Growth trends of spruce in the Orlické hory Mts.

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ABSTRACT: In 2002, height and diameter growth of spruce was investigated in the Orlické hory Mts. (the Czech Republic). The aim was to confirm and to quantify a growth increase in stands of different age, and to reveal the relation between growth and climate, and level of nitrogen deposition. Stem analyses of ten sample trees of mature spruce stand (average age 163 years) confirmed a significant increase in height and diameter growth since the mid-eighties of the 20th century. Nearly 75% of radial increment variability could be explained by climatic factors. Growth in the last 10 years corresponded well to weather conditions. Analysis of the growth – nitrogen deposition relationship showed negative correlations, but the results were not statistically significant. Comparison of the height growth curves of young stands (11–47 years) proved that the younger the stand, the steeper the growth curve. The height of the youngest stands was on average the double of the height of older stands at the same age. The values of the height growth of young stands significantly overreached the yield table values in all the age classes analyzed.

Keywords: growth trends; increment; spruce; nitrogen deposition; climate; Orlické hory Mts.

In the 1980's and 1990's many studies were worked out, focused on forest stand growth in Europe. Most of the studies proved a significant growth increase in the last decades (ERIKSSON, JOHANSSON 1993; SCHOPFER et al. 1994; KOUBA 1995; SPIECKER et al. 1996, and others). The cause of today's growth trends has not been explained in a satisfactory way yet. Changes in the level and composition of deposition (mainly of nitrogen) were enhanced by CO_2 concentration in the atmosphere and increased air temperature, and last but not least, changes in forest management are also generally the main factors considered to be a cause of accelerated growth (KARJALAINEN et al. 1999). However, depending on site conditions, tree species and provenance, different combinations of these factors can be limiting.

On the one hand, growth acceleration can increase the production of forest stands, on the other hand it can also be an unwanted effect – nutrition misbalance, higher sensitivity to extreme weather conditions (frost, drought), higher risk of damage by wind, and higher sensitivity to damage by insect pests (SPIECKER 1999).

Since the mid-nineties recurrent heavy damage to forest stands in the Orlické hory Mts. and Krušné hory Mts. was recorded in the Czech Republic. Several types of damage were observed in the first area – drying of terminal shoots, dieback of the lower part of tree crown, dieback of the upper crown part. In the Krušné hory Mts., mainly in the western part of the ridge, intensive yellowing of spruce stands was observed, indicating significant nutrition disturbances. Simultaneously, extreme height increments of damaged stands were observed in both areas. It seems to be probable that the high production and great damage are connected with a high nitrogen input to the ecosystem. This hypothesis is a basis of the project *Impact of Current Nitrogen Deposition on Growth Increase and Nutrition Quality of Spruce Stands* solved in the Forestry and Game Management Research Institute Jíloviště-Strnady (FGMRI) since 2001. The project is focused on the above-mentioned problematic areas and on the area of the Žďárské vrchy Mts. studied as a control locality.

The goals of the project are to confirm and to quantify an increase in height and diameter growth of spruce stands of different age, growing in similar site conditions, and to investigate the relation of growth to environmental parameters (climate, nitrogen deposition). In the first stage, in 2002, height and diameter growth of spruce were analyzed in the area of the Orlické hory Mts.

METHOD

The localisation of stands where height and diameter growth was analyzed is shown in a map (Fig. 1). Basic stand characteristics are presented in Table 1.

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Fig. 1. Localisation of sample sites on the map of forest areas – Orlické hory Mts.

Stem analysis

For the stem analysis ten dominant trees were cut in the mature spruce stand 360C1, Šerlišský mlýn locality. The stand originated partly from natural regeneration and partly from plantation. The stand belonged to a set of permanent research plots managed by FGMRI, Opočno Research Station. It was used as a control plot – since 1958 no silvicultural operations were carried out there, with the exception of incidental fellings (1967/68, 1971, 1984). The measurement of deposition started in 1986.

Selected sample trees should be with no mechanical stem or crown damage, no stem rot, and not affected by sudden opening of the canopy, if possible. Before cutting the height and diameter at breast height (dbh) were measured in all the sample trees, and tree orientation according to the compass points was marked on the stem. The first stem disc was taken at the height of 130 cm above ground (dbh), other discs in two-meter sections. The last disc was taken at a distance of about 2–4 m from the tree top, under the whorl to which the length of individual internodes from the tree top was measured. Discs were also taken from stumps to determine the exact age of trees. The surface of the discs was sanded to improve tree-ring visibility. Radial increments were measured on each disc at 4 radii in the direction of the four main compass points. Measuring was done using a digital position-meter KUTSCHENREITER to the nearest 0.01 mm. In total 132 stem discs were measured.

Individual ring-width series were cross-dated, checked and corrected for missing and false rings. Dating and correction of the series were done using the DAS programme, dating was verified statistically by the COFECHA programme (HOLMES et al. 1986). Verified series were used to determine the height growth of trees, derived as an average height increment in the corresponding stem section, as a quotient of the section length (2 m) and the difference in tree-ring number at the beginning and at the end of two-meter section. Current height increment was approximated by mean five-year increment. The outputs of stem analyses were used to calculate basal area increments and volume increments in five-year periods (KORF 1953).

To stress the trends of increment development and to compare the sample trees in a better way the values of current increment were expressed in standardised form – it is a current increment expressed as percentage of mean increment (RÖHLE 1999).

Table 1. Characteristics of sample sites

Type of tree-ring analysis	Stand number	Localisation		Altitude	Age in 2001		Forest site type	Site index[3]
		E longitude	N latitude		FMP[1]	TRA[2]		
1. Stem analysis	360C1	16 22 33	50 19 51	960	129	163	acid beech-spruce wood	22
2. Tree-ring analysis of young stands	360C4	16 22 33	50 19 51	960	47	43	acid beech-spruce wood	22
	360C5	16 22 33	50 19 51	960	34	34	acid beech-spruce wood	26
	360C8	16 22 33	50 19 51	960	19	25	acid beech-spruce wood	22
	18C4	16 26 46	50 16 22	930	38		acid beech-spruce wood	24
	359E8	16 22 00	50 19 54	900	24		acid beech-spruce wood	24
	20Aa2	16 26 03	50 16 50	1,010	24		acid beech-spruce wood	26
	2Bb2	16 21 22	50 19 21	880	18		acid spruce-beech wood	22
	16Cc2	16 24 25	50 18 48	930	18		acid beech-spruce wood	22
	31Aa2	16 23 19	50 17 05	870	17		acid beech-spruce wood	26
	47Bb2	16 30 13	50 13 13	940	14		acid beech-spruce wood	18
	83Ff2	16 26 32	50 14 57	1,000	14		acid beech-spruce wood	16
	19B2	16 26 46	50 16 22	960	13		dwarf beech-spruce wood	18
	62Bb2	16 27 44	50 14 17	970	12		acid beech-spruce wood	16
	358B4	16 21 46	50 20 09	970	11		acid beech-spruce wood	22

[1]FMP average age of the stand according to forest management plan data
[2]TRA average age of the stand determined by the tree-ring analysis of stump discs
[3]Site index expressed as mean height of the stand at the age of 100 years

The ring-width series of breast-height discs (in total 40 series) were used to evaluate the climate – growth relationship. The series were standardised to eliminate the age trend by the programme ARSTAN (HOLMES et al. 1986). As the first step, the trend was approximated by a negative exponential function or regression line and the index series was obtained. As the second step, a cubic smoothing spline with 50% frequency cut-off of 128 years was fitted to these index series. The remaining autocorrelation was removed by autoregressive modelling (each series was modelled as an autoregressive process where the order for the individual series was selected by first-minimum Akaike Information Criterion search). The resulting index series were aggregated by calculating mean values for the local chronologies.

The data of the Czech Hydrometeorological Institute (CHMI), of the nearest station Deštné v Orlických horách, were used for dendroclimatic evaluation. The station is located at a distance of 5 km from the sample site, at the altitude of 635 m a.s.l. Thus the difference in elevation between the station and the sample site is more than 300 m. Nevertheless, a similar course of monthly temperature and precipitation values can be assumed.

Average monthly temperatures and total monthly precipitation for the period 1957–2001 were at disposal. The residual local chronology (series of ring-width indices with removed autocorrelation) was correlated gradually to mean monthly temperatures and precipitation from May of the previous year to September of the current year when the given ring was formed (in total 17 months). Then the response function was computed using the PRECON programme (FRITTS 1996). The input variables were the same as in the simple correlation analysis. The response function is a form of multiple linear regression analysis where the predictor variables are principal components of a number of monthly mean temperature and total precipitation values. Thus climate variables are used to calculate the amount of explained chronology variability and to quantify the relative importance of the original individual climate variables. The total amount of the explained chronology variability (expressed by coefficient of determination) is taken to be a measure of the strength of the climate-forcing signal. The sign and magnitude of regression coefficients for individual monthly climate variables characterise the nature of the tree-growth/climate link (BRIFFA, COOK 1990).

In the period 1988–1997, the deposition in Šerlišský mlýn locality was measured directly in the mature spruce stand where in 2001 sample trees were taken for the stem analysis. Then it was possible to compare the ring-width indices and the height increments (using the lengths of individual internodes measured from the tree top) to the values of total annual nitrogen, sulphur and fluorine deposition.

Tree-ring analysis of young spruce stands

Young stands for the analysis of height and diameter growth were selected to cover the age interval from 10 to 50 years and to have similar site conditions as the mature stand. Besides, the stands of the first two age categories were distributed proportionally along the main ridge of the Orlické hory Mts., where the spruce stands recently started to be heavily damaged.

Three stands were selected from a set of permanent research plots in Šerlich. The remaining 11 young stands were selected from a set of 51 plots where chemical analysis of needles was done in 2001 in the framework of the study *The State of Nutrition and Air Pollution Load of Young Spruce Stands in the Orlické hory Mts.* (ŠRÁMEK et al. 2001).

In the young stands two cores from the opposite sides of the tree stem, or one disc alternatively, were taken from 15–20 sample trees. The cores were taken or a disc was cut under the whorl to which the length of individual internodes was measured from the tree top. The height above ground of this point ranged between 0.6 m in the youngest stands and 1.5 m in the stand of the age from 30 to 50 years. The surface of the cores and discs was sanded and the ring widths were measured with the digital position-meter KUTSCHENREITER. In standing trees the height increments were determined by measuring the length of individual internodes from the tree top with the

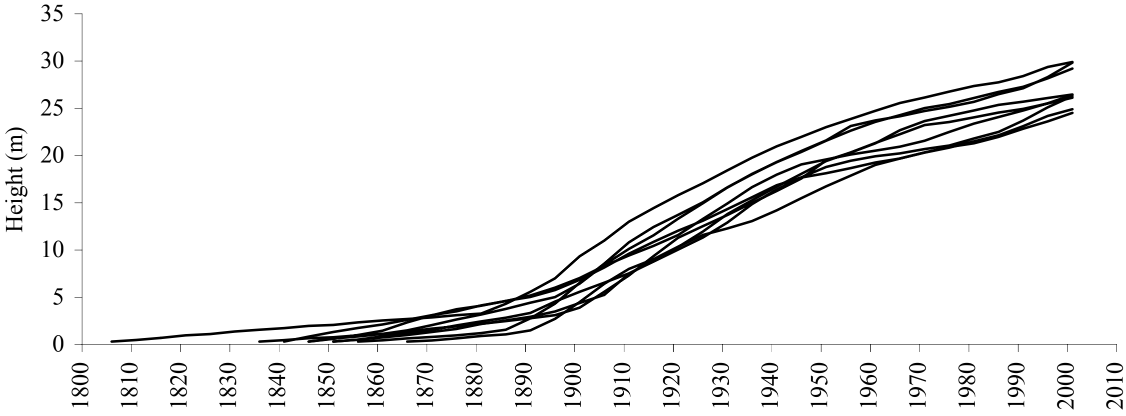

Fig. 2. Height growth curves

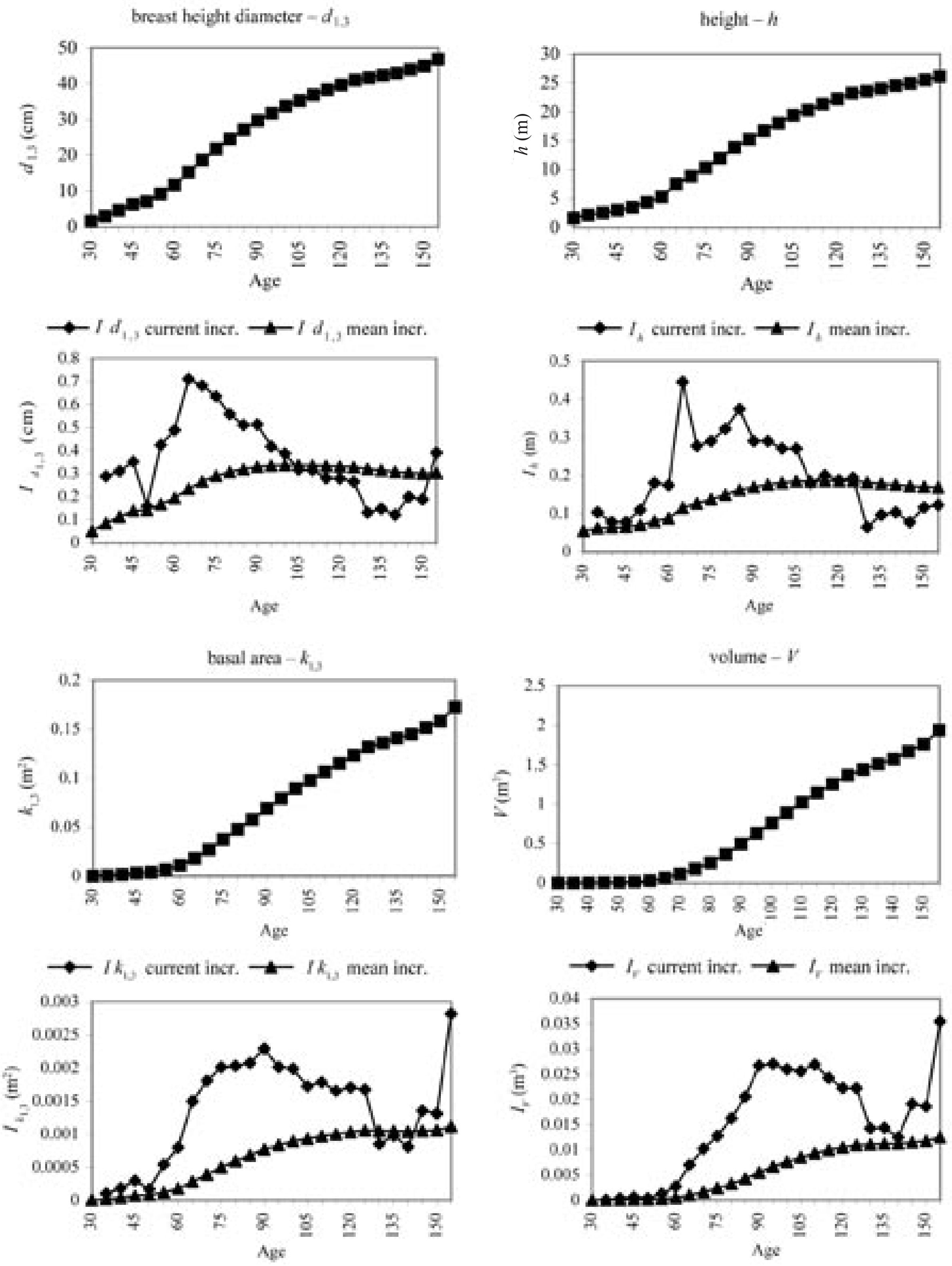

Fig. 3. Sample tree No. 20 – growth and increment curves of mensurational variables

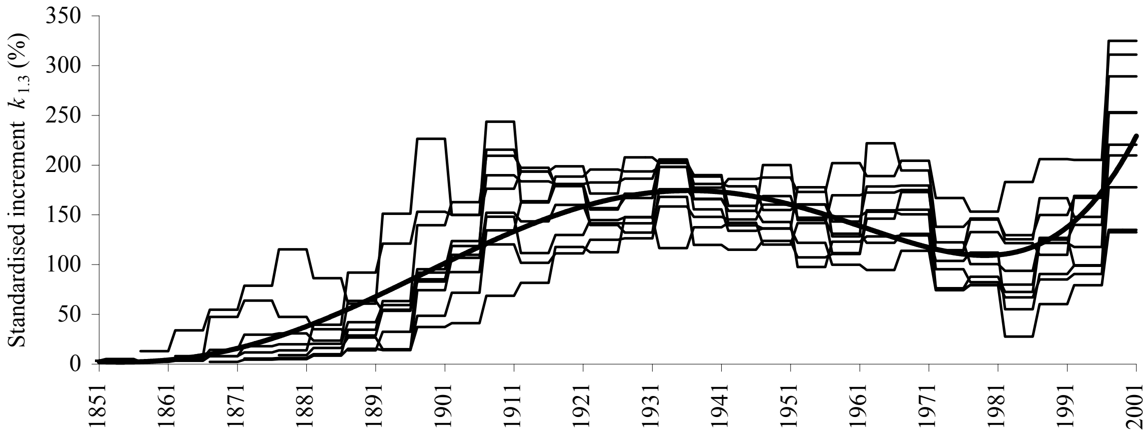

Fig. 4. Standardised basal area increment

measuring pole SOKKIA. The sample trees represented the mean stem of the stand.

For further evaluation the young stands were divided into 4 groups according to the age classes. The height growth curves for individual age classes were plotted against the site index curves of yield tables (ČERNÝ et al. 1996). The site index curves were used as a growth reference.

For each stand a height increment was calculated for the period of the last 7–10 years. Using paired *t*-test, the deviation between the real height increment and the table value was tested statistically. To estimate the site index of a stand at the beginning of the tested interval, two different approaches were used: 1. mean stand height was estimated as the arithmetical mean of heights of individual trees, 2. interval estimate of the mean stand height was calculated (95% interval), and for further processing the upper limit of this interval was used (more severe variant of the test).

RESULTS

Stem analysis

The absolute age of sample trees, determined by the tree-ring analysis of stump discs, ranged between 140 and 200 years. For all the sample trees, differently long periods of suppressed growth were proved in the young stage. It is the evidence of initial tree development under the canopy of mature stand. The period of suppression lasted 41 years on average. Most of the trees were released during a relatively short period, in the eighties of the 19^{th} century. Despite of significant differences in the age of sample trees, the course of height growth curves was synchronous since the time of release (Fig. 2).

In Fig. 3 the growth curves of diameter, tree height, basal area and stem volume, and the curves of current and mean increments of these variables are shown for sample tree No. 20, well representing the whole set.

Current diameter increment increased at first, after reaching the culmination point it decreased slowly and it was lower than the value of mean diameter increment. During the last 15 years the diameter increment started to increase. In the last five-year period the values of current increment of most trees overreached the values of mean increment again.

Compared to diameter increment, the height increment was more variable, but in general it showed similar trends like the diameter increment. Considering frequent top breaks in the stand, the height increments could be evaluated only in a half of the sample trees.

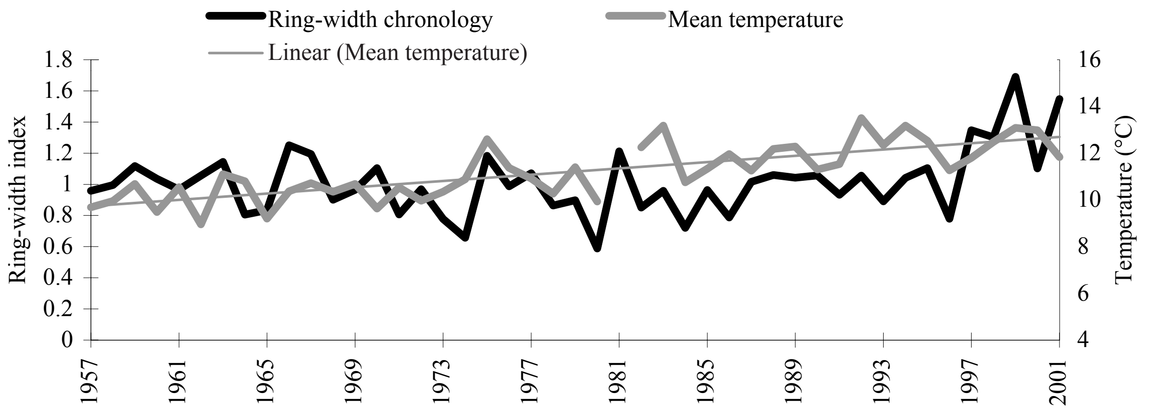

Fig. 5. Ring-width chronology compared to mean temperature during the vegetation period (April–September)

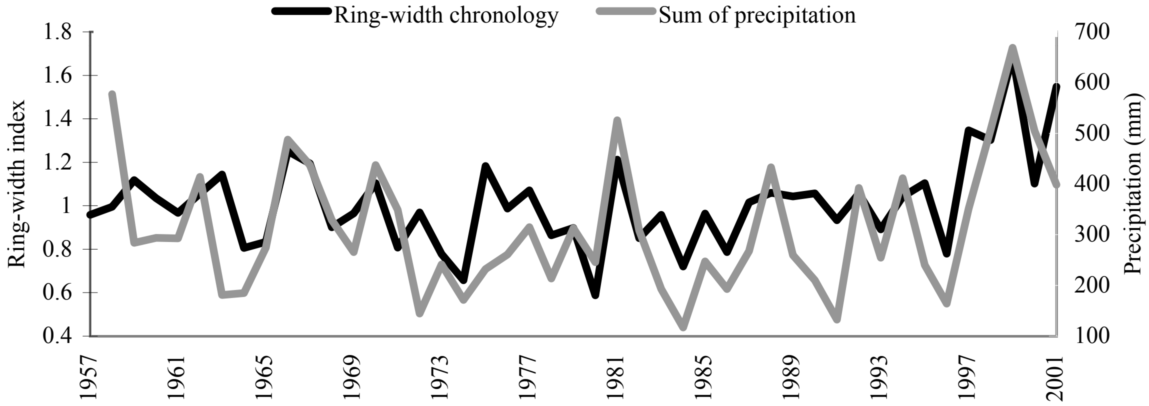

Fig. 6. Ring-width chronology compared to the sum of precipitation in July of the previous year, and February, March of the current year

Atypical development of growth is even more evident from the increment curves of basal area and stem volume. At the given diameter dimensions of sample trees, even a small increase in radial growth resulted in a sharp increase in basal area increment, and also in stem volume increment. The curves of current and mean increment of these values did not often intersect. The mean increment is thus permanently increasing, not culminating yet.

The trends of current increment development are better visible when relevant current increments of all sample trees are plotted in one graph in standardised form as a function of date. Due to frequent top breaks, the basal area increment is the most objective way of expressing the growth (Fig. 4). Increased growth since the mid-eighties is evident. During the last five-year period the values of current increment exceeded the values of the first culmination.

Analysis of the climate – growth relationship proved a significant impact of weather conditions during the given and previous year on radial increments.

The results of correlation analysis showed that growth was positively influenced mainly by temperatures during the vegetation period in the given year, and by precipitation in July of the previous year and early spring of the given year. The results of response function correspond well to the results of simple correlation. The regression coefficients for temperatures in July of the given year and for precipitation in July of the previous year were statistically significant ($\alpha = 0.05$), the relationship was positive in both cases. In total 74.3% of the chronology variability could be explained by average monthly temperatures and total monthly precipitation.

Fig. 5, illustrating a positive relationship between growth and temperature during the vegetation period, confirms that the temperature has an increasing trend since the beginning of investigation in 1957. Fig. 6 plots the values of ring-width indices together with the sum of precipitation in the months when a significant relation to growth was identified. Growth maxima well correspond to the precipitation maxima (1966, 1981, 1999).

The correlation analysis of the relationship between growth and deposition of nitrogen, sulphur and fluorine showed that both radial and height growth reacted negatively to higher inputs of these elements into the ecosystem. However, the correlation coefficients were not statistically significant (Table 2).

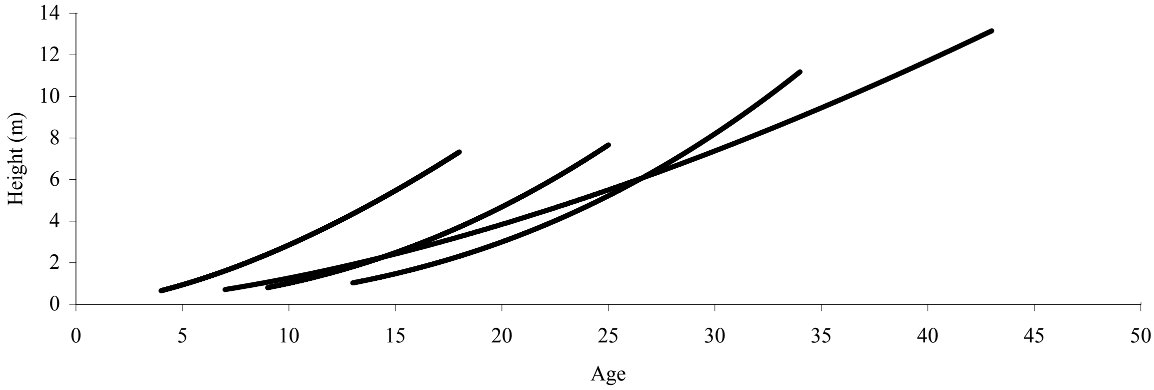

Fig. 7. Height growth curves of young stands

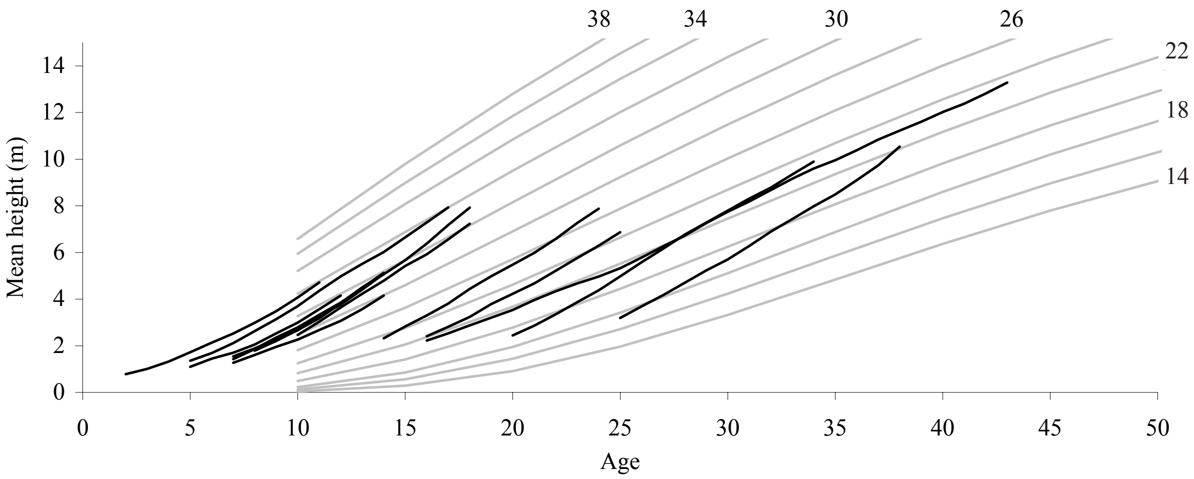

Fig. 8. Height growth curves of young stands compared to the site index curves of yield tables (ČERNÝ et al. 1996)

Table 2. Values of correlation coefficients of the growth – deposition relationship

	N	S	F
Radial growth	–0.28	–0.47	–0.36
Height growth	–0.45	–0.40	–0.51

r_{sig} 0.05 = 0.576

Tree-ring analysis of young spruce stands

In Fig. 7 the height growth curves of the stands of the 2nd to 5th age class are shown. At least at the beginning, the growth curves of the stands of 3rd and 4th age class were parallel to the growth curve of the 5th age class, however, the growth was accelerated in the last decade and the curves started to go up sharply. The course of height growth curve of the youngest stands is completely different – the mean height of these stands is double compared to the values of the older stands at the same age.

Comparing visually the height growth curves of 14 young stands with the site index curves of the yield tables (ČERNÝ et al. 1996), unusually sharp height growth was evident in today's young stands (Fig. 8). Only the stand representing the 5th age class showed development similar to that expressed by the site index curve.

Above-average values of height increment were also confirmed by the results of statistical test. A positive difference between the real and table values of height increment was statistically significant ($\alpha = 0.05$) in most stands. For stands 360C8 and 360C4 the difference was significant only in Test 1, it means in the less strict variant. In stand 360C4 two intervals of 10 and 20 years could be tested. The real growth was higher than the table value for the shorter interval in Test 1 only, meanwhile for the double length of the interval, the results of both variants of the Test were significant.

DISCUSSION

For all sample trees selected in the mature spruce stand, the origination of natural regeneration was proved. It is probably true because thanks to higher productivity and resistance to mechanical damage of the crown the individuals of the autochthonous population better fulfilled the criteria of sample tree selection. The long time of suppression did not impact tree vitality negatively, either. The oldest sample tree, suppressed for nearly 80 years, showed the highest growth rate in the time of unsuppressed development. Spruce under the given conditions shows a high level of suppression for a long time, with a stable growth trend of height increments. Slower spruce growth in the shade is compensated by higher sturdiness and toughness of wood (ZAKOPAL 1973).

The development of real increments was very different from the general model of increment function. Due to the significant increase in production during the last two decades, the current diameter and height increments overreached the values of mean increment again, or in the basal area and volume increment the curves of current and mean increment did not often intersect. It means that in diameter and height the mean increment was increasing again after its first culmination, in the basal area and volume the culmination of the mean increment was not reached yet.

The development of increments of individual mensurational variables is separate in time – at first height increment culminates, then diameter increment followed by basal area, and much latter volume increment (ŠEBÍK, POLÁK 1990). The same authors presented the following age of current increment culmination for spruce growing in average site conditions: 1. height increment 30 to 40 years, 2. volume increment 110–130 years. However, the time of culmination can be shifted significantly forward, due to shading by a mother stand in the young stage. This fact was proved for the analyzed sample trees – the height increment culminated on average at the age of 73 years, the volume increment reaches the highest values just now, at the average age of 163 years. When eliminating the first stage of suppressed growth, the culmination of the current increments would be about 40 years earlier. These values are comparable to those shown in the literature.

The development of current basal area and volume increment was strongly irregular, however. Similar irregularities in volume increment were also revealed by GUTTENBERG (1915), who recorded the first culmination of volume increment at the age of 80 years, then the increment decreased and started to increase at the age of 115 years again. According to Guttenberg, the cause of irregular development was probably natural decline or cutting of neighbouring competing trees, followed by sudden opening of the canopy to which the trees responded by growth increase. Guttenberg analyzed 30 spruces in total (up to 300 years old), only two of them reached the maximum of mean volume increment. In the other trees the curves of current and mean increment did not intersect.

The significant growth increase of sample trees from Šerlišský mlýn locality during the last 15 years cannot be considered only as a result of the last incidental felling carried out in 1984, however. First, the height growth was also increasing, in dominant trees the impact of canopy density was negligible. Second, an increasing trend of diameter growth was also recorded at the locality Luisino údolí in the Orlické hory Mts. (KROUPOVÁ, KYNCL 2001), and also at similar sites in other mountainous areas: Krušné hory, Jizerské hory and Krkonoše Mts. (KROUPOVÁ 2002). And last but not least, the growth acceleration was most pronounced during the last five years, 1997–2001, i.e. more than 10 years after the felling operation.

RÖHLE (1999) analyzed two spruce stands (110 and 143 years) in the region of Southern Bavaria, and he found an increase in volume increment since 1960, with no relation to the stand age. The development of standardised volume increment was similar to the development of the same variable for spruce from Šerlišský mlýn, only the period of an increase in the area of the Orlické hory Mts. was limited by the last two decades. Later start of growth increase could be connected with the high air-pollution load of the area from the fifties to the eighties of the 20th century. The results of the work reported by RÖHLE (1999) well correspond to the results of other studies focused on the growth trends of forest stands in Europe, giving evidence of a significant, in some cases even 60% increase of the increments mainly in Central Europe (SPIECKER et al. 1996).

Due to high precipitation sums in the Orlické hory Mts. (average annual sum of precipitation at the station Deštné v Orlických horách is 1,184 mm) and the altitude of the locality (950 m a.s.l.), a positive reaction of radial growth mainly to the temperature during the vegetation period was expected. This expectation was confirmed only partly. Growth was sensitive to summer drought in the year previous to the year in which the given tree-ring was formed, and to low precipitation at the break of winter and spring of the given year. Spruce as a tree species with shallow root system can probably suffer from water deficit on a steep, well-drained slope, even under relative high precipitation. Growth increase during the last ten years corresponds to weather conditions. The data of the station in Deštné v Orlických horách showed that the temperatures during the vegetation period were significantly above-average in this period, and not connected with strong summer drought.

The relation between growth and the level of nitrogen deposition was negative. The Orlické hory Mts. are one of the most afflicted areas in regard to nitrogen deposition. According to the results of deposition measurements in Šerlich locality (FGMRI), nitrogen deposition under the mature spruce stand was over 50 kg/ha/year at the end of the eighties. Since that time the values decreased gradually to about 30 kg/ha/year at the end of the nineties (LOCHMAN 2000). As REHFUESS et al. (1999) stated, most stands where the deposition level exceeded the value of 25 kg/ha/year for several years, could be close to the state of saturation.

The growth trends in the young stands could hardly be evaluated as the time series were too short. Therefore a comparison of the measured values to the yield tables was used. In such a comparison, certain limits of the use of site index curves as the reference have to be considered. Limits are given by the used method of site index curve construction, and by the time-limited validity of the curves. The tables (ČERNÝ et al. 1996) were constructed using the database of forest management plans developed by the Forest Management Institute. The index site curves have a character of inventory curves. The inventory curve precisely characterises the height growth curve of trees at a given site only in the case of strict homogeneity of the sample material – regular distribution of sample plots in the age and height classes. In reality, however, the overabundance of data on better quality sites in the young stands results in a sharp initial increase in site index curve, and on the contrary, the prevalence of data on poor sites in the old and very old stands results in the flattening of the curve with increasing age (HALAJ et al. 1987; SEQUENS 1994). The comparison of height growth of the young stands in the Orlické hory Mts. to the table values gave an evidence of significant overreaching of the reference values, despite of certain overestimate of tree height at the young age by the yield tables mentioned above. Considering changing growth conditions in time, the site index curves describe stand growth in the period when the data for the table construction were collected. So when we compared the measured values to the table values, in fact we compared the growth of presently growing young stands to the stand growth in the period from fifties to eighties of the 20th century.

CONCLUSION

The stem analysis of ten sample trees of the mature spruce stand from Šerlišský mlýn locality proved the increase in diameter and height growth since the mid-eighties of the 20th century. Increased growth could not be connected only with the last incidental felling in 1984. On the one hand, the height growth also increased, which is not affected by the changes in a tree competition with dominant trees, on the other hand, the increase in diameter growth was also recorded at comparable sites in other mountainous areas in the Czech Republic, and last but not least, the increase in growth was most pronounced only in the last five-year period of 1997–2001.

Nearly 75% of radial-increment variability could be explained by climatic factors. Growth increase in the last 10 years corresponds to weather conditions. Thus it could be supposed that the increased growth was probably a reaction to suitable climatic conditions during this period.

The analysis of the growth – nitrogen deposition relationship showed a negative correlation, both for the diameter and height growth. However, the values of the correlation coefficients were not statistically significant.

Comparison of the height growth curves of young stands proved that the younger the stand, the steeper the growth curve. The height of the youngest stands (10–20 years) was approximately a double of that of older stands at the same age. The values of height increments of young stands overreached significantly the table values in all analyzed age classes.

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Trendy přírůstu smrku v Orlických horách

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ABSTRAKT: V roce 2002 byly v Orlických horách vyšetřovány tloušťkové a výškové přírůsty smrku s cílem potvrdit a kvantifikovat vzestup přírůstů v porostech různého stáří a vyšetřit vztah přírůstů ke klimatu a k úrovni depozic dusíku. Kmenová analýza 10 vzorníků ze starého smrkového porostu prokázala výrazný vzestup tloušťkových a výškových přírůstů od poloviny osmdesátých let 20. století. Téměř 75 % variability radiálních tloušťkových přírůstů bylo možné vysvětlit pomocí teplot a srážek. Vývoj přírůstů v posledních deseti letech velmi dobře koresponduje s průběhem počasí. Korelační analýza vztahu přírůstů k depozicím dusíku ukázala negativní závislost, výsledky však nejsou signifikantní. Ze vzájemného srovnání vývojových výškových křivek mladých porostů (11–47 let) vyplynulo, že čím je mladší porost, tím strmější je průběh výškové křivky. Výška nejmladších porostů je přibližně dvojnásobná v porovnání s hodnotami výšek starších porostů ve stejném věku. Hodnoty výškových přírůstů mladých porostů významně převyšují tabulkové hodnoty u všech analyzovaných věkových stupňů.

Klíčová slova: růstové trendy; přírůst; smrk; depozice dusíku; klimatické podmínky; Orlické hory

Článek uvádí dílčí výsledky první etapy projektu *Vliv současných depozic dusíku na zvyšování přírůstů a kvalitu výživy smrkových porostů*, v jejímž rámci byly za použití dendrochronologických metod analyzovány přírůsty smrku v jednom dospělém (průměrný věk vzorníků 163 let) a 14 mladých porostech druhého až pátého věkového stupně v oblasti Orlických hor. Lokalizace odběrových míst je patrná z obr. 1, základní charakteristiky porostů uvádí tab. 1. Cílem práce bylo potvrdit a kvantifikovat vzestup přírůstů v porostech různého stáří a vyšetřit vztah přírůstů ke klimatu a k úrovni depozic dusíku.

Tloušťkové a výškové přírůsty vzorníků reprezentujících horní střední kmen dospělého porostu byly zjišťovány metodou podrobné kmenové analýzy (přírůsty byly analyzovány v dvoumetrových sekcích). Tloušťkový přírůst byl vypočten z naměřených radiálních přírůstů ve výčetní výšce. Výškové přírůsty byly odvozeny jako průměrné přírůsty v odpovídajících sekcích z podílu délky sekce a rozdílu počtu letokruhů na začátku a na konci dvoumetrové sekce. Běžný výškový přírůst byl aproximován průměrným pětiletým přírůstem. Výstupy kmenových analýz byly použity k výpočtu přírůstů na kruhové ploše a hmotových přírůstů v pětiletých intervalech. Pro zvýraznění trendů ve vývoji přírůstů a také pro lepší vzájemnou porovnatelnost vzorníků byly hodnoty běžných přírůstů vyjádřeny ve standardizované podobě (běžný přírůst vyjádřený v procentech průměrného přírůstu). Pro dendroklimatologické vyhodnocení byla převzata data ČHMÚ z meteorologické stanice Deštné v Orlických horách. Klimatická data byla porovnávána s průměrnou reziduální letokruhovou chronologií. Vztah přírůstu ke klimatu byl vyšetřován metodami jednoduché korelace a mnohonásobné lineární regrese (funkce odezvy). Pro období 1988–1997 byly k dispozici hodnoty celkové roční depozice dusíku, síry a fluoru pod dospělým smrkovým porostem, a proto bylo možné provést korelační analýzu vztahu depozic těchto prvků k tloušťkovým a výškovým přírůstům.

V mladých porostech byl tloušťkový přírůst zjišťován letokruhovou analýzou s odběrem dvou vývrtů, případně jednoho kotouče ve výčetní výšce z 15–20 vzorníků reprezentujících střední kmen porostu. Výškové přírůsty byly určeny proměřením délek jednotlivých internodií od vrcholku stromu. Vývojové výškové křivky skupin porostů sdružených podle věkových stupňů byly porovnány s bonitními křivkami Taxačních tabulek (Černý et al. 1996). Za použití párového *t*-testu byla statisticky otestována odchylka skutečného výškového přírůstu od tabulkových hodnot.

Kmenová analýza prokázala autochtonní původ vzorníků z dospělého smrkového porostu – u všech bylo zjištěno různě dlouhé období potlačeného růstu v mládí. I přes značný věkový rozdíl, daný různě dlouhou dobou vývoje v zástinu pod mateřským porostem, byl průběh výškových křivek od okamžiku uvolnění stromků jednotný (obr. 2). Zjištěné průběhy přírůstů všech veličin se značně odlišují od obecně formulovaného modelu přírůstové funkce. V důsledku výrazného vzestupu produkce v posledních dvou decenniích se hodnoty běžného přírůstu opětovně dostávají nad hodnoty přírůstu průměrného, resp. u přírůstu na kruhové ploše a u objemového přírůstu často k protnutí křivek běžného a průměrného přírůstu vůbec nedošlo (obr. 3). Znamená to, že u tloušťky a výšky průměrný přírůst po první kulminaci opět stoupá, u přírůstu na kruhové ploše a u objemového přírůstu kulminace průměrného přírůstu ještě nenastala. Po vynesení běžných přírůstů na kruhové ploše ve standardizované podobě ještě lépe vynikne vzestup přírůstů od poloviny osmdesátých let. V poslední pětileté periodě pak hodnoty běžných přírůstů dokonce přesahují hodnoty z období první kulminace (obr. 4). Zvyšování přírůstů nelze považovat pouze za důsledek posledního provedeného těžebního zásahu v roce 1984. Jednak stoupá i výškový růst, na jehož velikost u nadúrovňových jedinců má konkurence sousedních stromů zanedbatelný vliv, jednak vzestup tloušťkových přírůstů zaznamenaný u smrku na srovnatelných stanovištích i v dalších horských oblastech ČR a v neposlední řadě vzestup přírůstů je nejmarkantnější až v poslední pětileté periodě 1997–2001.

Z výsledků korelační analýzy vyplynulo, že výši tloušťkových přírůstů pozitivně ovlivňují především teploty v průběhu vegetační doby v daném roce, dále srážkové úhrny v červenci předchozího roku a v předjaří roku daného. Výsledky funkce odezvy (response function) pro teploty a srážky byly v souladu s výsledky jednoduchých korelací. Téměř 75 % variability radiálních tloušťkových přírůstů, které mají těsný vztah k přírůstu hmotovému, bylo možné vysvětlit pomocí teplot a srážek. Vzestup přírůstů v posledních deseti letech velmi dobře koresponduje s průběhem počasí (obr. 5 a 6) a lze proto předpokládat, že zvýšený růst je zřejmě z větší části reakcí na příznivé klimatické podmínky v tomto období.

Korelační analýza vztahu přírůstů k depozicím dusíku ukázala negativní závislost jak pro tloušťkové, tak pro výškové přírůsty (tab. 2). Hodnoty korelačních koeficientů však nevycházejí jako statisticky významné.

Ze vzájemného srovnání vývojových výškových křivek mladých porostů vyplynulo, že čím mladší porost, tím strmější průběh výškové křivky (obr. 7). Výška nejmladších porostů je přibližně dvojnásobná v porovnání s hodnotami výšek starších porostů ve stejném věku. Hodnoty výškových přírůstů mladých porostů významně převyšují tabulkové hodnoty, a to u všech analyzovaných věkových stupňů (obr. 8).

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