Growth Reaction of European Silver Fir [*Abies alba* Mill.] Associated with Air Quality Improvement in the Sudeten Mountains

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Abstract

The Sudeten Mountains are a region where the level of industrial air pollution is high due to brown coal combustion, but now the impact of pollution on the environment has greatly decreased. In this paper we attempted to determine how this fact affected the condition of silver fir trees. Our conclusions are based mainly on measurements of trunk diameter increments of 250 fir trees representing 42 populations of this species in different parts of the Sudeten. The main conclusion is that silver fir, at least to the age of 130 years, has the ability to endure unfavourable conditions and can substantially increase its growth rate in association with air quality improvement.

Keywords: dendrochronology, forest decline, *Abies alba,* growth variation, ecology

Introduction

Silver fir (*Abies alba* Mill.) was one of the most important forest-forming species in the Sudeten Mountains 200 years ago, but is now relatively rare. Its stands are scattered and its share in forest stands is decreasing [4, 7, 8, 27, 39]. Recent research has shown that in the area of the Sudeten there are only 30-35 thousand fir trees, found in about 2500 locations [14]. In many locations their regeneration is poor, mainly because of considerable crown damage. Moreover, a significant decrease in the radial growth rate of tree trunks has been recorded [12, 23]. This is usually attributed to the high level of environmental pollution in that region, as silver fir is regarded as particularly sensitive to air pollution [e.g. 5, 24, 25]. Pollution's impact on the forests of the Sudeten Mountains were noted early in the 20th century in areas surrounding coal mines and other small industrial plants in mountain valleys. After the World War II, rich deposits of soft (brown) coal were discovered in the region where the borders of Poland, Germany and the Czech Republic meet. This region represents the largest basin of soft coal in Europe, with approximately 200-220 Mt being extracted annually (25% of the total production in Europe). The coal is burned locally in 17 major power plants with a total output over 15,000 MW. As a result, in this relatively small area (less than a quarter of the territory of the Netherlands), 3 Mt of SO_2 and approximately 1 Mt of NO_X are emitted each year. Adverse effects of air pollution were observed throughout the Sudeten region (in all three countries). Large-scale effects of pollution had already been detected at the end of the 1960s, and in the 1980s large-scale forest disturbances affected more than 46,000 ha in Poland. This was the first such serious decline in Polish mountain forests. [35]

In the early 1990s the Sudeten were included in the so-called "Black Triangle" located at the junction of borders between the Czech Republic, Germany and Poland and were subjected to pollution monitoring. Data found in statistical yearbooks and materials of the Provincial Inspectorate of Environmental Protection (Fig. 1) show that in the late 1980s and early 1990s, concentrations of sulphur dioxide, nitrogen dioxide and particulates in the air exceeded the

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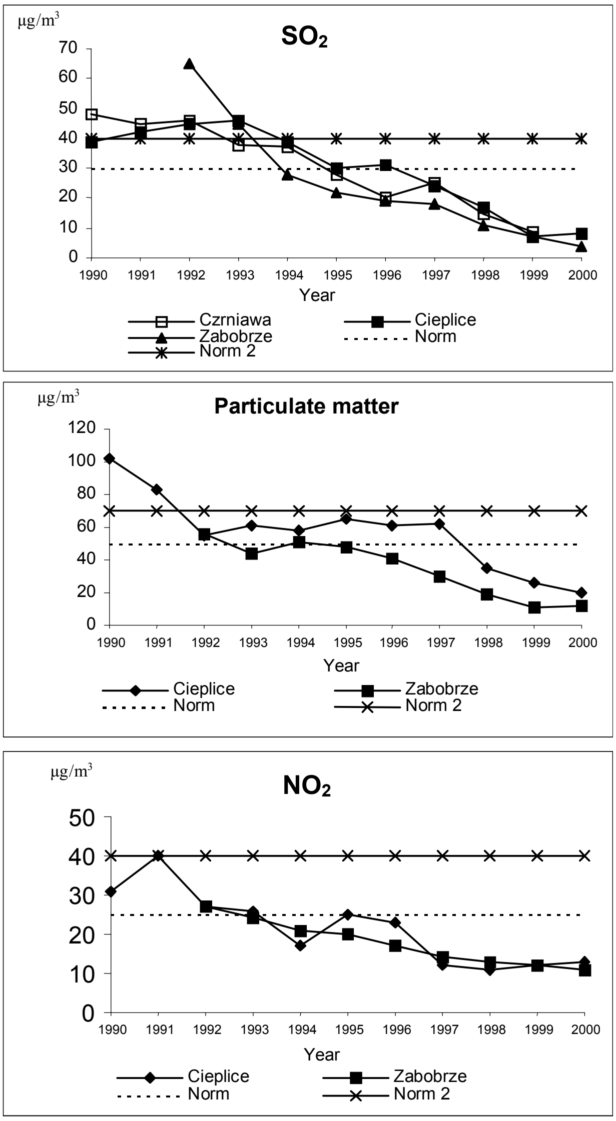

Fig. 1. Changes in annual mean concentration of sulphur dioxide, particulate matter and nitrogen dioxide in the air in 1990-2000 at several measurement stations [34].
Norm - maximum permissible annual mean concentration in buffer zones of health resorts [29]. Norm 2 - maximum permissible annual mean concentration in other areas [29].

maximum permissible levels, but in the late 1990s they decreased considerably and are now below the permissible level [36]. This is undoubtedly associated with the considerable decrease in emission of pollutants, especially from Czech and German factories and power plants near the Polish border [1] (Fig. 2). Thus the pressure of pollution on the environment has greatly decreased in that region.

In this study we analyzed the effect of the pollution abatement on the condition of silver fir trees on the basis of measurements of radial growth of the trunk at breast height. Our main aim was to determine the general growth trend. The differences between the populations, resulting from factors that are often difficult to assess, were less important in this case.

Experimental Procedures

Analysed Populations

For this study, we selected randomly 42 populations of European silver fir during a field survey conducted in the Sudeten in 1999–2001. Their geographical distribution is shown in Fig. 3. Most of them were small, because about 90% of Sudetian fir populations are composed of up to 20 individuals. As the number of studied populations was relatively high, they should have represented a variety of habitats colonized by silver fir. Most of the fir populations occupied the forest habitat type that is the most common in the Sudeten: mixed mountain forest (LMG, forest classification), which mainly corresponds with potential habitats of acidophilic mountain beech forest, *Luzulo luzuloides-Fagetum,* (phytosociological classification). The majority of the forest stands were located at altitudes ranging from 400 m to 700 m. Greater differences were observed in exposure, taxonomic composition, and density of the stands. In many localities, forest stand density was relatively low, which resulted in strong injuries under the influence of heavy pollution [10, 14, 24]. In mountain conditions, forest stand density is lower and growth conditions of individual trees are more variable. Exposure and location of the trees in respect to slope are among the factors whose effects are enhanced [32].

Sampling

Trunk diameter growth at breast height (1.3 m above ground) was estimated on the basis of wood cores extracted with Pressler's increment borers from 250 trees representing 42 localities of the studied species in different parts of the Sudeten. Most of the trees belonged to Kraft's class II, which includes dominant overstorey trees (criteria applied by Jaworski [23]). In each locality, samples were taken from 5-10 trees, depending on the total number of fir trees in the locality (which is usually very low in the Sudeten). Additionally, 1-2 trees from other classes (i.e. co-dominant and substorey trees) were sampled for comparison. One core was extracted from the side facing the slope, and the second perpendicular to the first.

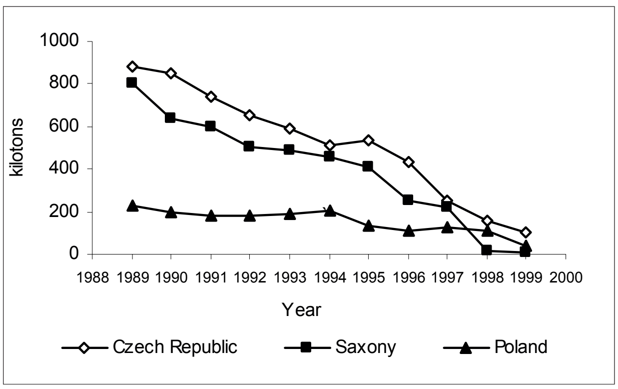

Fig. 2. Trends in emission of SO_2 in the Black Triangle region in 1989-1999. [1].

Fig. 3. Geographical distribution of examined European silver fir populations.

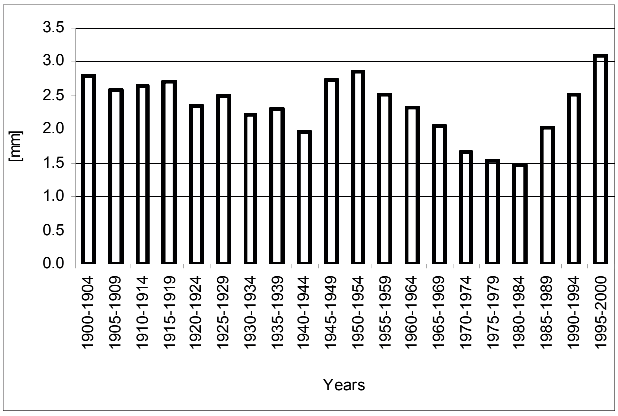

Fig. 4. Mean width of annual rings of fir trees of Kraft's class II (dominant overstorey) in 5-year periods in the Sudeten.

Measurement and Analysis of Growth Ring Data

The first stage of research after sampling was the measurement of ring widths and initial analysis of the data according to the classical dendrochronological methods described in detail, for example, by [16, 31]. Widths of annual growth rings were measured to the nearest 0.01 mm by the LINTAB apparatus. The initial data processing was carried out with the use of CATRAS and TSAP software [2, 30]. The software enables synchronization of growth sequences and grouping according to similarity between growth curves. Synchronic location of growth curves was verified visually on the screen. Further analysis of data was also carried out with the use of the above-mentioned software, which belongs to the Dendrochronological Program Library created at the University of Arizona in Tucson. The COFECHA software [19, 20, 21] was used for verification of synchronization of growth curves. That program identifies missing rings and indicates their location in the measured sample. Doubtful samples were measured again, and then the verifying procedure was repeated. Results of measurements were repeated and shown in charts. The statistical analysis was calculated by STATISTICA software.

Results and Discussion

Results of the majority of earlier studies on European silver fir resources in the Sudeten were pessimistic [4, 7,

Table 1. Results of Tukey's test of differences between mean width of annual rings of fir trees in 5-year periods in the Sudeten.

years

years	1900-1904	1905-1909	1910-1914	1915-1919	1920-1924	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-2000
1900-1904		1.00	1.00	1.00	0.85	0.99	0.31	0.55	**0.00**	1.00	1.00	1.00	0.64	**0.02**	**0.00**	**0.00**	**0.00**	**0.01**	1.00	0.99
1905-1909			1.00	1.00	1.00	1.00	0.93	0.99	0.08	1.00	0.99	1.00	1.00	0.27	**0.00**	**0.00**	**0.00**	0.17	1.00	0.29
1910-1914				1.00	0.99	1.00	0.62	0.87	**0.01**	1.00	1.00	1.00	0.92	**0.04**	**0.00**	**0.00**	**0.00**	**0.02**	1.00	0.46
1915-1919					0.92	1.00	0.32	0.60	**0.00**	1.00	1.00	1.00	0.69	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	1.00	0.67
1920-1924						1.00	1.00	1.00	0.63	0.65	0.12	1.00	1.00	0.94	**0.00**	**0.00**	**0.00**	0.84	1.00	**0.00**
1925-1929							0.98	1.00	0.07	0.98	0.54	1.00	1.00	0.29	**0.00**	**0.00**	**0.00**	0.17	1.00	**0.01**
1930-1934								1.00	0.98	0.06	**0.00**	0.88	1.00	1.00	**0.02**	**0.00**	**0.00**	1.00	0.87	**0.00**
1935-1939									0.73	0.17	**0.01**	0.99	1.00	0.98	**0.00**	**0.00**	**0.00**	0.92	0.99	**0.00**
1940-1944										**0.00**	**0.00**	**0.01**	0.50	1.00	0.81	0.14	**0.03**	1.00	**0.01**	**0.00**
1945-1949											1.00	0.99	0.23	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.99	0.49
1950-1954												0.54	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.52	0.98
1955-1959													1.00	0.07	**0.00**	**0.00**	**0.00**	**0.03**	1.00	**0.00**
1960-1964														0.90	**0.00**	**0.00**	**0.00**	0.76	1.00	**0.00**
1965-1969															0.29	**0.01**	**0.00**	1.00	0.06	**0.00**
1970-1974																1.00	0.99	0.47	**0.00**	**0.00**
1975-1979																	1.00	**0.03**	**0.00**	**0.00**
1980-1984																		**0.00**	**0.00**	**0.00**
1985-1989																			**0.02**	**0.00**
1990-1994																				**0.00**
1995-2000																				

8, 12, 24]. They showed that localities of this species were scattered, crown health was often poor, and natural regeneration was rarely observed. By contrast, our results are quite optimistic. Figure 4 presents mean width of annual rings of fir trees of Kraft's class II in 5-year periods in the Sudeten. Table 1 presents results of Tuckey's test of differences between the analyzed (5-year) periods. The presented data revealed a remarkable increment depression

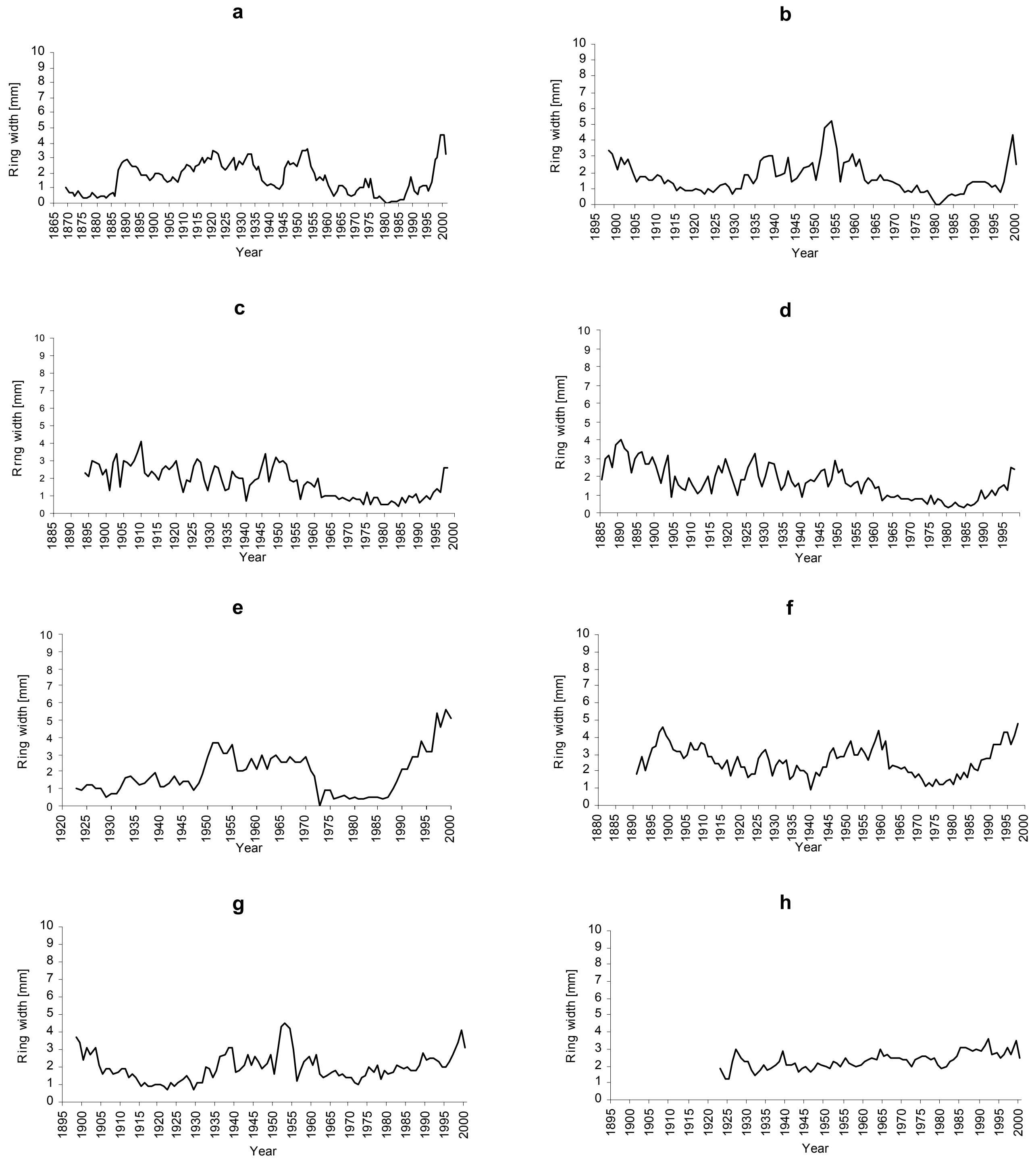

Fig. 5. Annual ring-width data of selected silver fir specimens: a - no. 8 from population Lubawka (its growth rate clearly decreased in the early 1970s and the decreasing trend is continued); b - no. 2 from population Międzygórze (clear increasing trend observed not only in dominant trees, but also in this co-dominant tree, which grew relatively quickly in the last period); c - no. 5 from population Kamienna Góra - Lipienica (seriously damaged in 1965-1990); d - no. 1 from population Kamienna Góra - Lipienica (its growth rate did not decrease during the period of general decline of fir stands); e - no. 1 from population Szklarska Poręba - Krokusy (grew relatively quickly in the juvenile period, probably in full sunlight); f - no. 3 from population Szklarska Poręba - Zieleniec (grew relatively quickly in the juvenile period, probably in full sunlight).

in 1970-1984. The 5-year means of this period are lower and significantly different from almost all means of the other analyzed periods (except: 1940-1944, 1965-1969, 1985-1989.). However, the average increase in 1995-2000 is greater than all the others; the difference is statistically non-significant only in the case of 5-year means in 1890-1919 and 1945-1954.

Figs. 5 and 6 show ring-width curves of selected trees and populations (mean values for Kraft's class II). As in the case above, a marked increase in ring width can be observed in the last few years after a period of long-term decline. Fig. 3a shows a tree whose growth rate clearly decreased in the early 1970s and the decreasing trend is continued. The tree is weak and gradually passes from Kraft's class II to class III. However, such a situation is observed in only about 8% of analyzed trees. In all the other trees some increase in ring width can be observed in the last few years after a period of long-term decline (Figs. 5b, 5c, 6a, 6b, 6c, 6d, 6e, 6f, 6g). In some trees the latest rings are wider than any earlier rings (Figs. 5b and 5c). A clear increasing trend is observed not only in dominant trees but also in co-dominant and even substorey trees (Fig. 5b). In many localities, trees with seriously damaged crowns started to produce very wide annual rings (Fig. 5c). The role of the main crown was then played by a secondary crown developed from dormant buds. A significant increase in radial growth rate at breast height in the last few years was recorded in all localities except Opawica, which is the easternmost locality (Fig. 6h). This is a relatively young population (80 years old), which has a very high growth rate and did not decline in the 1970s and 1980s. A similar reaction was also observed in single trees from other Sudetian populations (Fig. 5d). The growth rate of those individuals, in contrast to the neighbouring trees, did not decrease during the period of general decline of fir stands. Their mean ring widths were relatively high and virtually no drastic changes were noticed in their growth curves. Those trees were also dis-

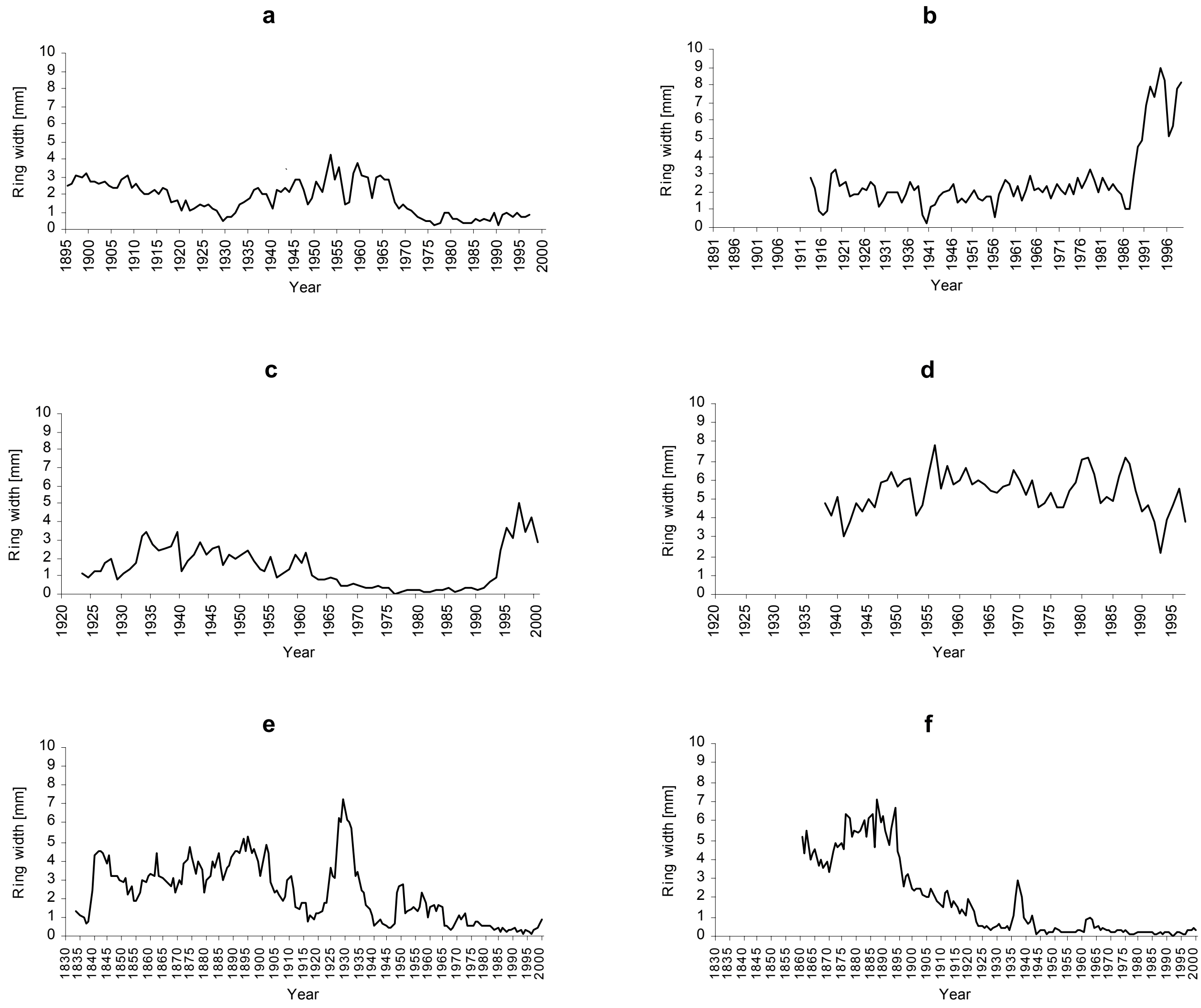

Fig. 6. Mean width of annual rings of fir trees of Kraft's class II (dominant overstorey) in different populations: a - Świeradów - Rębiszów (Western Sudeten); b - Śnieżka II (Western Sudeten); c - Ogorzelec (Central Sudeten); d - Sokołowsko (Central Sudeten); e - Bardo Mikołajów (western part of Central Sudeten); f - Międzylesie (Western Sudeten); g - Prudnik - Głuchołazy (Western Sudeten); h - Prudnik - Opawica (eastern part of Western Sudeten).

tinguished by healthy crowns and occupied dominant positions in the forest stands. Smaller changes in ring width in the last period are also observed in specimens that are about 200 years old. This applies in particular to trees that grew relatively quickly in the juvenile period, probably in full sunlight (Figs. 5e and 5f). Many researchers suggest that such trees age much more quickly and have a lower growth rate in their old age [24, 26, 28].

Sudetian forest stands with fir trees are usually not dense. Thus, the dynamic growth in the last few years could partly result from the so-called "release effect". However, this applies only to the last 5 years or so, because until the late 1990s, the decrease in forest stand density was associated with defoliation and a fast dieback of tree crowns. In some cases the trees developed many suckers, which partly compensated for the unfavourable changes in tree crowns. Nevertheless, the trees usually formed narrower rings in that period. Even today the relationship between crown health and decrease in forest stand density is strong [14, 15].

Most of the studied trees are over 100-year-old, but their ring-width reactions are usually very dynamic. This may attest to the vitality of the fir trees that survived the period of unfavourable environmental conditions in the Sudeten.

Symptoms of fir health improvement have also been observed in other parts of the natural range of this species [17, 13, 38]. This phenomenon is usually believed to be associated with pollution abatement. The increase recorded in our study was particularly strong, but also the decrease in pollution level was substantial. It seems particularly important that daily extremes of SO_2 concentration had been greatly reduced [36].

Some other factors may also contribute to the positive growth trend. Recently an increase in forest productivity was observed, mainly in Central Europe [33, 34]. This is believed to be linked with climatic changes and increased availability of CO_2 and nitrogen compounds deriving from industrial air pollution [9, 18, 34]. It is very likely that in the Sudeten an interaction occurs between the above-mentioned factors and industrial pollution abatement. However, the former factors do not seem to be responsible for the radical altering of the general growth trend because, as recent research shows, in the last period their changes were not as substantial as those of air pollution level [e. g. 9, 11, 15, 33].

The dynamic increase in tree growth rate may be related to characteristics of the species. Silver fir is regarded as very sensitive to modification of environmental conditions [5, 24, 25]. The results of this study show that this feature is reflected not only in strong negative reactions to stress, but also in a dynamic regeneration as a reaction to improvement of growth conditions – in this case to pollution abatement. Similarly, forest management handbooks [e.g. 3, 6, 24, 37], give examples of fir trees that survived for many decades in very shaded conditions and showed an intensive growth reaction when the access of sunlight increased. According to Jaworski [22] the ability to increase the growth rate rapidly in such a situation is possible thanks to the strong development of root systems of shaded fir trees. The fir trees in whose photosynthetic apparatus is greatly reduced due to acid precipitation probably maintain large root systems and this enables the dynamic regeneration as a reaction to pollution abatement.

Conclusions

In the Sudeten Mountains air pollution has recently decreased, which was concomitant with an increase in the growth rate of silver fir trees in that region. We found that silver fir, at least to the age of 130 years, preserves the ability to endure unfavourable conditions and can greatly increase the growth rate as a reaction to demission of stress of various origins – in this case air pollution with products of coal combustion. Many of the individuals whose growth was the most limited under the influence of stress reacted the most strongly to pollution abatement.

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