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## Changes of *Abies alba* crown state and stand quality class in the Sudety Mountains

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**Abstract:** Sudety Mts. are a region where the level of industrial air pollution was very high due to brown coal combustion. In this paper I presents the assessments concerning the fir stand quality class and crown vitality. The study were carried out between 1999 and 2001 and supplemented with studies made in 1997 and 2005. My conclusions are based on measurements of 3529 fir trees representing 481 populations of this species in different parts of the Sudety Mts. The stand quality class of the fir in the Sudety Mts. are better than expected but about 0,5 degree lower than in the Carpathians. Our results confirm the reports concerning the strong and very strong damage of fir crowns in the Sudety Mts. in the 1990's. It was calculated that the average fir in the Sudety Mts. stands has a primary crown with a length that is approximately 19% of the total tree height and which is damaged in approximately 36%. At approximately 23% of the total height the average fir develops a regeneration crown. An additional factor which contributed to fir damage was their frequent presence in thinned stands. In these places the process of crown reconstruction from a wide to a denser is observed. In the recent years the level of industrial pollution in the Sudety Mts. has been strongly reduced. This particularly concerns sulphur oxides. This has contributed to the improvement of the crown health of the studied species, but the crown regeneration is slower than the trunk diameter increment.

The crown damages have so far been proportional to the altitude. Trees which grow in stands located in lower areas have healthier crowns. Trees which grow in broken canopy and on hilltops are more vulnerable to the impact of pollution carried by wind and fog. The severe damage to the top parts of the crown has a negative effect on the cone crop of the fir.

**Additional key words:** industrial pollution, forest decline, acid fog, ecology, fir regeneration.

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### Introduction

The forestry and botanical publications of the 1990's concerning the fir (Boratyński 1991, Mejnartowicz, et al. 1994, Zientarski et al. 1995, Jaworski et al. 1995, Małek 1996, Boratyński et al. 1998, Barzdajn et al. 1999 and Barzdajn 2000) showed that the resources of this tree in Sudety Mountains was vary low and its was in bad condition witch caused that its existence was threatened. This was caused primarily by the inappropriate forest management which was un-

favourable for the fir and, secondly, by the high pollution levels. The dying out and rapid elimination of the fir from forests was also recorded by the author of the present paper, who studied the issue in selected stands between 1995 and 1996 (Boratyński and Filipiak 1997). In this situation it became a priority to develop a comprehensive programme for saving this species in the Sudety area. It was assumed that the starting point for this programme was a comprehensive, quantitative and qualitative assessment of the tree resources. Furthermore, another important task

was to compare the health conditions of the fir with the growth conditions in order to determine the direct causes of the withdrawing of this tree from its stands. The present publication presents the results of studies concerning the degree of fir crown damage and stand quality class, which were carried out between 1999 and 2001 and supplemented with studies made in 1997 and 2005. Both the abovementioned factors, particularly the first one (e.g. Jaworski et al. 1995) are well suited to evaluate the vitality of the trees.

## Study area

The studies covered the area of the Izerskie Mountains, Karkonosze, Rudawy Janowickie, Kaczawskie Mountains, Krucze Mountains, Kamiennie Mountains, Wałbrzyskie Mountains, Sowie Mountains, Stołowe Mountains, Bardzkie Mountains, Bystrzyckie Mountains, Złote Mountains, Bialskie Mountains and the Śnieżnik Massif as well as Opawskie Mountains and the foothill areas of the particular ranges.

## Methods

Firstly a preliminary review was carried out of the available data concerning the location of the studied species. This data came from floristic publications (Boratyński 1991, Kosiński 2001), data from forest forest inventory („stand description”), results of earlier own investigations carried out in the years 1995–1996, and, mainly, inquiry data from forest officers. The collected information was verified by using of a more detailed questionnaire filled in 1998 by workers employed in Sudetian forest districts and during field research conducted in 1999–2001. The 481 out of a total of 2575 localities were inspected and 3529 fir trees were measured. These were representative of all the mountain ranges and various conditions of fir growth in the Sudety Mts.

During field research, number of silver-fir trees within localities, the vertical and horizontal distribution of the fir and its presence in the particular mountain ranges, forest habitat types and topographic conditions were noted.

The study included also making the following measurements:

- Measuring at each inspected stand the tree diameters at breast height taking (two measures across) and the height of the trees. In stands where there were small numbers of fir all the firs were measured, whereas in stands where there were more of these trees 30 firs were measured. Subsequently, the average height and the average diameter at breast height was calculated for each stand and for selected groups of stands. The average height constituted the basis for establishing the stand quality

class (“bonitacja”) of a given stand by making a comparison of the given value (average height and age) with table data (Czuraj 1997) in the chart form (height curves for individual stand quality class).

- Reading the stand quality class for 1100 stands with a larger number of firs from “stand description” (this data is not given for stands with small numbers of fir trees). The data thus obtained was analysed separately.
  - Analysing the state of the primary crown formed during the growth and development of each tree and analysing the state of the secondary, regeneration crowns developed on the trunk by generating regeneration shoots. In each analysed tree stand approximately 30 randomly chosen trees were assessed by determining in per cent the length of the stem covered by the primary crown and the regeneration crown, the degree of the primary crown damage, the type of crown top and the degree of secondary (regeneration) crown development. The degree of crown damage was determined by taking into account the degree of crown deformation, i.e. branch loss in the lump of the conical or cylinder shape which could be created by turning the crown around the axis of the stem (Jaworski et al. 1995). Attention was also paid to the degree of thinning of the crown, i.e. needle loss, based on illustrations in an atlas of damages (Innes 1990). The particular trees were included in one of the five damage groups according to the following principle: healthy crowns – loss of needles not exceeding 10%; slightly damaged crowns – loss of needles between 10 and 25%; averagely damaged crowns – loss of needles between 25 and 40%; strongly damaged crowns – loss of needles between 40 and 60%; very strongly damaged crowns – loss of needles above 60%. The type of top was determined according to the classification used by Jaworski (Jaworski 1979; Jaworski et al. 1995):
1. Conical top: growth of main shoot ( $w$ ) is clearly higher than the growth of side shoots ( $b$ ).
  2. Narrow paraboloidal or rounded top  $\frac{w}{b} \approx 1$ .
  3. Wide paraboloidal top: the growth was stopped during the last several years ( $w < b$ ).
  4. Flat top: the growth was stopped more than ten years ago.

Comments concerning crown top and tree stem damage were recorded separately.

The development of regeneration shoots on the trunk beyond the primary crown zone (secondary crown development) was determined according to the following classification: lack of development; weak development – single short shoots; good development – approximately 0.5 m long shoots on average at every 20–30 cm on the trunk; very good develop-

ment – more than 0.5 m long shoots on average distributed densely, i.e. less than every 20 cm on the trunk. The statistical analysis were made with using  $\chi^2$  test.

## Results

Figures 1 and 2 present the average stand quality class of the fir growing in various landscape forms and at various altitudinal belts. The presented data proves that the growth of the studied species is clearly better in stands growing on concave land forms, particularly river valleys. It is not surprising that similar growth reactions can be observed for most of our trees, with the fir in particular since it a species that has high requirements regarding soil and air humidity. The average height on the other studied land forms is also good and justifies cultivation. The only exception is hill tops where the fir should not be planted. The data

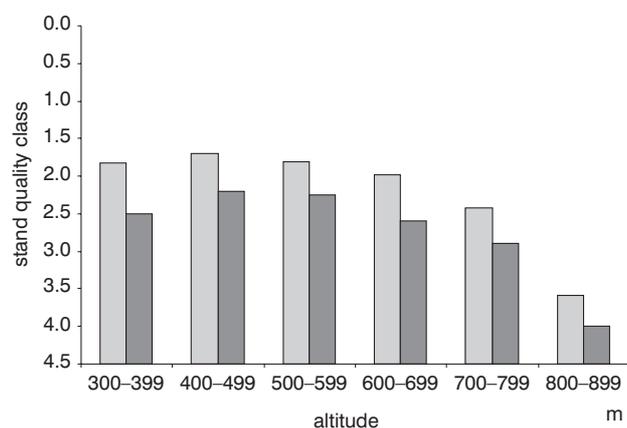


Fig. 1 Average stand quality class of *Abies alba* growing in various altitude in Sudety Mts.

light bars – average stand quality class calculated by the author on the basis of heights of 3529 trees from 481 localities; dark bars – average stand quality class calculated by the data from forest inventory („stand descriptions”) of 1100 stands

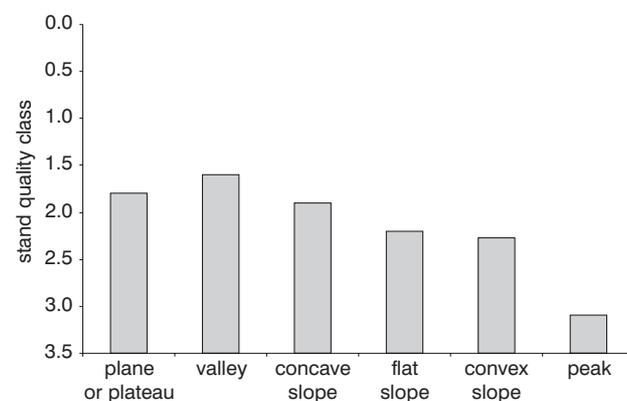


Fig. 2 Average stand quality class of *Abies alba* of the fir growing in various landscape forms in Sudety Mts (calculated by the author on the basis of heights of 3529 trees from 481 localities)

from Figure 1 also emphasises the relatively small stand quality class difference, i.e. 0.6 degree, at the altitude section of 200–800 metres above sea level. Above 800 m the stand quality class of the fir clearly deteriorates.

Figures 3, 4, and 5 present data concerning the health of the crowns. Most trees are featured by damaged crowns with over 30% having strongly and very strongly damaged crowns, whereas only 25% of the trees have healthy or slightly damaged crowns. The vitality of crown deteriorate from East to West (Fig. 3), but the differences are statistically not significant. It was calculated that the average fir in the Sudety stands has a primary crown with a length that is approximately 19% of the total tree height and which is damaged in approximately 36%. At approximately 23% of the total height the average fir develops a regeneration crown and the remaining 58% of the tree comprises a relatively clear trunk. It is generally assumed that the best growth for this species is ensured by a crown which constitutes approximately 60% of the tree height, without a secondary crown developed from regeneration shoots (Jaworski 1979; Jaworski et al. 1995). Therefore, the older firs in the Sudety Mountains have strongly reduced and fairly strongly dam-

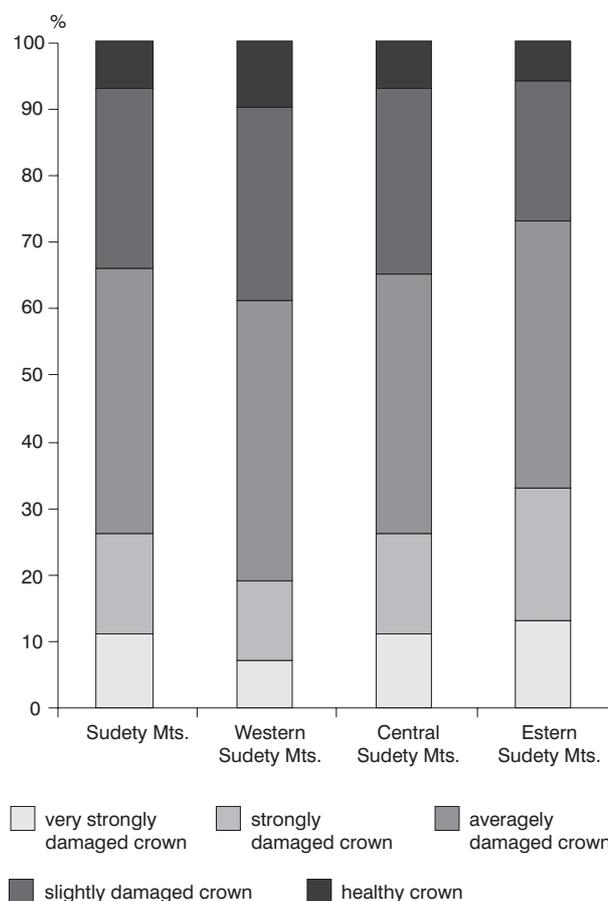


Fig. 3. Damage of primary crown of *Abies alba* in various part of Sudety Mts.

aged crowns. The crown damages have so far been proportional to the height above sea level (Fig. 4). Trees which grow in stands which are located in lower areas have healthier, not so strongly damaged crowns.

A big number of trees display the process of crown regeneration which is most apparent in canopy opening stands. Crown regeneration by developing regeneration shoots extends the lives of trees, but for a long time does not affect the increase of flowering and seed bearing. Data concerning the development of regeneration shoots below the primary crown is presented in the Figure 5.

The type of crown top (Fig. 6) also may convey of tree health and growth trends. It is usually assumed (Jaworski et al. 1996) that trees which are healthy and grow strongly in height are featured by conical tops, trees with narrow paraboloidal tops grow in height less intensively, wide paraboloidal tops prove growth stoppage for several years and flat tops, the so-called "stork nests", are a symptom of growth stoppage for more than ten years. In general there is a trend for old firs to stop growing and develop flat tops. Nevertheless, the large share of trees with flat tops in stands of middle age tree classes shows that there is a premature decline of their growth in height. Trees with flat and wide paraboloidal crown tops constitute a majority in the fir stands of the Sudety Mountains (Fig. 6) and while this is partly undoubtedly related to their age it also shows the not so good condition of growth in height.

In general, better health is observed in stands which grow in stream valleys and in the lower sec-

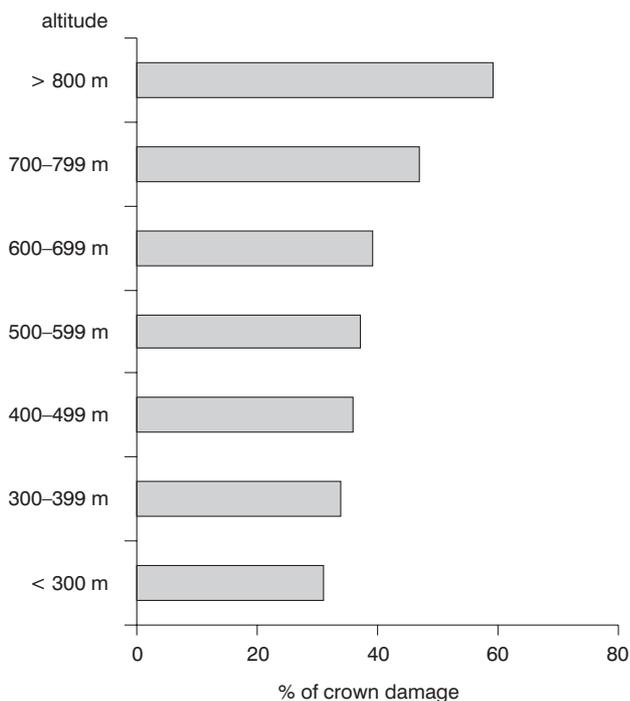


Fig. 4. Damage of primary crown of *Abies alba* in various altitude in Sudety Mts.

tions of the slopes of higher hills, in stands which are shielded and which grow in deep soil with better water supplies. Definitely worse health is observed among firs growing on hilltops in shallow and dry soil. Trees which grow in broken canopy and on hilltops are more vulnerable to the impact of pollution carried by wind and fog.

The assessments of stands in the regeneration class (KO) and so called "for regeneration class" (KDO) are particularly bad. The firs which grow here in open canopy usually display strongly reduced primary crowns or do not have these crowns at all and they survive only due to the developed regeneration crowns. They do not flower and do not form cones, thus they are not capable of reproduction for which they have been left on the renewing surfaces.

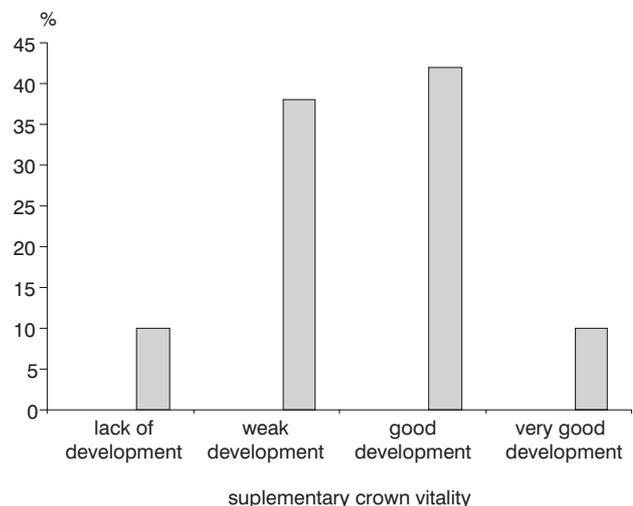


Fig. 5. Development of regeneration shoots on the *Abies alba* trunk beyond the primary crown zone (regeneration crown development) in Sudety Mts.

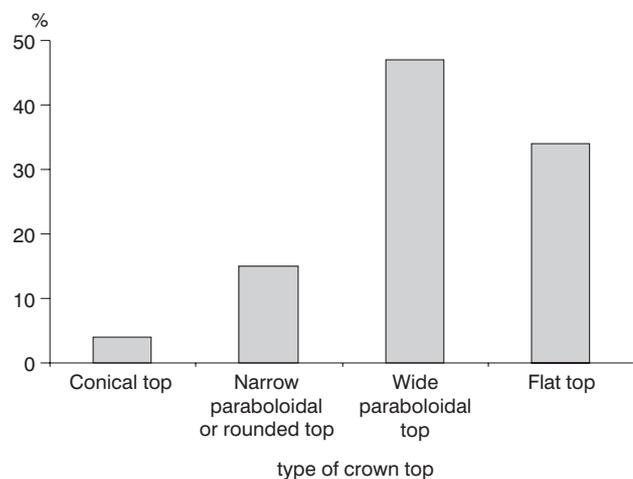


Fig. 6. Participation of trees of *Abies alba* characterized with various form of top of crowns in Sudety Mts.

The firs which grow in a combination with spruces are presently on average less damaged than the firs which grow in a combination with beeches

Figure 7 present the results of the crown quality assessments made in 1997, 2000 and 2005 in 10 tree stands where permanent observation areas were established (Filipiak 2002). With time the vitality of primary and regeneration crown damage regularly improved, particularly in the period between 2000 and 2005. The differences between distributions are statistically significant ( $p \leq 0.05$ ). The smallest changes has recorded in relation to top type (Fig. 7 C).

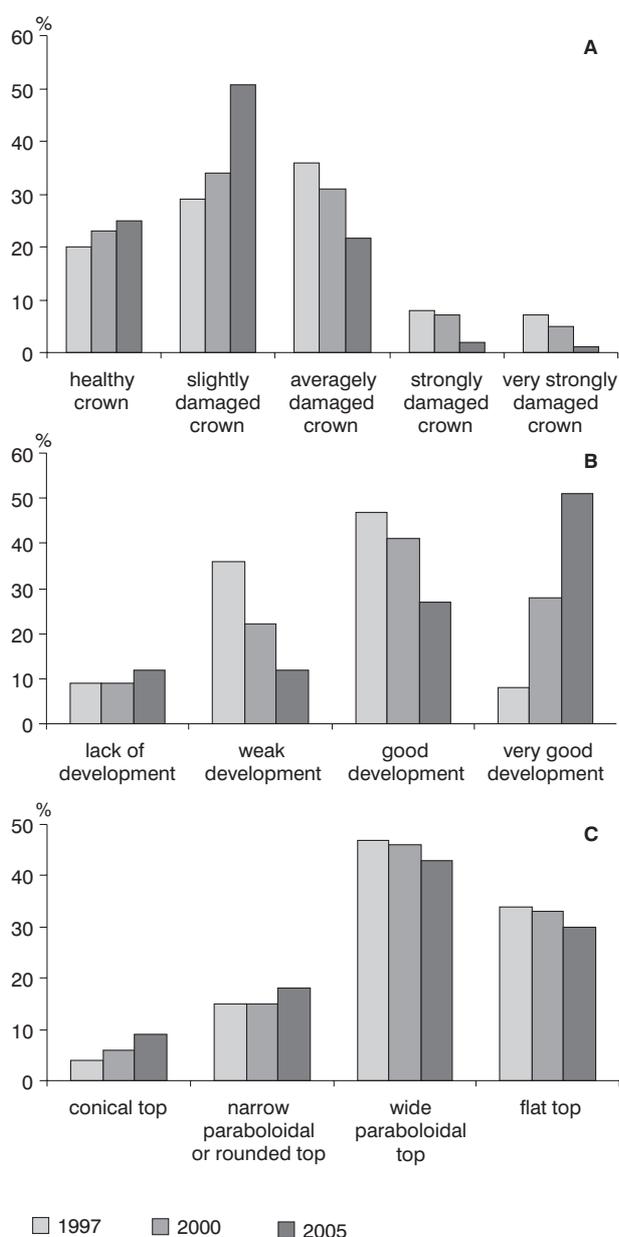


Fig. 7. State of *Abies alba* crown in 10 selected stands in Sudety Mts in the years: 1997, 2000 and 2005

A – damage of primary crown; B – development of regeneration shoots on the trunk beyond the primary crown zone (regeneration crown development); C – participation of trees with various form of top

## Discussion

The average stand quality class for all the studied stands is 2.04 and is almost equal to the average stand quality class of the fir in the Carpathian Mts. calculated on the basis of Sabor's (1999) data. It should, however, be noted that the data for Carpathian stands come from forest management records ("stand description") in which the stand quality class is usually slightly lower than the real. Hence, the thus determined stand quality class in the Sudety Mountains is on average 0.52 degree lower than this determined by the author on the basis of the average height and this value is the one by which the stand quality class in Sudety Mts. may be lower than the average stand quality class in the Carpathian Mts. This can be easily explained by the better habitats in the Carpathians and the strong and long-lasting growth stoppage in the Sudety Mountains caused by industrial pollution. It is difficult to precisely determine how the stand quality class described in the present paper (calculated by the author on the basis of average height), particularly that of the stands with small numbers of fir trees, relates to the stand quality class of fir stands which are remnants (it is impossible to determine which bio-social class the trees that are still alive come from). Nevertheless, on average the results concerning the stand quality class of the fir in the Sudety Mountains are better than expected.

The results presented above confirm the reports concerning the strong and even very strong damage of fir crowns in the Sudety Mountains (Zientarski et al. 1994, Jaworski et al. 1995, Boratyński and Filipiak 1997, Barzdajn et al. 1999). An additional factor which contributed to fir damage was their frequent presence in thinned stands. According to Jała and Błaś (2000), a significant concentration of pollution, particularly pollution carried by fog deposits, is observed on the edge of stands and this, most probably, is also true for trees growing in very loose canopy density. It seems that an acute majority of the damage was caused by the so-called "episodes", i.e. short-term periods with significantly high concentrations of pollution in a given area on a slope as a result of specific combinations of atmospheric conditions (Sobik et al. 1997). The Sudety are a mountain range with a large number of foggy days, hence the more frequent occurrence of strongly acidic deposits (Sobik et al. 1997). The destructive impact of acidic fog was proven, among others, by Igawa et al (1997). The mentioned above atmospheric phenomena are more frequent in the higher parts of the slopes and these are also more easily reached by vast-range pollution. Hence the stronger crown damage at higher altitudes and in the upper part of the slopes as well as in stands of open canopy.

According to assessments made between 1996 and 1997 in 60 tree stands with a higher share of the stud-

ied species (Boratyński and Filipiak 1997), the average fir in the stands of the Sudety Mountains stands has a primary crown with a length that is approximately 17.5% of the total tree height and which is damaged in approximately 40%. At approximately 21% of the total height the average fir develops a re-growth crown and the remaining 61.5% of the tree comprises a relatively clear trunk. The comparison with data from 1999–2001 indicates, therefore, a slight improvement in the health of the crowns.

In the recent years the level of industrial pollution in the Sudety Mountains has been strongly reduced. This particularly concerns sulphur oxides. It seems that this has contributed to the improvement of the crown health of the studied species. The research made by Zawada (2001), and Filipiak and Ufnalski (2002, 2004) shows that recently we have also been dealing with the regeneration of tree trunk diameter increment. Interestingly, the diameter increment is faster than crown regeneration. Whilst between 1996 and 1997 most firs had strongly damaged crowns the trunk increment was significantly better than in 1980–1985 (the maximum depression) and in 2000–2001, when the condition of the crowns improved only slightly, it reached the value from the 1950's, i.e. before the depression period. Jaworski et al. (1995) has noted the regeneration of fir diameter increment in Southern Poland with an almost imperceptible improvement of crown condition. He suggests that this growth increase may be related to the increase in the biological productivity in the northern hemisphere. This factor should be taken into account also in relation to the present study, but it seems that it cannot be solely responsible for such a significant trunk increase as has been observed in the Sudety Mountains. It is very probable that during the maximum depression period of trunk diameter growth the condition of the crowns could have been even worse than that shown in this publication as well as in a work from 1997 year (Boratyński and Filipiak 1997). This could have referred to the regeneration crown in particular. The primary crowns were already strongly reduced and regeneration shoots had not yet developed. Jaworski (1979) evaluates the process development of shoots on the trunk as highly negative. According to this author, their development is related to the process of primary crown degeneration. The development of shoots on the trunk depreciates the cultivation value of the trees and the technical value of their wood. On the other hand, however, with the strong pollution impact in the Sudety the development of these shoots made it possible for many firs to survive. The highest diameter increase in the Sudety Mountains was observed among strongly damaged lone firs or those growing in loose canopy density. These are the trees that display the best regeneration crown development which has significantly increased

the surface of the assimilation apparatus. Many factors indicate that the assimilation apparatus, particularly in the most exposed part of the crown, was regularly damaged by acid rain and fog. Therefore, it seems highly probable that during this period the photosynthetic capacity of this apparatus was clearly limited and the trees expended all their life energy on current regeneration. With a certain lower level of pollution the needles ceased to be damaged and the firs began using their energy for reinforcing the trunk (by increasing its width) and this seems to be of key importance in conditions of loose canopy density. The second task is to regenerate, or rather reconstruct the crown from a wide one which is typical for trees which live in stands to a denser one which is more advantageous in more open areas. In the discussion of the issue of fir crown regeneration attention should be paid to the fact that the crown consists of needles from many years. Hence its regeneration cannot be a rapid process. By Jaworski and Skrzyszewski (1986) the crown of fir first class quality consists of needles from 10 years. This suggests that in the case of severe damage the full regeneration may take from 5 to even 9 years.

Comparative research carried out between 1996 and 2005 has recorded the smallest changes in relation to top type. This, however, is not surprising bearing in mind the generally slow rate of crown regeneration which usually starts at the bottom. The average age of the studied firs is, at present, 105 years. According to yield tables (Czuraj 1997) with fir of this age the annual top increment for second stand quality class is from 10 to 18 cm. Similar growths are observed in relation to side shoots. Furthermore, the top increment values presented above refer to firs growing in stands. In looser canopy, and this is usually the case in the present study, the top growth may be slower.

Finally, it should be emphasised that severe damage to the top parts of the crown has a negative effect on the crop of the fir since the cones of this tree usually appear in this part of the crown.

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