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Radial growth trends of fir (*Abies alba* Mill.), beech (*Fagus sylvatica* L.) and pine (*Pinus sylvestris* L.) in the Świętokrzyski National Park (Poland)

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ABSTRACT: The objectives of this study are to determine a trend of the radial growth at breast height (b.h.) and to compare the radial growth of trees of younger and older generations in the XX century for fir (*Abies alba* Mill.), beech (*Fagus sylvatica* L.) and pine (*Pinus sylvestris* L.) in the Świętokrzyski National Park. In the investigated area fir, 41 to 200–300 years of age at breast height, gradually regenerated its radial growth after a very strong decline during 1971–1990, and most likely the process of vitality reduction and death of its stands of various age is slowly coming to an end. Pine showed a systematic decrease in the radial increment during 1885–1994, and there were no distinct symptoms indicating a change of this unfavourable trend. Beech showed no significant decrease in the radial increment during 1885–1994. In the Świętokrzyski National Park the differences in the radial growth between younger and older generations were noticeable only in the case of beech. The radial growth of trees of different ages was very similar in the case of fir and pine.

Keywords: *Abies alba*; *Fagus sylvatica*; *Pinus sylvestris*; radial increment; increment decline; increment regeneration; Świętokrzyski National Park

In Central Europe, in the 1960s and 1970s, there was a strong vitality and growth decline, and increased mortality of stands of various age composed of different tree species, including fir (*Abies alba* Mill.), beech (*Fagus sylvatica* L.) and pine (*Pinus sylvestris* L.) (e.g. CAPECKI, TULEJA 1974; JAWORSKI 1982, 1995; SCHÜTT et al. 1983; KRAUSE et al. 1986; KRAUSE 1989; BERT 1992; FABIJANOWSKI, JAWORSKI 1996; KOWALKOWSKI, JÓŹWIAK 1996; SPIECKER et al. 1996a,b). In the 1990s distinct symptoms of growth regeneration of trees of different species were observed (e.g. BECKER et al. 1995; JAWORSKI et al. 1995; KOWALKOWSKI, JÓŹWIAK 1996; SPIECKER et al. 1996a,b; ZAWADA 2000, 2001). Was there a real change of an unfavourable trend? Has the radial increment returned to values prior to the period of decline? Answers to these questions are very difficult for different reasons, including spatial differences in the extent of decline and regeneration of tree growth (BECKER 1989; KONTIC et al. 1990). We cannot speak about a real change of the unfavourable trend until the increment regeneration is noticeable in the entire natural range, including areas being under the effect of unfavourable factors (KONTIC et al. 1990; BECKER et al. 1994). In such a situation growth investigations of fir, beech, and pine are particularly important in the Świętokrzyskie Mountains where the abiotic, biotic, and anthropogenic factors still have a negative effect on forest stands (KOWALKOWSKI, JÓŹWIAK 1996).

Not many studies concerning the diameter increment dynamics of fir, beech, and pine were carried out in the Świętokrzyskie Mountains (GRANICZNY, UKLEJA-DOBROWOLSKA 1990; JAWORSKI et al. 1988, 1995, 2000; JAWORSKI, PAWŁOWSKI 1991). Most of these studies concerned fir, and pine and beech to a lesser extent (PODLASKI 1999). Also the increment of trees of the older generation, above 120–160 years of age, was studied little although such investigations are very interesting, providing the largest amount of data on the dynamics of the diameter increment of a given tree species (FELIKSIK 1990).

The objectives of this study are to determine a trend of the radial growth at breast height and to compare the radial growth of trees of younger and older generations in the XX century for fir, beech, and pine in the Świętokrzyski National Park.

MATERIALS AND METHODS

CHARACTERISTICS OF THE STUDY AREA

The permanent study points are located in the Święta Katarzyna, Święty Krzyż, and Chełmowa Góra Forest Divisions of the Świętokrzyski National Park at 50°50´–50°58´ N, 20°48´–21°08´ E.

Investigated forests occur on typical brown and grey brown podzolic soils (KOWALKOWSKI 1991), which led to the development of the following associations:

Dentario glandulosae-Fagetum, *Abietetum polonicum*, and *Pino-Quercetum* (the association names are given according to MATUSZKIEWICZ, MATUSZKIEWICZ 1996).

The annual average air temperature measured during a long-term observation period (1955–1994) at Święty Krzyż meteorological station (geographical position: 50°51´ N, 21°03´ E; 575 m above sea level) was +5.9°C, the average monthly air temperature was –5.2°C in January, and +15.9°C in July, the average annual precipitation was 923 mm, and the growing season lasted for about 182 days.

FIELD WORK

The research was carried out in 1993–1995. In the Święta Katarzyna, Święty Krzyż and Chełmowa Góra Forest Divisions of the Świętokrzyski National Park, a total of 251 permanent study points were selected at random in the P_2 areas (975 m × 1,030 m) (PODLASKI 1999) of a network of the SINUS System of Information on Natural Environment (CIOŁKOSZ 1991).

In the surroundings of each permanent study point firs, beeches, and pines were selected, one tree of each species from the younger generation, and the same from the older generation. The selected trees were always growing at the shortest distance from the permanent study point. However, the number of selected trees depended on the species composition and age of stands growing in the surroundings of each permanent study point. In total the numbers of selected trees were as follows:

A) 207 fir trees of the younger generation, 61–120 years of age at b.h. (breast height);
B) 49 fir trees of the older generation, above 150 years (to 200–300 years) of age at b.h.;
C) 199 beech trees of the younger generation, 21–80 years of age at b.h.;
D) 22 beech trees of the older generation, above 110 years (to 150–200 years) of age at b.h.;
E) 61 pine trees of the younger generation, 41–100 years of age at b.h.;
F) 16 pine trees of the older generation, above 120 years (to 150–250 years) of age at b.h.

Sample trees were selected from Kraft class II in one-storey stands, or from the upper storey (100 according to IUFRO) in many-storey stands.

The selected trees were permanently marked, and their d.b.h. (two crosswise measurements, the first one from the side of the slope) and height were measured. In the autumn 1994 and spring 1995 two increment cores reaching the pith were taken at b.h. from each sample tree. The first core was taken from the side of the slope, and the second perpendicularly to the first one. Generally, trees of the older generation were deformed by rot, and not all cores reached the pith.

DATA ANALYSIS

Methods of the measurement and verification of the annual ring width

Using a binocular microscope every tenth annual ring was marked on the increment cores and then the increment of the annual rings was measured with 0.01 mm accuracy.

The measurement results from two cores of each tree were verified by comparison of the radial increment at b.h., and the means were computed for each calendar year. The dendroscales obtained for each tree were compared with published dendroscales for fir, beech, and pine worked out for the area of the Świętokrzyskie Mountains (FELIKSIK 1987, 1990; JAWORSKI, PAWŁOWSKI 1991; JAWORSKI et al. 1995, 2000). If any irregularity in increment was discovered, a correction of increment series was carried out, or such a sample tree was discarded, and another sample tree was selected in the surroundings of the same study point. During the verification of the increment the corrections were made in the case of 5 firs and 5 pines, and the repeated selection of 24 firs, 1 beech, and 5 pines took place.

The age at b.h. was determined for each tree of the younger generation. The investigated tree species require a different number of years in order to reach 1.3 m in height:

A) fir:
  1. in one-storey and one-generation stands – from 20 to 30 years (average 25 years) (GAZDA 1988; DOBROWOLSKA 1999);
  2. in many-storey and many-generation stands – from 25 to 35 years (average 30 years) (GAZDA 1988);

B) beech: from 8 to 16 years (average 12 years) (JAWORSKI 1995);
C) pine: from 5 to 7 years (average 6 years) (SZYMAŃSKI 1986; JAWORSKI 1995).

The age determined at b.h. was consequently used in a subsequent part of the work because the increment cores permitted to determine the age precisely in the case of trees of the younger generation. The actual age may be estimated by addition of the number of years required to reach 1.3 m in height to the age at b.h. although this method is little precise, especially in the case of fir (ZASADA 1998).

Analysis of radial increment at breast height of investigated trees of younger and older generations

All increment series of fir, beech, and pine of the younger and older generations in distinct classes of age at b.h. were fitted using the fifth order polynomial regression function, and 99% confidence bands were determined. The values of coefficients of the regression function were found using the quasi-Newtonian estimation procedure or the simplex estimation procedure (MYERS 1990; NETER et al. 1996; BRANDT 1999).

RESULTS

THE CHARACTERISTICS OF SAMPLE TREES

The mean d.b.h. of sample trees of the younger generation was 42 cm for fir, 44 cm for beech, and 47 cm for pine. The mean height was 25 m for fir, 24 m for beech, and 22 m for pine. The mean d.b.h. of sample trees of older generation was 68 cm for fir, 94 cm for beech, and 61 cm for pine. The mean height was 31 m for fir, 30 m for beech, and 24 m for pine.

ANALYSIS OF THE RADIAL GROWTH TREND OF TREES OF THE YOUNGER AND OLDER GENERATIONS OF INVESTIGATED SPECIES

Fir

The width of annual rings of fir trees of the younger generation was fitted with the following functions of polynomial regression:

A) Fir trees 41–60 years of age at b.h. (increment had been fitted since 1945):

$$y = 2.876247 - 0.125135x - 0.597439 \cdot 10^{-2}x^2 + 0.102904 \cdot 10^{-2}x^3 - 0.305937 \cdot 10^{-4}x^4 + 0.269980 \cdot 10^{-6}x^5 \quad (1)$$

$L = 48$, $N = 2,351$, $R = 0.4702$

where: y – width of annual rings,
x – calendar year,
L – number of sample trees,
N – number of annual increments,
R – nonlinear correlation coefficient.

B) Fir trees 61–80 years of age at b.h. (increment had been fitted since 1925):

$$y = 2.984816 - 0.396556x + 0.303490 \cdot 10^{-1}x^2 - 0.876659 \cdot 10^{-3}x^3 + 0.112904 \cdot 10^{-4}x^4 - 0.546815 \cdot 10^{-7}x^5 \quad (2)$$

$L = 93$, $N = 6,199$, $R = 0.4698$.

C) Fir trees 81–100 years of age at b.h. (increment had been fitted since 1905):

$$y = 3.122312 - 0.367559x + 0.242430 \cdot 10^{-1}x^2 - 0.609273 \cdot 10^{-3}x^3 + 0.658271 \cdot 10^{-5}x^4 - 0.257247 \cdot 10^{-7}x^5 \quad (3)$$

$L = 48$, $N = 4,190$, $R = 0.2962$.

D) Fir trees 101–120 years of age at b.h. (increment had been fitted since 1885):

$$y = 1.830223 - 0.163744x + 0.114843 \cdot 10^{-1}x^2 - 0.271910 \cdot 10^{-3}x^3 + 0.265554 \cdot 10^{-5}x^4 - 0.915096 \cdot 10^{-8}x^5 \quad (4)$$

$L = 18$, $N = 1,917$, $R = 0.3402$.

The width of annual rings of fir trees of the older generation had been fitted since 1880 using the following function of polynomial regression:

$$y = 1.425890 - 0.127825x + 0.127011 \cdot 10^{-1}x^2 - 0.330825 \cdot 10^{-3}x^3 + 0.336342 \cdot 10^{-5}x^4 - 0.118951 \cdot 10^{-7}x^5 \quad (5)$$

$L = 49$, $N = 4,953$, $R = 0.3671$.

The radial increments of fir trees of the older and younger generations were very similar in all analysed periods (Figs. 1A,B,C,D, 4A, Table 1).

The radial increments of fir trees for the periods 1941–1950 and 1951–1960 differed little, showing an increase in the case of trees of the older as well as younger genera-

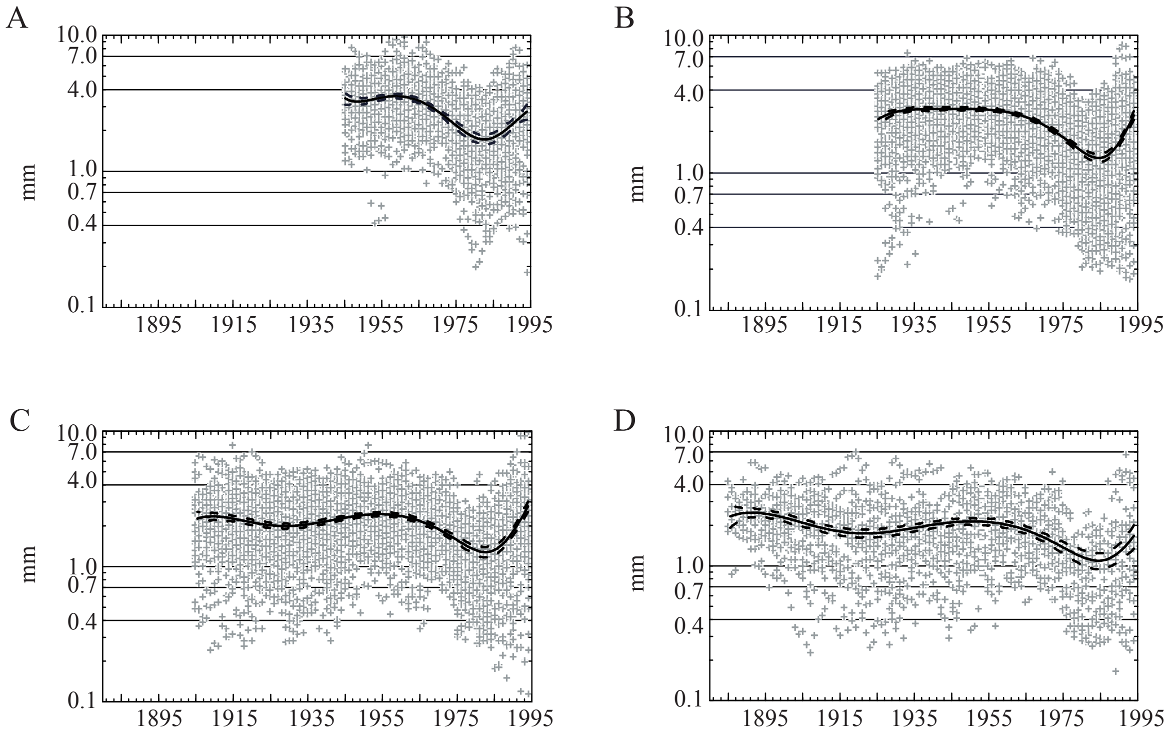

Fig. 1. Width of annual rings and functions of the fifth order polynomial regression with 99% confidence bands (dashed lines) for fir trees of the younger generation; A – fir trees 41–60 years of age at b.h.; B – fir trees 61–80 years of age at b.h.; C – fir trees 81–100 years of age at b.h.; D – fir trees 101–120 years of age at b.h.

Table 1. The mean annual radial increment at b.h. of fir, beech, and pine of the younger and older generations in distinguished periods of calendar years

Species	Generation	Age at b.h. (years)	Number of sample trees	Mean annual radial increment at b.h. during: (mm) 1941–1950	1951–1960	1961–1970	1971–1980	1981–1990	1991–1994
Fir	Younger	41–60	48	–	–	3.21	2.15	1.89	2.53
		61–80	93	2.86	2.86	2.58	1.68	1.45	2.13
		81–100	48	2.22	2.42	2.17	1.49	1.49	2.30
		101–120	18	1.85	2.24	1.88	1.36	1.04	1.64
	Older	above 150	49	2.33	2.96	2.81	1.77	0.86	1.50
Beech	Younger	21–40	48	–	–	–	4.25	4.77	3.87
		41–60	112	–	–	3.18	3.49	4.03	3.52
		61–80	39	2.94	2.78	2.83	3.14	3.22	3.13
	Older	above 110	22	2.55	2.53	2.61	2.51	2.31	2.26
Pine	Younger	41–60	24	–	–	2.88	2.19	1.56	1.56
		61–80	22	3.07	2.43	1.87	1.20	0.85	0.94
		81–100	15	1.83	1.47	1.30	1.00	0.69	0.66
	Older	above 120	16	1.31	1.08	0.91	0.73	0.59	0.54

tion (Table 1). In 1961–1970 the radial increment of fir decreased, and during 1971–1980 this reduction process distinctly increased in strength. The greatest decrease in increment occurred in the case of fir trees of the older generation (Table 1). The next decade (1981–1990) was characterised by further decrease in the radial increment of fir trees of the investigated generations (Table 1).

During three consecutive decades (1961–1990) the maximum decrease in the mean annual radial increment at b.h. was observed in fir trees of the older generation (2.10 mm), and fir trees 61–80 years of age at b.h. (1.41 mm) (Table 1). Fir trees of the older generation were characterised by high increment decreases in two decades (1971–1990), while fir trees 61–80 years of age at b.h. were characterised by a relatively high and regular increment decrease in individual periods (1961–1990) (Table 1).

The graphs of distribution of the annual ring widths and the regression functions for fir trees of the younger and older generations showed a strong increment decrease during 1971–1990 (Figs. 1A,B,C,D, 4A). Its maximum in the case of fir trees 41–60 and 61–80 years of age at b.h. occurred more or less in 1980 (Fig. 1A,B), in the case of fir trees 81–100 and 101–120 years of age at b.h. in 1981–1983 (Fig. 1C,D), while in the case of fir trees of the older generation in about 1985 (Fig. 4A).

Some fir trees during the period of increment decrease reached the minimum annual increment below 0.2 mm, and most of the trees decreased their increment to 1 mm (Fig. 1A,B,C,D, 4A). The maximum increment, which in the earlier period reached over 5 mm for a considerable number of fir trees, during the increment decrease period (especially near the decrease maximum) did not reach 4 mm for any of the investigated fir trees (Figs. 1A,B,C,D, 4A). Since 1986 fir trees have been gradually increasing their increment reaching the value from before 1965, but some trees still continue to grow slowly (Figs. 1A,B,C,D, 4A).

The youngest fir trees, 41–60 years of age at b.h., were characterised by the greatest width of annual rings during the entire study period (Fig. 5a).

Beech

The width of annual rings of beech trees of the younger generation was fitted using the following functions of polynomial regression:

A) Beech trees 21–40 years of age at b.h. (increment had been fitted since 1965):

$$y = 2.647740 + 0.716952x - 0.855533 \,.\, 10^{-1}x^2 + 0.450751 \,.\, 10^{-2}x^3 - 0.113312 \,.\, 10^{-3}x^4 + 0.110960 \,.\, 10^{-5}x^5 \quad (6)$$

$L = 48, N = 1{,}428, R = 0.2247.$

B) Beech trees 41–60 years of age at b.h. (increment had been fitted since 1945):

$$y = 2.843357 + 0.378205x - 0.381116 \,.\, 10^{-1}x^2 + 0.149220 \,.\, 10^{-2}x^3 - 0.261715 \,.\, 10^{-4}x^4 + 0.172278 \,.\, 10^{-6}x^5 \quad (7)$$

$L = 112, N = 5{,}395, R = 0.2510.$

C) Beech trees 61–80 years of age at b.h. (increment had been fitted since 1925):

$$y = 2.848059 + 0.108917x - 0.893653 \,.\, 10^{-2}x^2 + 0.267104 \,.\, 10^{-3}x^3 - 0.350111 \,.\, 10^{-5}x^4 + 0.172867 \,.\, 10^{-7}x^5 \quad (8)$$

$L = 39, N = 2{,}518, R = 0.1409.$

The width of annual rings of beech trees of the older generation had been fitted since 1880 by the following function of polynomial regression:

$$y = 2.391771 - 0.451942 \,.\, 10^{-1}x + 0.444450 \,.\, 10^{-2}x^2 - 0.120384 \,.\, 10^{-3}x^3 + 0.120499 \,.\, 10^{-5}x^4 - 0.404859 \,.\, 10^{-8}x^5 \quad (9)$$

$L = 22, N = 2{,}194, R = 0.3392.$

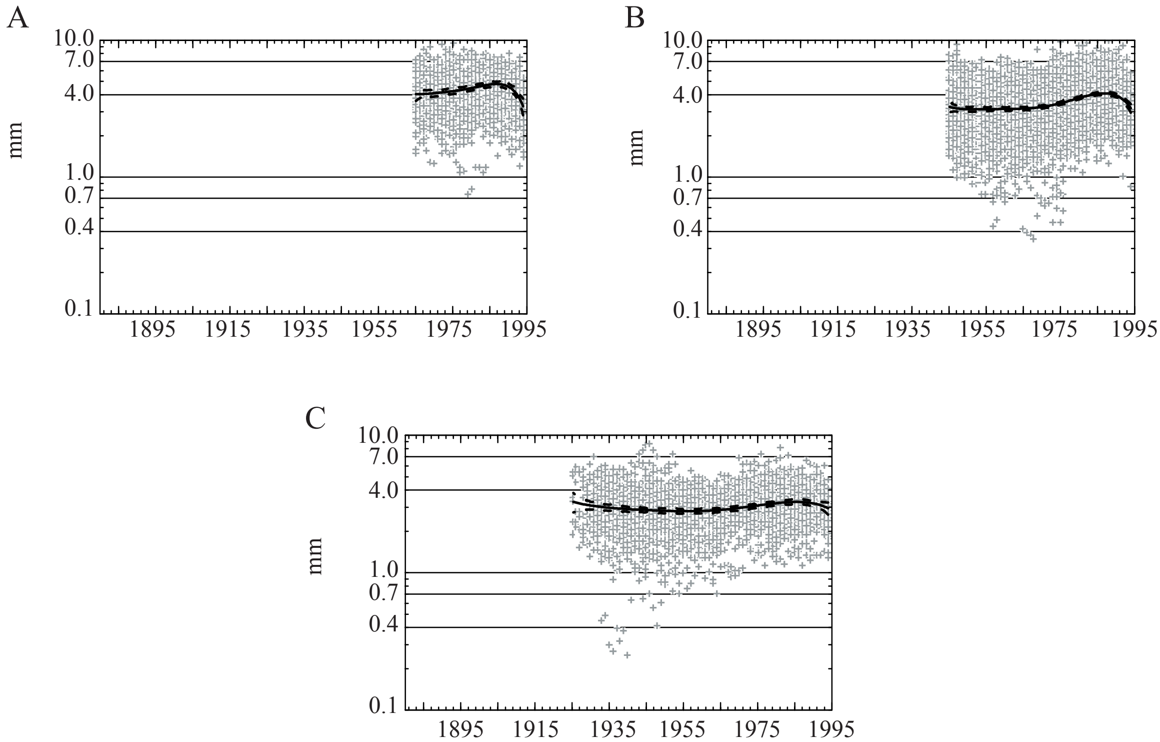

Fig. 2. Width of annual rings and functions of the fifth order polynomial regression with 99% confidence bands (dashed lines) for beech trees of the younger generation; A – beech trees 21–40 years of age at b.h.; B – beech trees 41–60 years of age at b.h.; C – beech trees 61–80 years of age at b.h.

The radial increment at b.h. of beech trees of the older and younger generations differed in all analysed periods (Figs. 2A,B,C, 4B, Table 1).

Beech trees of the older generation were characterised by a very slow and regular decrease in the radial increment during consecutive periods (1941–1994) (Table 1).

Beech trees of the younger generation were characterised by a gradual increase in the radial increment during five decades (1941–1990) and its decrease during the last period: 1991–1994. The greatest increase and the greatest decrease occurred in the case of beech trees 41–60 years of age at b.h. (Table 1).

The graphs of distribution of the annual ring widths and the regression functions for beech trees of the younger and older generations showed almost a smooth increase with small decrease after 1990 (Figs. 2A,B,C, 4B).

The greatest increment reduction after 1990 occurred in the case of beech trees 21–40 years of age at b.h., and the smallest one in the case of beech trees 61–80 years old (Figs. 2A,C). The radial increment of beech trees of the older generation did not decrease after 1990 (Fig. 4B).

The beech trees were characterised by a large annual increment reaching up to 10.0 mm (Figs. 2A,B,C). Trees of the younger generation showed the annual radial growth of 0.2–10.0 mm, while it was 0.2–7.0 mm in trees of the older generation (Figs. 2A,B,C, 4B). It is worthy of note that the youngest and the oldest beech trees had the same minimum annual increment, and this proves high growth dynamics of this tree species.

The youngest beech trees, 21–40 years of age at b.h., were characterised by the greatest width of annual rings during the entire study period (Fig. 5B).

Pine

The width of annual rings of pine trees of the younger generation was fitted by the following functions of polynomial regression:

A) Pine trees 41–60 years of age at b.h. (increment had been fitted since 1945):

$$y = 1.653549 - 0.430723 \,.\, 10^{-1}x + 0.123442 \,.\, 10^{-2}x^2 + 0.309704 \,.\, 10^{-3}x^3 - 0.122894 \,.\, 10^{-4}x^4 + 0.127888 \,.\, 10^{-6}x^5 \qquad (10)$$

$L = 24$, $N = 1{,}154$, $R = 0.6045$.

B) Pine trees 61–80 years of age at b.h. (increment had been fitted since 1925):

$$y = 1.074074 - 0.806128 \,.\, 10^{-1}x + 0.700895 \,.\, 10^{-2}x^2 - 0.159684 \,.\, 10^{-3}x^3 + 0.175977 \,.\, 10^{-5}x^4 - 0.805768 \,.\, 10^{-8}x^5 \qquad (11)$$

$L = 22$, $N = 1{,}497$, $R = 0.6614$.

C) Pine trees 81–100 years of age at b.h. (increment had been fitted since 1905):

$$y = 0.737450 - 0.532092 \,.\, 10^{-1}x + 0.664139 \,.\, 10^{-2}x^2 - 0.220509 \,.\, 10^{-3}x^3 + 0.311468 \,.\, 10^{-5}x^4 - 0.153137 \,.\, 10^{-7}x^5 \qquad (12)$$

$L = 15$, $N = 1{,}294$, $R = 0.6921$.

The width of annual rings of pine trees of the older generation had been fitted since 1880 by the following function of polynomial regression:

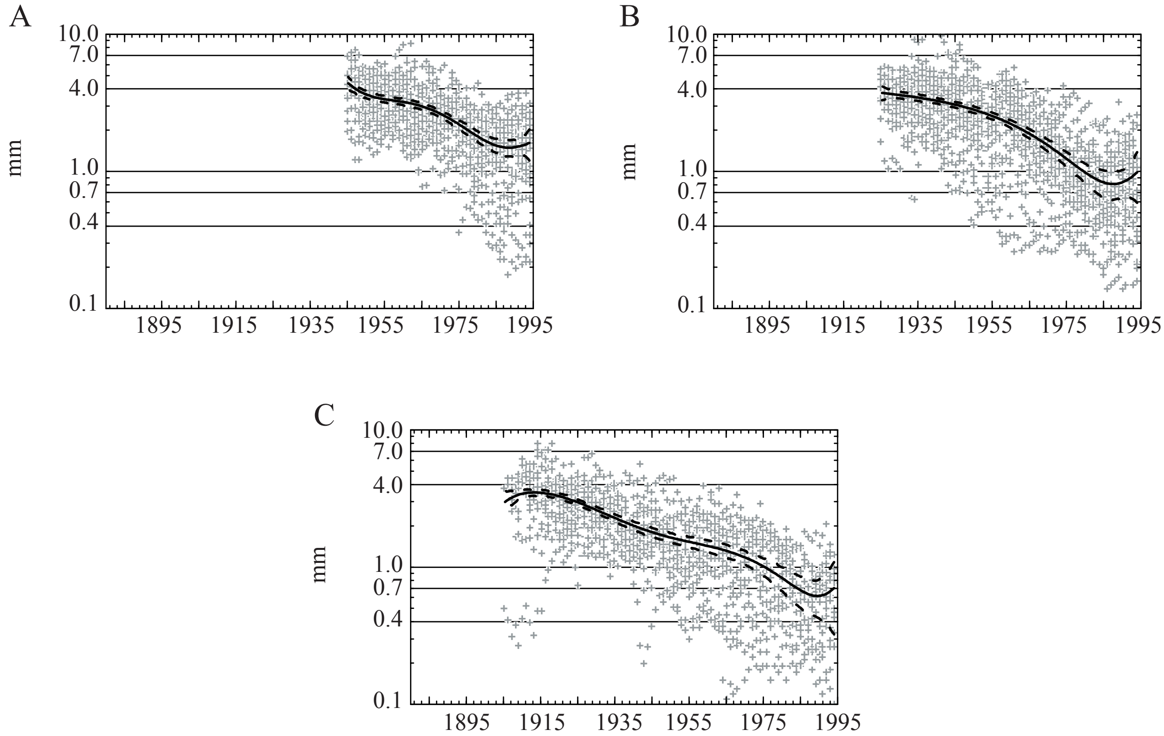

Fig. 3. Width of annual rings and functions of the fifth order polynomial regression with 99% confidence bands (dashed lines) for pine trees of the younger generation; A – pine trees 41–60 years of age at b.h.; B – pine trees 61–80 years of age at b.h.; C – pine trees 81–100 years of age at b.h.

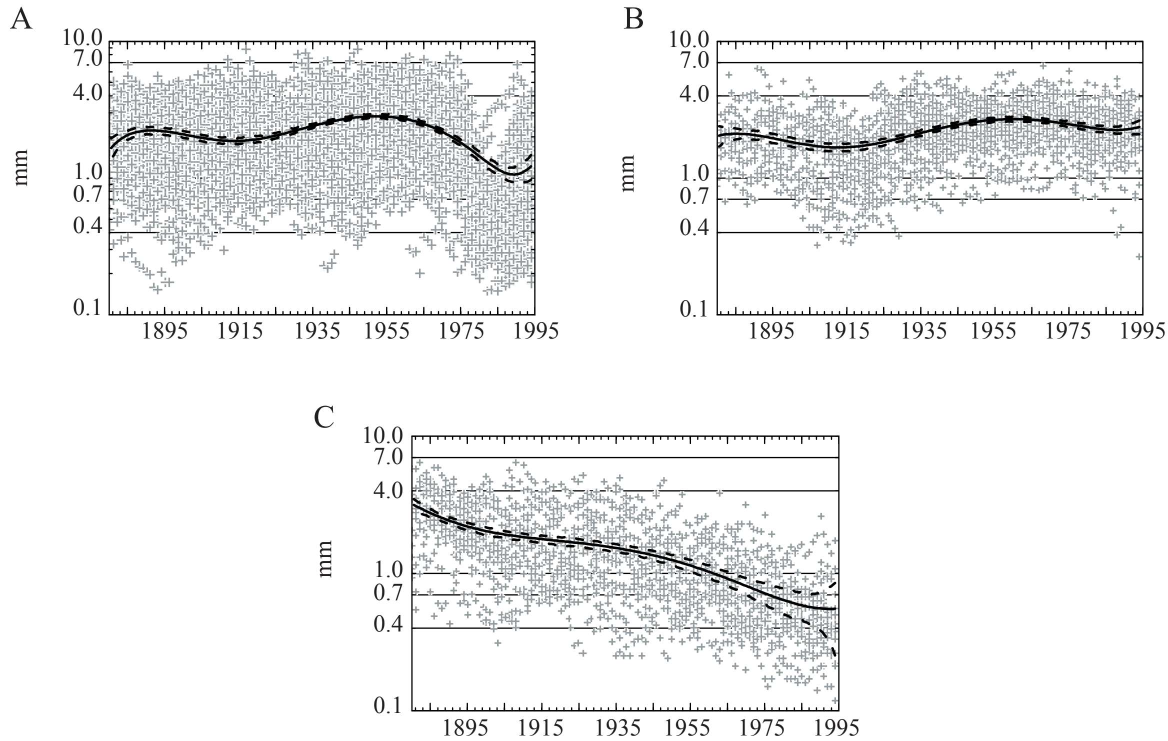

Fig. 4. Width of annual rings and functions of the fifth order polynomial regression with 99% confidence bands (dashed lines) for trees of the older generation; A – fir trees over 150 years of age at b.h.; B – beech trees over 110 years of age at b.h.; C – pine trees over 120 years of age at b.h.

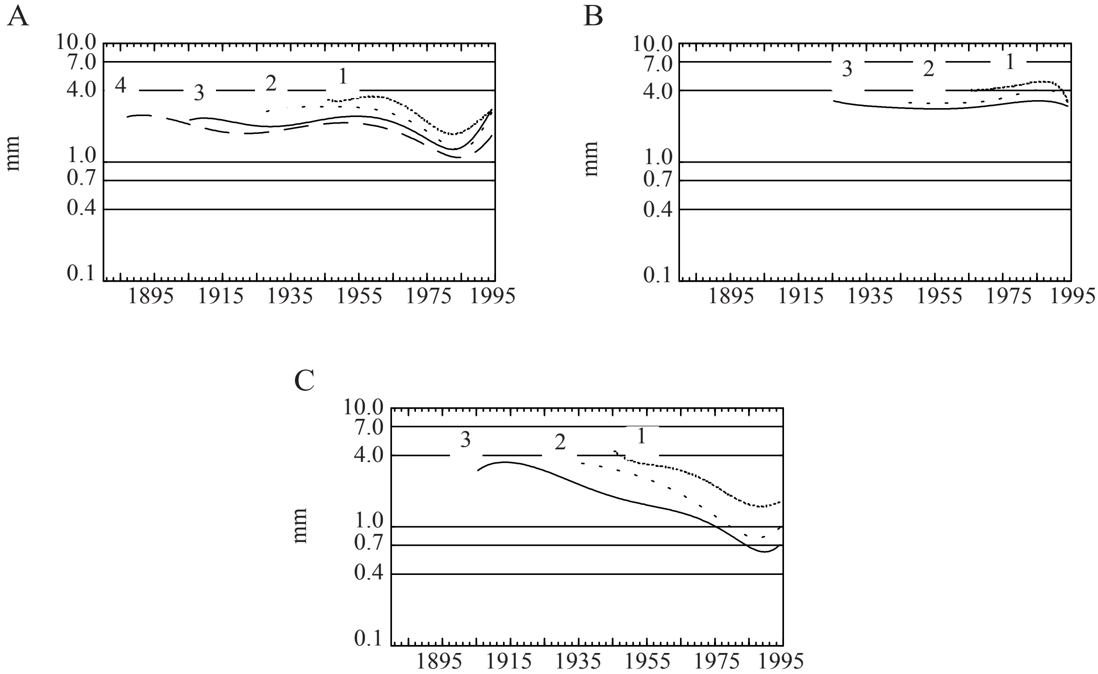

Fig. 5. Functions of the fifth order polynomial regression for trees of the younger generation; A1 – fir trees 41–60 years of age at b.h.; A2 – fir trees 61–80 years of age at b.h.; A3 – fir trees 81–100 years of age at b.h.; A4 – fir trees 101–120 years of age at b.h.; B1 – beech trees 21–40 years of age at b.h.; B2 – beech trees 41–60 years of age at b.h.; B3 – beech trees 61–80 years of age at b.h.; C1 – pine trees 41–60 years of age at b.h.; C2 – pine trees 61–80 years of age at b.h.; C3 – pine trees 81–100 years of age at b.h.

$$y = 0.461274 + 0.242362 \cdot 10^{-1}x - 0.122932 \cdot 10^{-2}x^2 + 0.460639 \cdot 10^{-4}x^3 - 0.614810 \cdot 10^{-6}x^4 + 0.269871 \cdot 10^{-8}x^5 \quad (13)$$

$L = 16, N = 1,736, R = 0.5615.$

The mean annual radial increments of pine trees of the older and younger generations were very similar during all periods analysed (Figs. 3A,B,C, 4C, Table 1).

Pine trees of the older and younger generations showed a gradual decrease in the radial increment during the consecutive growth periods (1941–1994) (Table 1). The greatest decrease in increment occurred in the case of pine trees 61–80 years of age at b.h. (Table 1).

The graphs of distribution of the annual ring widths and the regression functions for pine trees of the younger and older generations showed a decreasing tendency of increment with small increase after 1990 (Figs. 3A,B,C, 4C).

A little improvement in the annual ring width was shown by pine trees of the older generation (Fig. 4C). The growth dynamics of pine trees varied, but in the last years more and more trees were characterised by a very small width of annual rings (Figs. 3A,B,C, 4C).

Similarly like in the case of fir and beech the youngest pine trees, 41–60 years of age at b.h., were characterised by the greatest width of annual rings during the entire study period (Fig. 5C).

DISCUSSION

The radial growth trend of fir presented in this paper is similar to that presented by JAWORSKI and his co-workers (1995) for fir in its entire natural range in Poland, in pure stands as well as in stands with a high percentage of fir. After a distinct decrease in fir increment in most sample areas during 1961–1970 and 1971–1980, there was an increase in over a half of sample areas during 1981–1990 (JAWORSKI et al. 1995).

The radial growth trend of fir and pine of the Świętokrzyskie Mountains presented in this paper approximates that presented by JAWORSKI and PAWŁOWSKI (1991). Both these species decreased their increments during 1961–1970 and 1971–1980, and then there was an increment increase in fir and further increment decrease in pine during 1981–1985.

In mixed stands, prevailing in the Świętokrzyski National Park, generally composed of fir, beech, and possibly pine, the beech trees growing in openings created by fir decline, and under the canopy of pine, had the best growth conditions while the pine trees, gradually shaded from the bottom and on its sides by beech and fir, grew under the most unfavourable conditions.

Generally, the increment of fir increased in the same period as the increment of beech decreased, and vice versa. This may have been caused by different growth responses to the effect of meteorological conditions. In the Świętokrzyskie Mountains fir, opposite to beech, does not require a low temperature and large amount of precipitation in June (FELIKSIK et al. 2000). Perhaps the meteorological conditions of June cause different, closely connected with each other, responses of fir and beech.

In Europe, a detailed analysis of the diameter increment of fir, beech, and pine, considering the growth tendencies since 1960 at least (most often since 1900) showed in the case of:

A) fir

1. in Germany, France, Italy, the Czech Republic, and Slovak Republic a gradual increase in increment with local decreases during 1961–1990 (e.g. BRONZINI et al. 1989; PIVIDORI 1991; KANTOR et al. 1995; PRETZSCH 1996; STERBA 1996; BADEAU et al. 1996);
2. in Switzerland and Austria an increase in the increment (e.g. KÖHL 1996; ZING 1996; SCHADAUER 1996);

B) beech

1. in Germany, the Czech Republic, and Slovak Republic the stability of the increment (e.g. PRETZSCH 1996; UNTHEIM 1996; DITTMAR 1999);
2. in Denmark, Switzerland, France, Austria, Slovenia, and Spain an increase in the increment in most areas (e.g. BADEAU et al. 1995, 1996; SKOVSGAARD, HENRIKSEN 1996; KÖHL 1996; ZING 1996; SCHADAUER 1996; KOTAR 1996; MONTERO et al. 1996);

C) pine

1. in Finland, Norway, Sweden, Germany an increase or stability of increment (e.g. ZETTERBERG et al. 1996; MIELIKÄINEN, SENNOV 1996; MIELIKÄINEN, TIMONEN 1996; ELFVING et al. 1996; ELFVING, NYSTRÖM 1996; ERIKSSON, KARLSSON 1996; PRETZSCH 1996; UNTHEIM 1996; STERBA 1996);
2. in Switzerland, France, Austria, and Spain an increase in the increment in most areas (e.g. KÖHL 1996; BADEAU et al. 1996; SCHADAUER 1996; MONTERO et al. 1996).

The radial growth trends, shown above, dominated in each of the countries mentioned. However, over smaller areas there occurred a local variation depending in the first place (but not always) on the level of air pollution (SPIECKER et al. 1996a,b).

It may be concluded that the trend in the diameter increment of fir and beech in the Świętokrzyski National Park was in agreement with observations carried out by other authors in Poland and other countries of Europe. This is not true for pine. In the Świętokrzyskie Mountains a constant decrease in the pine increment was proved while in most papers a not decreasing tendency of the increment in this species in Europe is stressed. Most probably the cause of this phenomenon is a gradual elimination of pine from mixed stands of the Świętokrzyskie Mountains by shade-tolerant beech, and fir to a lesser extent.

Since 1986 fir in the Świętokrzyski National Park had increased its radial increment. Till 1994 not all trees regained its value from before 1965 because its regeneration still continued, and in some cases the regeneration was not possible at all, due to strong injury of fir trees. Unfavourable abiotic, biotic, and above all, anthropogenic factors still affect the forests of the Świętokrzyskie Mountains (KOWALKOWSKI, JÓŹWIAK 1996). In spite of this, fir regenerated its increment, which is a significant proof of the final phase of the phenomenon of decline of this species. However, it should be remembered that some fir trees are still weakened, and the radial increment has not reached the value of the period 1941–1970 (JAWORSKI et al. 2000). Thus, upon unfavourable meteorological factors an increased mortality of this tree species may occur again.

Trees of different age were characterised by a similar trend in the radial increment in the case of fir and pine. Most likely it was connected with the effect of very strong factors causing changes in the increment of all trees of both species (FABIJANOWSKI, JAWORSKI 1996; KONTIC et al. 1990; SPIECKER 1999; MANNING 2001). A similar radial increment of trees of different age in the case of fir and pine indicates that both these species in the Świętokrzyskie Mountains were under constant pressure of factors strongly affecting their growth. Beech is a more resistant species, which was shown by an absence of significant disturbances in its radial increment and the differences in the radial growth trend between trees belonging to different age generations.

The silvicultural programme in the partially protected reserves of the Świętokrzyski National Park should mainly aim at vital stands well adapted to sites. Pine is the most seriously endangered species in the investigated area while beech is the least endangered one, and fir is in a middle position in this respect.

Pine stands in the Świętokrzyskie Mountains are mainly of artificial origin, established using a planting stock imported from various, sometimes remote places. Most mixed stands with high proportion of pine are also of artificial origin. Pine trees growing alone or in small groups may be of natural origin, and some of them may represent a race distinguished from the Świętokrzyskie Mountains as Polish pine (SVOBODA 1953). It seems necessary to carry out investigations on this race with determination of its native localities, and then collection of its seeds and utilisation in silvicultural programmes.

In order to increase the increment and vitality of pine, with simultaneous protection of Polish pine, the stands with this species in their species composition should be tended carefully. Careful tending is required by natural regeneration of pine established in small openings or at edges of pine groups.

Fir, in spite of the improvement of its vitality, is still an endangered species and requires careful tending treatments. Conversion of the existing one-storey and two-storey stands into many-storey selection forest should be undertaken. It is a very difficult task because of low fir vitality, low crown density of stands, and complete absence of regeneration at some places. Of great concern are fragments of land where the forest was removed several years ago, and no regeneration was established. In some situations perhaps pine (possibly larch or mountain ash) could be used as a nurse crop.

Proper conditions for the development of mixed stands with participation of pine, fir, and beech in the Świętokrzyskie Mountains are provided by the improved gradual nest cutting and partial cutting methods. Particularly favourable for beech is the modification of the partial cutting method with partial cuttings in groups, which decreases a silvicultural risk by formation of stands of diversified structure (KORPEĽ 1991).

CONCLUSIONS

1. The estimation of the radial increment trend in the Świętokrzyski National Park showed in the case of:
   A) Fir: a very strong increment decrease during 1971–1990 and a distinct change from decreasing to increasing tendency since 1986 (for the older and younger generations);
   B) Beech:
      1. of the older generation – very slow and regular radial increment decrease during 1941–1994;
      2. of the younger generation – a gradual increase in the radial increment during 1941–1990 and their decrease during the last period 1991–1994;
   C) Pine: a regular decrease in the radial increment of trees of the older and younger generations during 1941–1994.
2. In the Świętokrzyski National Park fir, 41 to 200–300 years of age at b.h., gradually regenerates its diameter increment after a very serious decrease during 1971–1990, and most likely the decline process of fir stands is coming slowly to its end. Pine is still showing a strong decrease in the diameter growth and there are no symptoms of change in this unfavourable trend.
3. The differences in the radial increment trend between trees of the younger and older generations appear only in the case of beech. The younger and older generations in the case of fir and pine were very close to each other in this respect.
4. From among the investigated main forest tree species of the Świętokrzyski National Park pine and fir require a careful tending in order to improve their vitality and growth. Presently, beech is the most expansive species, and in its case the silvicultural treatments should concentrate on the improvement of not only its vitality but also its trunk quality.

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Trendy radiálního růstu jedle bělokoré (*Abies alba* Mill.), buku lesního (*Fagus sylvatica* L.) a borovice lesní (*Pinus sylvestris* L.) v Národním parku Świętokrzyski v Polsku

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ABSTRAKT: Cílem studie je stanovení trendu radiálního růstu kmene ve výčetní výšce a porovnání radiálního růstu stromů mladší a starší generace ve XX. století u jedle bělokoré (*Abies alba* Mill.), buku lesního (*Fagus sylvatica* L.) a borovice lesní (*Pinus sylvestris* L.) v Národním parku Świętokrzyski v Polsku. Ve sledované oblasti jedle ve věku 41 až 200–300 let ve výčetní výšce postupně obnovila svůj radiální růst po velmi silném poklesu v letech 1971–1990 a s největší pravděpodobností končí proces snižování vitality a odumírání jejích porostů různého věku. Borovice vykazovala v letech 1885–1994 systematický pokles radiálního přírůstu a nezjistili jsme žádné zřetelné příznaky ukazující na změnu tohoto nepříznivého trendu. U buku nedošlo v letech 1885–1994 k významnému poklesu radiálního přírůstu. V Národním parku Świętokrzyski existoval rozdíl v radiálním růstu mezi mladšími a staršími generacemi pouze v případě buku. Radiální růst stromů různého věku u jedle a borovice byl velmi podobný.

Klíčová slova: *Abies alba*; *Fagus sylvatica*; *Pinus sylvestris*; radiální přírůst; pokles přírůstu; obnovení přírůstu; Národní park Świętokrzyski

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