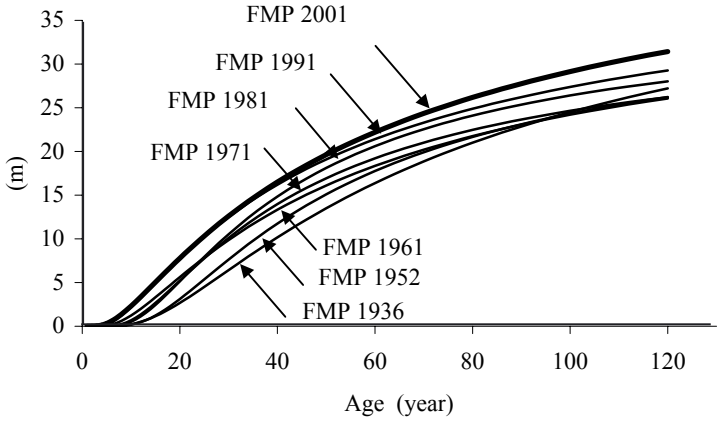

Fig. 1. Fitted mean stand heights of spruce in FMP Kostelec n. Č. l.

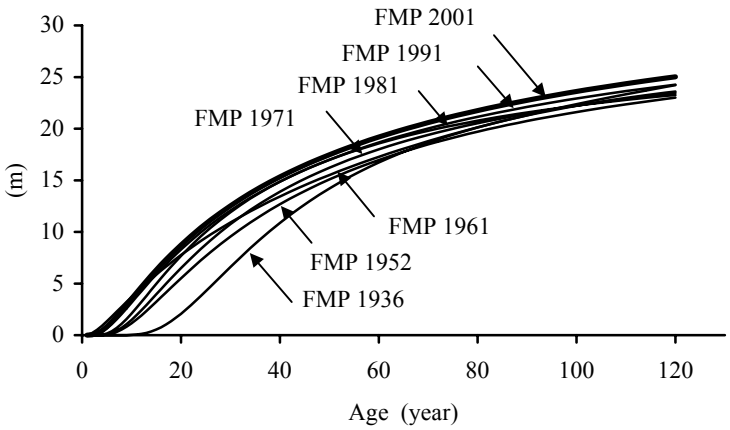

Fig. 2. Fitted mean stand heights of pine in FMP Kostelec n. Č. l.

Results of curve fitting

For the purpose of data evaluation, the height data were sorted into age classes in accordance with the mean values recognized and fitted. In the first place, table overviews were created in dependence on the year of the survey. The results of sorting the height data from FMPs and PRPs of both tree species are presented in Tables 5 and 6.

The scope of the dotted field of stand heights expresses a relatively broad amplitude of height stratification of this variable in the given period. Nearly all FMPs show a shift of the level of height classes in dependence on the increasing calendar age. The curve of height data in FMP 1936 and FMP 1952 is rather indistinctive, but we have to bear in mind, in the first case, that a lower number of measured data was obtained, and in both cases, the methodology of stand height measurement could show certain inaccuracy as the height could be only estimated.

Fitted curves of the height growth of spruce and pine from all FMPs are presented in Figs. 1 and 2.

Spruce height data from selected FMPs

From the total number of seven FMPs, the data from the years of 1936, 1971, 1991 and 2001 were selected for detailed graphical representation of height growth of spruce and pine. Except for the 1936 fitted height curve, which from the age of 100 years coincided with the data of the 1971 curve, the sequence of the three remaining curves shows an upward trend whose absolute values are presented in Table 5 and demonstrated in Fig. 3. At the age of 100 years, the fitted mean stand heights reach the fol-

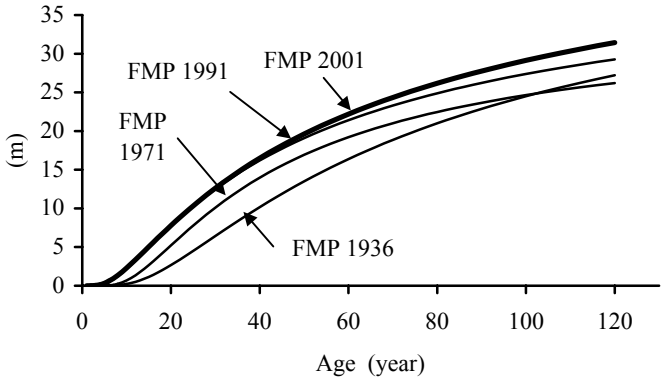

Fig. 3. Fitted mean stand heights of spruce in FMP Kostelec n. Č. l.

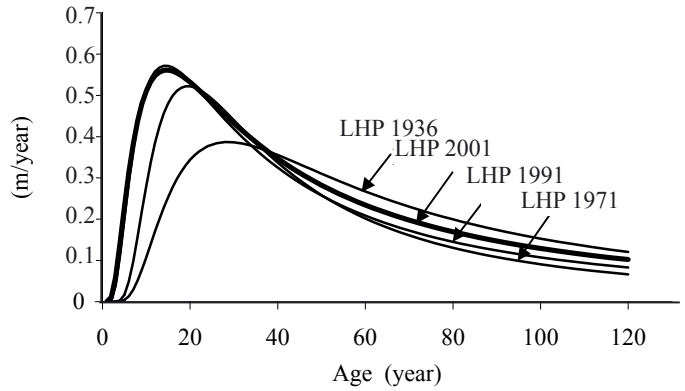

Fig. 4. Current height increment of spruce in FMP Kostelec n. Č. l.

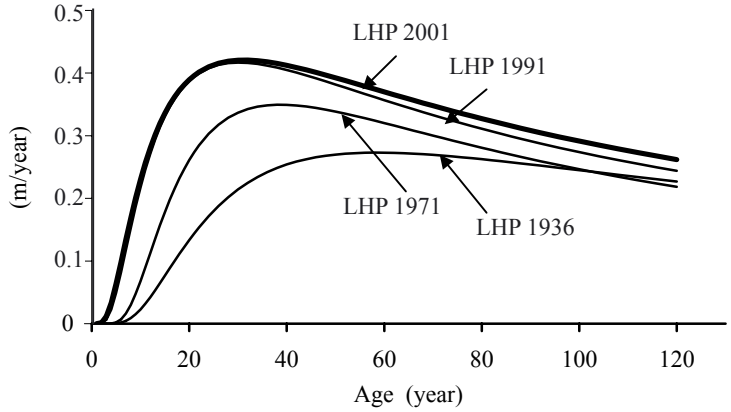

Fig. 5. Mean height increment of spruce in FMP Kostelec n. Č. l.

lowing values: FMP 1936 – 24.5 m; FMP 1971 – 24.7 m; FMP 1991 – 27.4 m; FMP 2001 – 29.1 m.

Fitted curves of the current and mean height increment values of spruce are presented in Figs. 4 and 5. In dependence on the calendar age, the age of culmination of the spruce height increment shows a decrease.

The particular age of culmination of the current spruce height increment measured on FMPs (1936, 1971, 1991

Table 5. Survey of height measurements of spruce from the data of FMP of Kostelec and measurements on PRP (real values and fitted values)

Age cl.	FMP Kostelec n. Č. l.								Measurement on PRP					
	1936		1971		1991		2001		65/74		75/84		85/94	
	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*
10			0.2	*0.7*	0.7	*2.2*	1.3	*2.3*						
20			3.4	*5.2*	5.0	*7.7*	5.1	*7.8*	9.4	*9.0*				
30	6.0	*6.4*	7.9	*10.1*	9.8	*12.5*	9.8	*12.6*		*12.9*	12.7	*12.2*		
40	8.3	*10.2*	12.3	*14.0*	14.5	*16.2*	14.4	*16.5*	14.3	*15.5*	16.0	*16.9*	16.3	*16.0*
50	12.3	*13.5*	15.5	*16.9*	17.7	*19.1*	17.8	*19.6*	16.2	*17.2*	19.3	*19.6*	20.0	*20.6*
60	15.9	*16.4*	18.0	*19.2*	20.9	*21.4*	21.2	*22.2*	18.9	*18.4*	20.9	*21.2*	23.2	*23.0*
70	17.8	*18.9*	20.2	*21.0*	23.8	*23.3*	24.5	*24.4*	20.5	*19.4*	22.7	*22.3*	23.8	*24.3*
80	19.4	*21.0*	22.2	*22.5*	24.8	*24.9*	27.2	*26.2*	21.0	*20.1*	23.6	*22.9*	24.9	*25.1*
90	21.3	*22.9*	23.5	*23.7*	25.8	*26.2*	27.5	*27.8*	22.9	*20.6*	24.8	*23.4*	25.9	*25.6*
100	23.8	*24.5*	24.8	*24.6*	26.7	*27.4*	28.5	*29.1*	19.8	*21.1*	25.6	*23.8*	27.1	*25.9*
110		*25.9*	23.8	*25.5*	28.0	*28.4*	30.1	*30.4*	19.7	*21.5*	22.3	*24.0*	28.8	*26.1*
120	30.5	*27.2*	25.5	*26.2*	28.6	*29.3*	30.6	*31.4*			22.6	*24.2*	24.5	*26.2*
130			27.0	*26.8*	27.2	*30.1*	32.4	*32.4*					24.6	*26.3*
140			23.0	*27.4*	31.7	*30.8*	30.2	*33.3*						
150			22.0	*27.8*			33.5	*34.1*						
160														

Table 6. Survey of height measurements of pine from the data of FMP of Kostelec and measurements on PRP (real values and fitted values)

Age cl.	FMP Kostelec n. Č. l.								Measurement on PRP					
	1936		1971		1991		2001		65/74		75/84		85/94	
	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*	r. v. (m)	*f. v. (m)*
10			0.4	*1.5*	1.4	*3.2*	1.6	*3.5*						
20			3.7	*6.5*	5.2	*8.3*	6.3	*8.7*	9.4	*8.5*				
30	6.0	*6.6*	8.2	*10.8*	9.1	*12.1*	10.4	*12.5*	10.9	*11.8*	14	*13.3*		
40	7.0	*10.9*	13.6	*13.9*	14.3	*14.9*	13.6	*15.3*	12.6	*14.1*	14.8	*15.9*	18.5	*17.1*
50		*14.2*	15.4	*16.2*	16.5	*17.0*	17.4	*17.5*	15.7	*15.7*	17	*17.7*	16.5	*18.9*
60	20.3	*16.7*	16.7	*18.0*	18.4	*18.7*	16.5	*19.2*	17.7	*16.8*	19.2	*18.9*	19.7	*20.1*
70	18.0	*18.6*	18.5	*19.4*	20.1	*20.0*	21.1	*20.6*	18.8	*17.8*	20.3	*19.8*	21.4	*21.0*
80	18.9	*20.1*	18.6	*20.5*	21.5	*21.2*	22.7	*21.8*	18.8	*18.5*	21.5	*20.5*	22.5	*21.7*
90	20.2	*21.3*	20.9	*21.5*	22.2	*22.1*	20.3	*22.7*	18.8	*19.1*	21	*21.0*	22.8	*22.2*
100	21.8	*22.2*	22.2	*22.2*	22.3	*22.9*	24.0	*23.6*	19.3	*19.6*	21.1	*21.4*	22.8	*22.5*
110	22.3	*23.0*	23.7	*22.9*	22.7	*23.6*	25.0	*24.4*	20.3	*20.1*	20.9	*21.8*	22.5	*22.9*
120	24.3	*23.6*	23.3	*23.5*	24.0	*24.3*	25.3	*25.0*	21.1	*20.4*	22.5	*22.1*	23.1	*23.1*
130	26.3	*24.1*	23.6	*23.9*	24.5	*24.8*	24.9	*25.6*	21.9	*20.7*	22.7	*22.3*	22.9	*23.3*
140	21.5	*24.6*	23.3	*24.4*	23.7	*25.3*	26.2	*26.1*	18.8	*21.0*	24.3	*22.5*	24.8	*23.5*
150			22.8	*24.8*	25.5	*25.8*	23.5	*26.6*			20.5	*22.7*	25.4	*23.7*
160					24.5	*26.2*							20.9	*23.8*

and 2001): 28, 20, 16 and 14 years, with the maximum values of the current increment at the time of culmination: 0.39, 0.52, 0.57 and 0.56 m.

The particular age of culmination of the mean spruce height increment measured on selected FMPs: 58, 38, 30, and 32 years, and the maximum values of the mean increment at the time of culmination: 0.27, 0.35, 0.42 and 0.42 m.

Pine height data from selected FMPs

As above, the data from the FMPs of Training Forest Enterprise Kostelec n. Č. l. from 1936, 1971, 1991 and 2001 were selected for detailed graphical representation of fitted data on pine height growth trends (Fig. 6 and Table 6). The curves of the height growth show an interesting similarity. The curve of fitted height growth of pine, as well as of spruce, at the age of 100 shows the following values: FMP 1936 and 1971 the same value of 22.2 m, FMP 1991 – 22.9 m and FMP 2001 – 23.6 m.

Fitted curves of current and mean pine increment are presented in Figs. 7 and 8. Similarly, in dependence on the calendar age, the particular age of culmination of the pine height increment shows a decrease.

The particular age of culmination of the current pine height increment measured on selected FMPs (1936, 1971, 1991 and 2001): 28, 14, 10 and 10 years, with the maximum values of the current increment at the time of culmination: 0.47, 0.52, 0.56 and 0.62 m.

The particular age of culmination of the mean pine height increment measured on selected FMPs (1936, 1971, 1991 and 2001): 50, 28, 22 and 22 years, and the

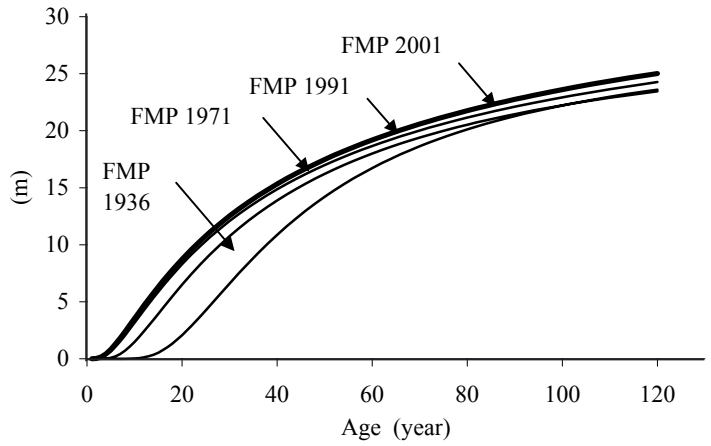

Fig. 6. Fitted mean stand heights of pine in FMP Kostelec n. Č. l.

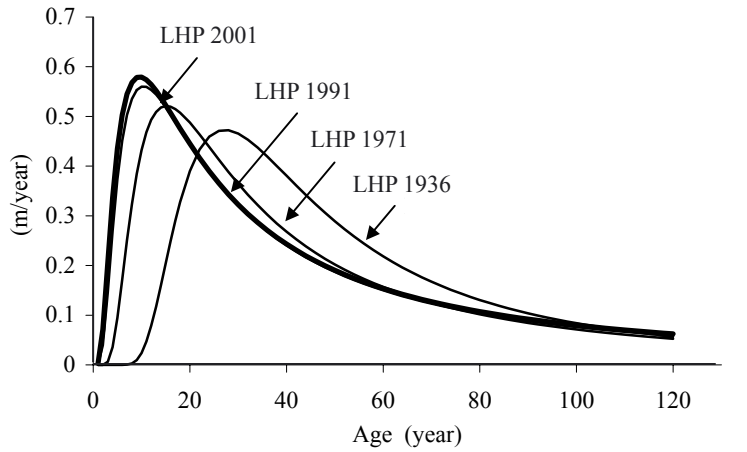

Fig. 7. Current height increment of pine in FMP Kostelec n. Č. l.

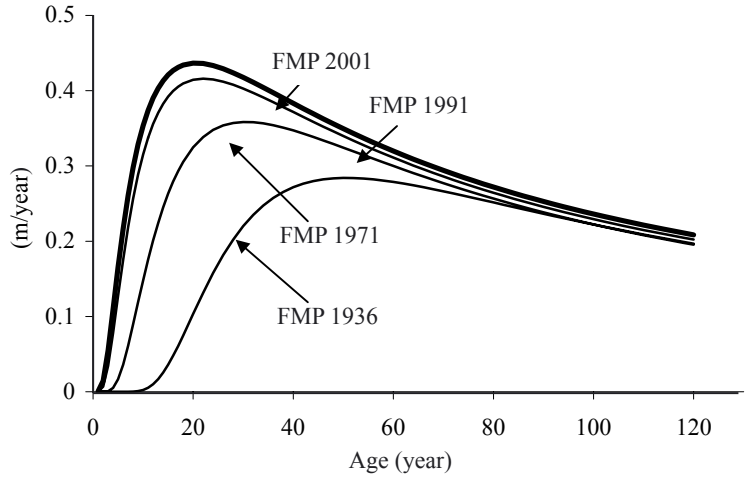

Fig. 8. Mean height increment of pine in FMP Kostelec n. Č. l.

maximum values of the mean increment at the time of culmination: 0.28, 0.37, 0.42 and 0.45 m.

Height data from selected PRPs

Besides the empirical material obtained from the series of FMPs from the area of the Training Forest Enterprise Kostelec n. Č. l., the data from measurements on pilot research plots (PRPs) were also utilized for research on stand height of both tree species. To reach at least comparable growth conditions, research plots from forest vegetation zones similar to the area of the Training Forest Enterprise Kostelec n. Č. l. were selected (2nd, 3rd and 4th FVZ) to obtain spruce height data.

Spruce height data from selected PRPs

Table 5 presents real mean height data in accordance with age classes, divided into ten-year periods of measurements: 1965/1974, 1975/1984 and 1985/1994.

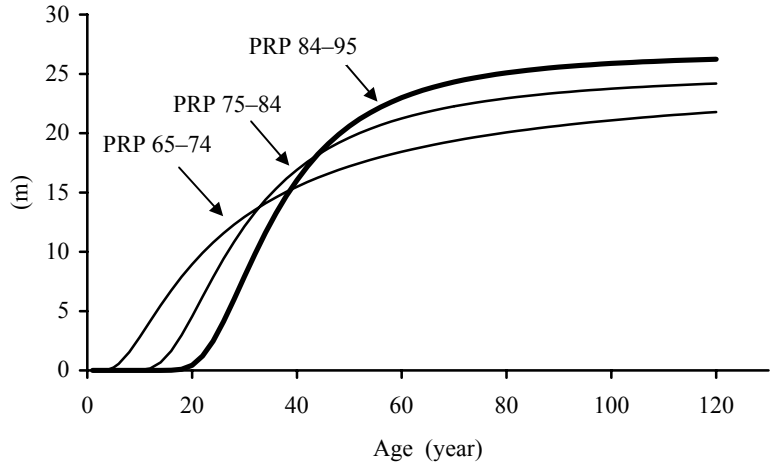

Fig. 9. Fitted mean stand heights of spruce in selected PRPs

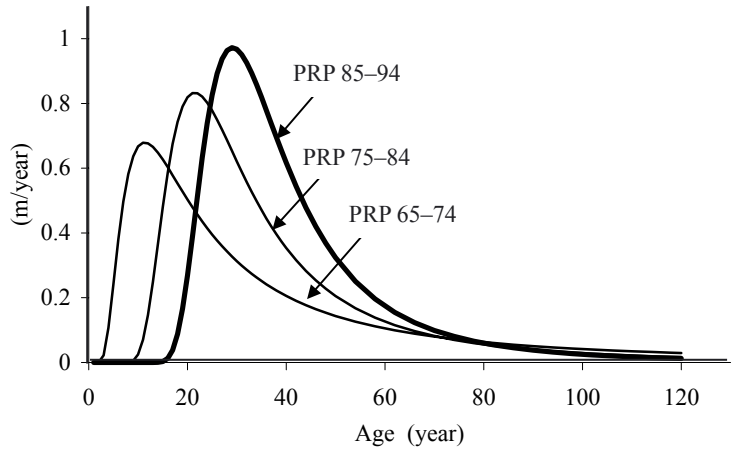

Fig. 10. Current height increment of spruce in selected PRPs

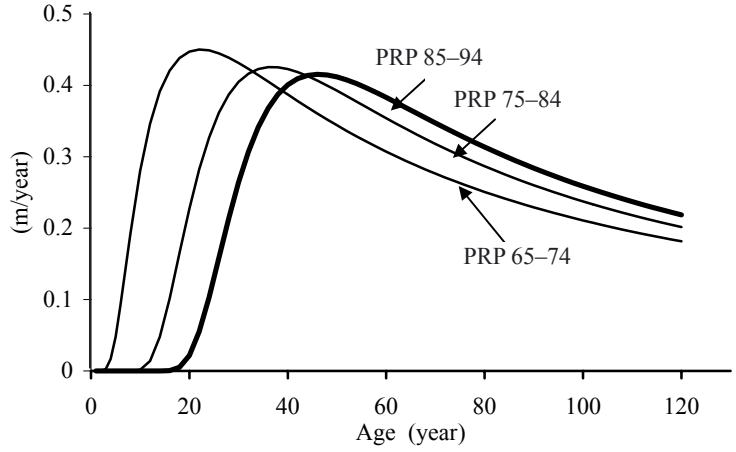

Fig. 11. Mean height increment of spruce in selected PRPs

In comparison with the other results, the fitted height curves (Fig. 9) from the age of 60 years are also almost parallel to the upward trend according to the time of measurement. At the age of 100 years, they reach the following fitted values: PRP 1965/74 – 21.1 m; PRP 1975/84 – 23.8 m; PRP 1985/94 – 25.9 m.

Contrary to the FMP data, the sequence of culmination of current and mean increment is reversed, resulting from the decreasing kurtosis of fitted height curves (Figs. 10 and 11).

The particular age of culmination of the current spruce height increment measured on selected PRPs: 11, 21 and 29 years, with the maximum values at the time of culmination: 0.68, 0.83 and 0.97 m.

The particular age of culmination of the mean spruce height increment measured on selected PRPs: 22, 37 and 46 years, and the maximum values at the time of culmination: 0.45, 0.44 and 0.42 m.

Pine height data from selected PRPs

Average data on mean stand heights of pine from the selected PRPs that, similarly to spruce, represent the 2nd, 3rd and 4th FVZ are presented in Table 6. Fig. 12 shows the

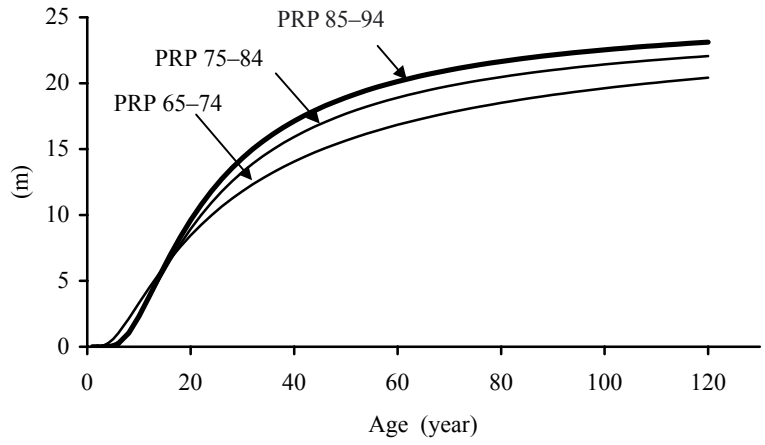

Fig. 12. Fitted mean stand heights of pine in selected PRPs

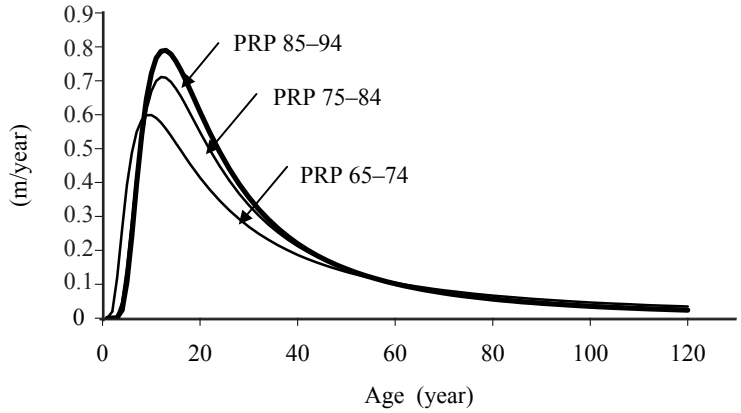

Fig. 13. Current height increment of pine in selected PRPs

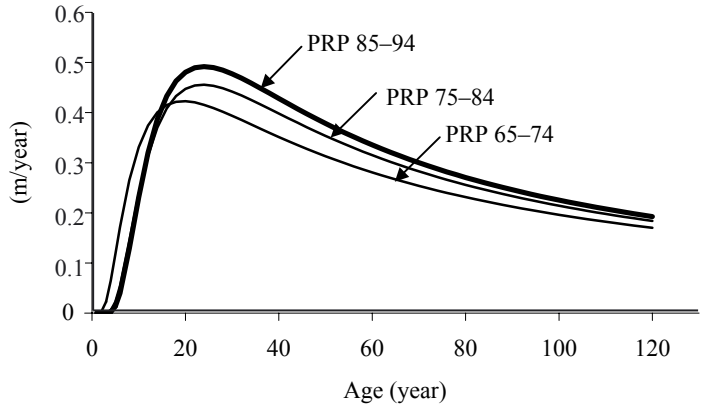

Fig. 14. Mean height increment of pine in selected PRPs

curves of fitted heights sorted in three ten-year age periods of measurements. The depicted data show, similarly to spruce, an upward parallel trend in almost the whole age span. At the age of 100 years, they reach the following fitted values: PRP 1965/74 – 19.6 m; PRP 1975/84 – 21.4 m; and PRP 1985/94 – 22.5 m.

This tree species also shows the reversed sequence of culmination of current and mean increment, resulting from the decreasing kurtosis of fitted height curves (Figs. 13 and 14).

The particular age of culmination of the current pine height increment measured on selected PRPs: 10, 12 and 13 years, with the maximum values at the time of culmination: 0.60, 0.71 and 0.79 m.

The particular age of culmination of the mean pine height increment measured on selected PRPs: 20, 24 and 24 years, and the maximum values at the time of culmination: 0.42, 0.46 and 0.49 m.

SUMMARY AND RESULTS

To determine the stand height growth quite an extensive empirical material was gathered from two sources. In the first place, it was continuous measurements of stand height on seven FMPs in the area of the Training Forest Enterprise Kostelec n. Č. l. made in the times series of 65 years: 4,313 height data on spruce and 1,524 height data on pine. The second source of information was continuously measured pilot research plots (1965–1994), where only the areas of the 2nd, 3rd and 4th forest vegetation zone were selected to allow comparison with the surveyed areas of the Training Forest Enterprise Kostelec n. Č. l. The selection provided 790 height data on spruce and 662 height data on pine. Empirical data were analytically fitted by Korf's growth function.

The results of height survey are presented in the graphical form in figures, and in the numerical form in tables. Graphical comparison of the values of mean stand heights from continuous calendar measurements taken from different empirical material, though representing similar growth conditions, confirmed the anticipated upward trend of the height growth of both tree species in dependence on growth and calendar year of measurements.

Partial intersecting of fitted curves of the mean stand heights occurs in both tree species especially in 1936 to 1961 in younger stands, while from 100 years on the data show the upward height growth trend as well. The accuracy of measurements of the main variable is confirmed by later controls taken by the Forest Management Institute, which seem to show hardly any measurement error, and the mean heights were accurately measured in all prepared FMP, especially in recent decades. Calculated mean stand heights from the empirical material constitute survey curves of heights in stands in the given areas for the given tree species and year of measurement.

The hypothetical upward trend of height curve development was confirmed, which is more prominent in spruce than in pine stands. Graphical comparison of the fitted height curves shows changes which occurred during the past 65 years from the FMP data and grouping into three

ten-year periods in PRPs showed the dependence of a change in the height growth trend of both tree species on the year for which the height trend is scheduled.

The survey curves of height growth illustrate that stands at the particular age reach in a series of measurement usually a higher level of stand height than older stands would have reached at the same age. The sets of height data therefore characterize height growth at individual calendar horizons and confirm changes in the height growth that influence, though not equally, both tree species in connection with changeable surroundings in dependence on the calendar age.

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Změny trendů průběhu výškového růstu smrku a borovice na podkladě opakovaných měření na lesních hospodářských plánech Kostelec n. Č. l. a z poloprovozních výzkumných ploch České republiky

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ABSTRAKT: V měnících se růstových podmínkách by se metodické postupy měly více zaměřovat na zjišťování procesů aktuálně v lese probíhajících. Řada studií v tomto směru ukázala, že současné modely růstu lesa se liší od dřívějších pozorování, pokud jde o takové parametry, jako je výška. Příčiny těchto jevů zůstávají stále na úrovni hypotéz a dosavadními výsledky výzkumu se je zatím nepodařilo komplexně objasnit. V práci jsou uvedeny dílčí výsledky šetření růstu výšky v průběhu 65 let na podkladě vyhodnocení údajů sedmi lesních hospodářských plánů na LHC Kostelec n. Č. l. a opakovaných měření na PVP z období 1965–1994. Vzájemná porovnání věkových výškových růstových křivek získaných vyrovnáním hodnot empirických údajů naznačují svým rozdílným průběhem a zvyšující se strmostí závislost na kalendářním roce jejich měření. Naznačují tak zvyšující se výškový růstový trend u obou dřevin v dané oblasti.

Klíčová slova: smrk ztepilý; borovice lesní; střední porostní výška; trendy výškového růstu; běžný a průměrný výškový přírůst; věk porostu; letopočet; lesní vegetační stupně; lesní hospodářský plán (LHP); poloprovozní výzkumné plochy (PVP)

V článku jsou prezentovány některé dílčí výsledky výzkumu porostní výšky. Výškový růst je jednou ze základních biologických vlastností dřevin. Závisí hlavně na dřevině a jakosti stanoviště. Pro úzkou závislost výšky na stanovišti se výškové křivky dřevin všestranně využívají v lesnické taxaci, a to především při stanovení produkční schopnosti dřevin (bonitaci). Poznatky řady výzkumných pracovníků našich i z okolních států potvrdily, že u porostů na stejném stanovišti dochází s postupujícím věkem ke změnám výškového růstu. Potvrzují to i výsledky šetření růstu výšky našich hlavních jehličnatých dřevin smrku a borovice. Dříve uveřejněná vyhodnocení empirických údajů střední porostní výšky (KŘEPELA et al. 2000) byla nově rozšířena o výškové údaje smrku a borovice z LHP Kostelec 2001 na území školního lesního podniku Kostelec n. Č. l. a dále také o opakovaná měření na poloprovozních výzkumných plochách (PVP) obou dřevin založených Lesprojektem na celém území ČR. Plochy byly zakládány a opakovaně proměřovány v letech 1965–1994 a sloužily k získání potřebných údajů pro tvorbu růstových tabulek pro naše přírodní poměry.

Při výběru porostních skupin pro výběr výškových údajů z hospodářských knih LHP Kostelec byly vybrány porosty smrku a borovice tak, aby byly vyloučeny porostní zbytky nebo skupiny stromů silně ovlivněné sousedními porosty. Nižší počet těchto údajů pro borovici vyplývá z jejího zastoupení na lesním hospodářském celku. Celkem tak bylo vybráno 4 168 měření pro smrk a 1 524 pro borovici.

Pro databázi měření porostních výšek na výzkumných plochách PVP zakládaných na celém území České republiky byly vybrány údaje pouze z ploch na 2., 3. a 4. lesním vegetačním stupni, které jsou také zastoupeny i v oblasti Kostelce n. Č. l. Bylo vybráno 790 výškových měření pro smrk a 662 měření pro borovici.

Pokud se týká přesnosti zjišťování hlavní veličiny střední porostní výšky, je možné vycházet z pozdějších poznatků kontrol u ÚHÚL, které zjišťují, že tato měření nebývají zatížená žádnou systematickou chybou a střední výšky se při tvorbách LHP, a to zvláště v posledních několika desetiletích, měřily poměrně spolehlivě. Vypočítané průměrné porostní výšky z empirického materiálu vytvářejí inventarizační křivky výšek v porostech v dané oblasti pro danou dřevinu a letopočet měření.

Výzkum byl řešen v rámci grantu prof. Kouby Metody optimálního řízení vývoje a produkce lesů v měnících se růstových podmínkách při hospodářském a ekologickém riziku (č. 526/01/0922). Cílem řešení bylo grafické posouzení rozdílnosti výškových trendů obou dřevin z obdobných přírodních poměrů z hlediska porostního věku a letopočtu jejich měření. Skutečné porostní výškové údaje dřevin byly v závislosti na věku vyrovnány Korfovou růstovou funkcí (KORF 1939).

Z vyrovnaných průběhů středních výškových křivek smrku a borovice ze všech údajů podle jednotlivých LHP a opakovaných měřeních na PVP je patrná rozdílnost průběhu, která se projevuje jejich posunem se stoupajícím kalendářním věkem. Tento posun je výraznější u smrku než u borovice. Výsledky grafického vyhodnocení daného empirického materiálu středních porostních výšek s rozdílnou dynamikou jejich vývoje tak potvrzují trend zvyšování výškového růstu v závislosti na kalendářním věku.

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