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Disturbances in variation of the annual ring width of Norway spruce in the Polish Western Beskids Mountains

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ABSTRACT: Changes in radial increment of Norway spruce in 25 stands more than 100 years old were analysed. Stands were growing on sites of different exposure situated at 450–1,200 m above sea level in the Polish Western Beskids Mountains. In the mid-1990s a considerable increase in annual ring width was observed. The greatest increase occurred in trees growing at the highest altitudes. This phenomenon occurred after a long period of increment decrease at the turn of the 1970s. After 1990 as the annual ring width was increasing, the variation and amplitude of ring width also increased. The cause of a long-term increase in radial increment was the improvement of thermal and pluvial conditions during late winter and early spring having a substantial effect on Norway spruce growth. In the 1990s the period of rapid changes in thermal and pluvial conditions of summer began. After moist and cold summers there were hot and dry summers. This resulted in increased variations and amplitude of the growth responses of Norway spruce and contributed to the weakening of trees above 100 years of age. The increasing break-up of Norway spruce stands growing in the lower mountain zone of the Polish Western Beskids Mountains, observed in recent years, is the final effect of this process.

Keywords: tree-ring; ring width variation; Norway spruce; Polish Beskids Mountains

The width of the annual increment of the tree vascular tissue in the temperate climatic zone is a resultant of metabolic processes taking place under the influence of endogenous and exogenous factors. Their action is reflected in a short-term as well as long-term variation of radial increments (Fritts 1976). The appropriate analyses of sufficiently long series of chronologically arranged values of the tree annual ring width of a given taxon may be, among other things, the basis for determination of its site requirements, spatial diversification of growth responses and environmental threats. They also make it possible to study the history of growth conditions of trees and forest stands.

A major part of dendrochronological research on Norway spruce, conducted in Poland for many years, served the above-mentioned purposes (Bednarz et al. 1999; Feliksik, Wilczyński 2000, 2001, 2002; Wilczyński, Feliksik 2004; Wilczyński et al. 2004a; Zielski, Koprowski 2001).

After the break-up of many Norway spruce stands in the Sudetes Mountains (Godzik, Sienkiewicz 1990), following a forest calamity in that area, the interest in this tree species has considerably increased (Godzik et al. 1997; Sander et al. 1995; Szdzuj et al. 2001; Modrzyński 2001; Palátová 2004; Hynek 2004). Norway spruce is the main forest tree species in mountain areas of Poland. In the late 1990s foresters with anxiety reported about increasing mortality of Norway spruce in the lower mountain zone of the Western Beskids Mountains. Lately the mortality process has increased in strength affecting the whole stands. Therefore the research interest was focused on the Beskids. Some preliminary studies were carried out to assess the susceptibility of Norway spruce to climatic conditions depending on the

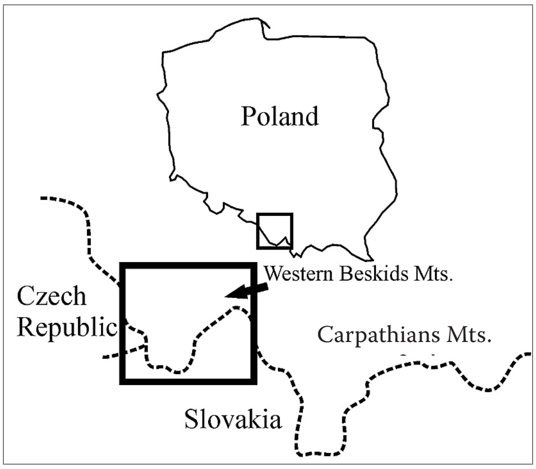

Fig. 1. Map of the study area. Polish Western Beskids

altitude of its localities in the lower mountain zone, and thus to find possible climatic reasons for the decline of its population in the Beskids (FELIKSIK, WILCZYŃSKI 2003a; WILCZYŃSKI, FELIKSIK 2004; HOLUŠA 2004).

During these investigations a specific variation of radial increments of Norway spruces, and especially its untypical disturbances, were noticed. Therefore a study reported in this paper was undertaken in order to determine the character and probable causes of this interesting response of trees.

MATERIAL AND METHODS

The study material originated from 25 Norway spruce stands growing on sites of different exposure and situated at different altitudes (from 450 m to 1,200 m a.s.l.) in the Polish Western Beskids (Fig. 1). The sites represented Norway spruce populations growing on high mountain coniferous forest sites, mountain mixed coniferous forest sites, mountain broadleaved forest sites and mountain mixed broadleaved forest sites. The sites were located in stands above 100 years of age in which the spruce was a dominant species. From selected 25 dominant and co-dominant trees in each stand the increment cores were taken with Pressler's increment borer; 1.5 m above the ground. We took one sample along the diameter parallel to the slope.

The width of annual rings was measured on the cores. As a resultant 625-time tree-ring series were obtained. The correctness of ring dating was checked using the program COFECHA (HOLMES 1986).

To assess the variability of the growth behaviour of Norway spruce trees during 1920–2003 the variation of their annual ring width and the course of tree-ring chronologies on individual sites were analysed. Their similarity was estimated on the basis of the coefficient of convergence (GL) (HUBER 1943; ECKSTEIN, BAUCH 1969):

$$GL = 100 \times m \times (n - 1)^{-1} \qquad (\%)$$

where: m – the number of convergent chronology sections,
n – the number of compared years.

For individual years the coefficients of variation of annual ring width were calculated. For this reason the site tree-ring chronology was calculated for each study site (25 trees). To each chronology the exponential curve was fitted, reflecting the trend of a decrease in annual ring width with age, especially characteristic of coniferous trees. The site tree-ring chronologies representing respective sites were subjected to indexing on the basis of exponential smoothing curves (COOK, HOLMES 1986). The growth indexes (I) were calculated according to the formula:

$$I_i = R_i \times Y_i^{-1}$$

where: R – the annual ring width,
Y – the value of fit-curve,
i – the year.

The indexed chronologies obtained in this manner were devoid of the so called senile trend, being natural for trees. However, they retained the long-term fluctuations of annual ring width caused by various external factors. Then by calculating the mean values of site tree-ring chronologies the regional tree-ring chronology was worked out.

Following the results of the previous research, stating that there is a different increment rhythm of Norway spruce in different parts of the lower mountain zone (FELIKSIK, WILCZYŃSKI 2003b; WILCZYŃSKI, FELIKSIK 2004), the tree-ring chronologies were constructed for three altitudinal levels of this zone: 450–750 m, 800–900 m and 950–1,200 m a.s.l.

Using the *response function* method (FRITTS 1976) the tree-ring chronologies for the three zones were estimated. The relationships between climate and increment were examined using the multiple regression method (response function), by applying the computer program RESPO (HOLMES 1994). Dependent variables were tree-ring indexes while independent variables were mean monthly temperatures and monthly sums of precipitation. The estimated chronology represents a theoretical course of diameter increment resulting from the effect of climatic conditions only. It was compared with indexed tree-ring chronology. The data obtained from the climatic station Żywiec of the Institute of Meteorology and Water Management were used for the analyses.

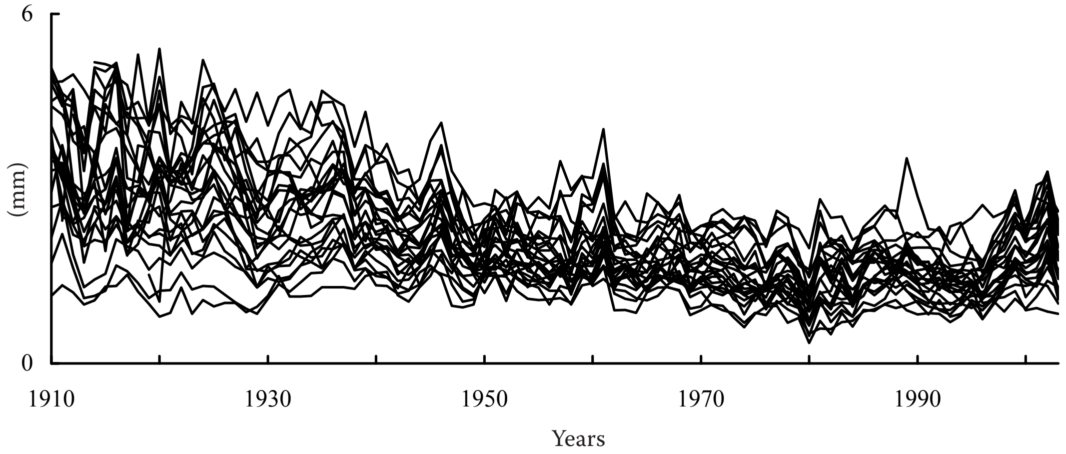

Fig. 2. Tree-ring chronologies of spruces from 25 forest sites

RESULTS

The site tree-ring chronologies developed during this study were characterised by a constant decreasing trend and a relatively convergent rhythm of annual radial increments (Fig. 2). In their course there was an increment depression which occurred at the turn of the 1970s with a strong decrease on all study sites in 1980. The periods of decreased convergence between chronologies followed by the periods of distinct improvement were observed at that time. This phenomenon is often encountered and has different climatic as well as non-climatic causes.

There was a gradual increase in annual ring width in the early 1980s observed on all sites while since the mid-1990s not only an increase of diameter increments but also a homogeneous rhythm of annual oscillations in ring width with simultaneous increase in amplitude have been observed (Fig. 2). In order to emphasise this phenomenon, the exponential curves were fitted to the chronologies, and then indexed chronologies were worked out (Figs. 3 and 4). In this case the period of increasing radial increments in the late 1990s has been brought into prominence (Fig. 4). This phenomenon may also be perceived very well in the regional indexed chronology (Fig. 5). The comparison between this chronology and the actual regional chronology confirmed a rapid increase in increments since 1996. In subsequent years this phenomenon was accompanied by a marked increase in tree-ring width variation (Fig. 6). It is interesting that the phenomenon described above is associated with the beginning of increased Norway spruce mortality in the area in question.

However, a detailed analysis of site chronologies indicated that the size and rate of increase in diameter increments distinctly differed from site to site (Figs. 2 and 4). It is known from previous research on Norway spruce of the area in question that its growth rhythm is different at different altitudinal levels of the lower mountain zone, and this is the result of its different sensitivity to environmental conditions

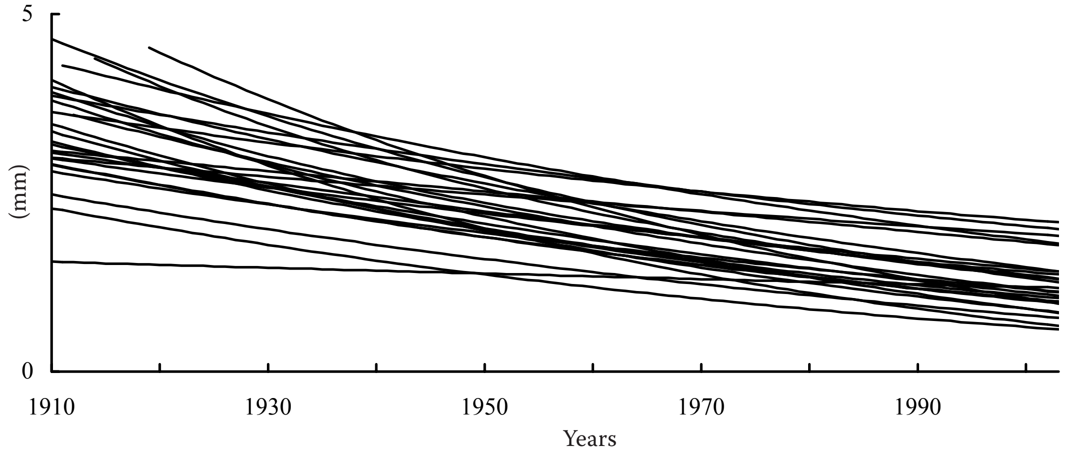

Fig. 3. Fitting curves of the tree-ring chronologies

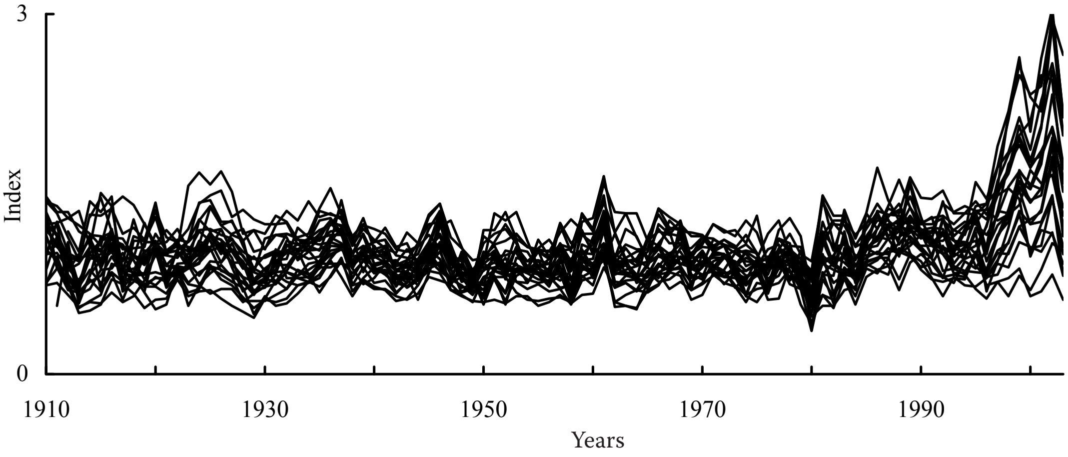

Fig. 4. Indexed tree-ring chronologies of spruces from 25 forest sites

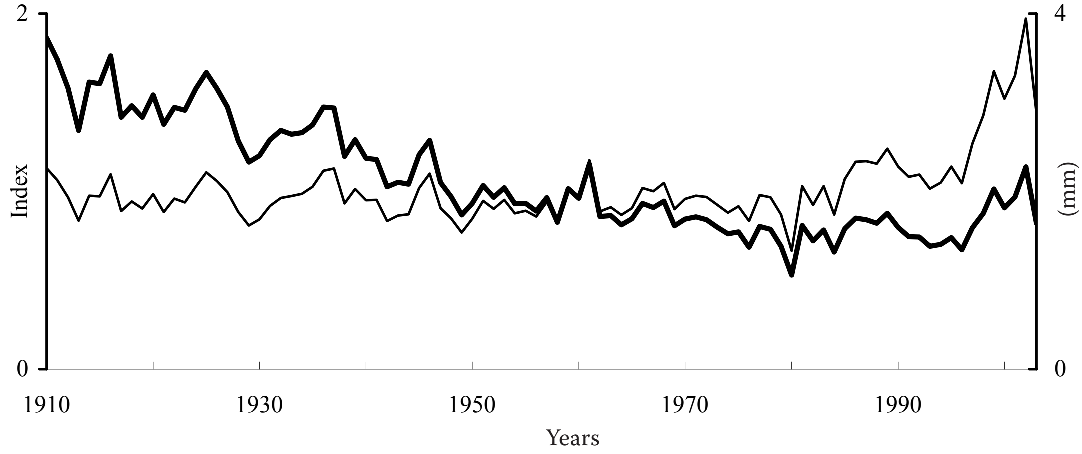

Fig. 5. Regional index chronology (thin line) and tree-ring chronology (thick line)

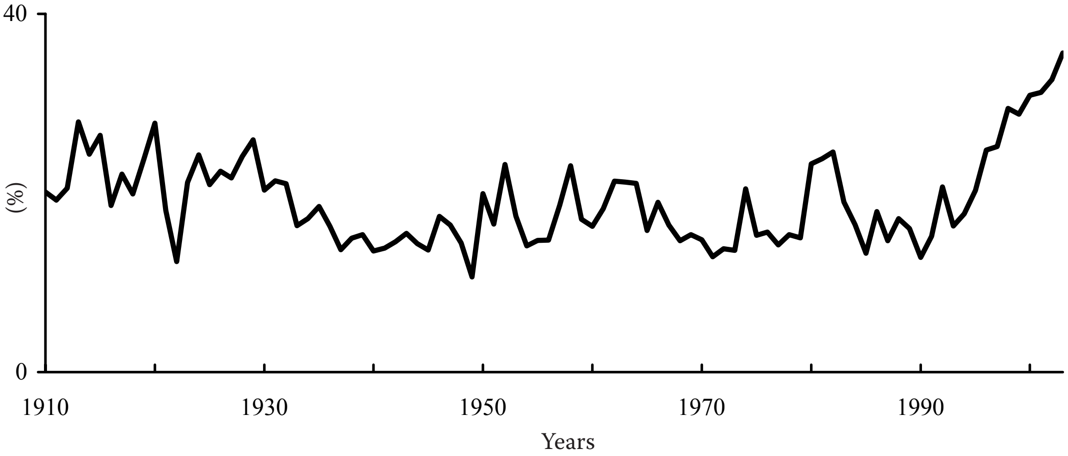

Fig. 6. Annual coefficients of variation of the tree-ring widths

(Feliksik, Wilczyński 2002, 2003a). This has been confirmed, among other things, by a gradual drop of homogeneity (convergence) of three-ring chronologies taking place along with increasing difference in the altitude of individual localities (Fig. 7). As a rule, at the difference in altitude of about 700 m the convergence of chronologies becomes insignificant. It often happens in mountain areas when the growth rhythm of trees on sites differing by about 50 m in altitude is different due to a rapid change in climatic

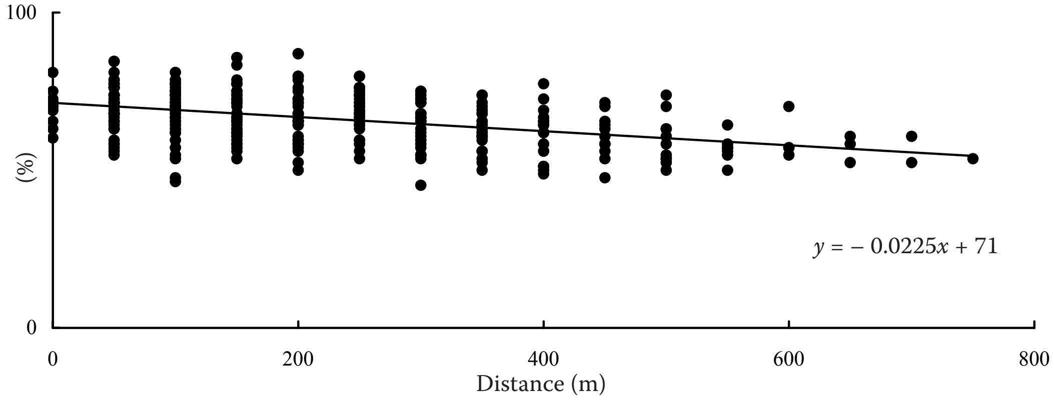

Fig. 7. Coefficients of convergence (GL%) of the tree-ring chronologies and altitudinal distance between sites for the period 1910–2003

and edaphic conditions with changes in altitude and terrain orography.

Keeping this in mind the indexed chronologies were constructed for each of the distinguished altitudinal levels of the lower mountain zone, and their course was compared with the chronology estimated on the basis of climatic data (Fig. 8). The comparison clearly showed that since 1995 the dynamics of

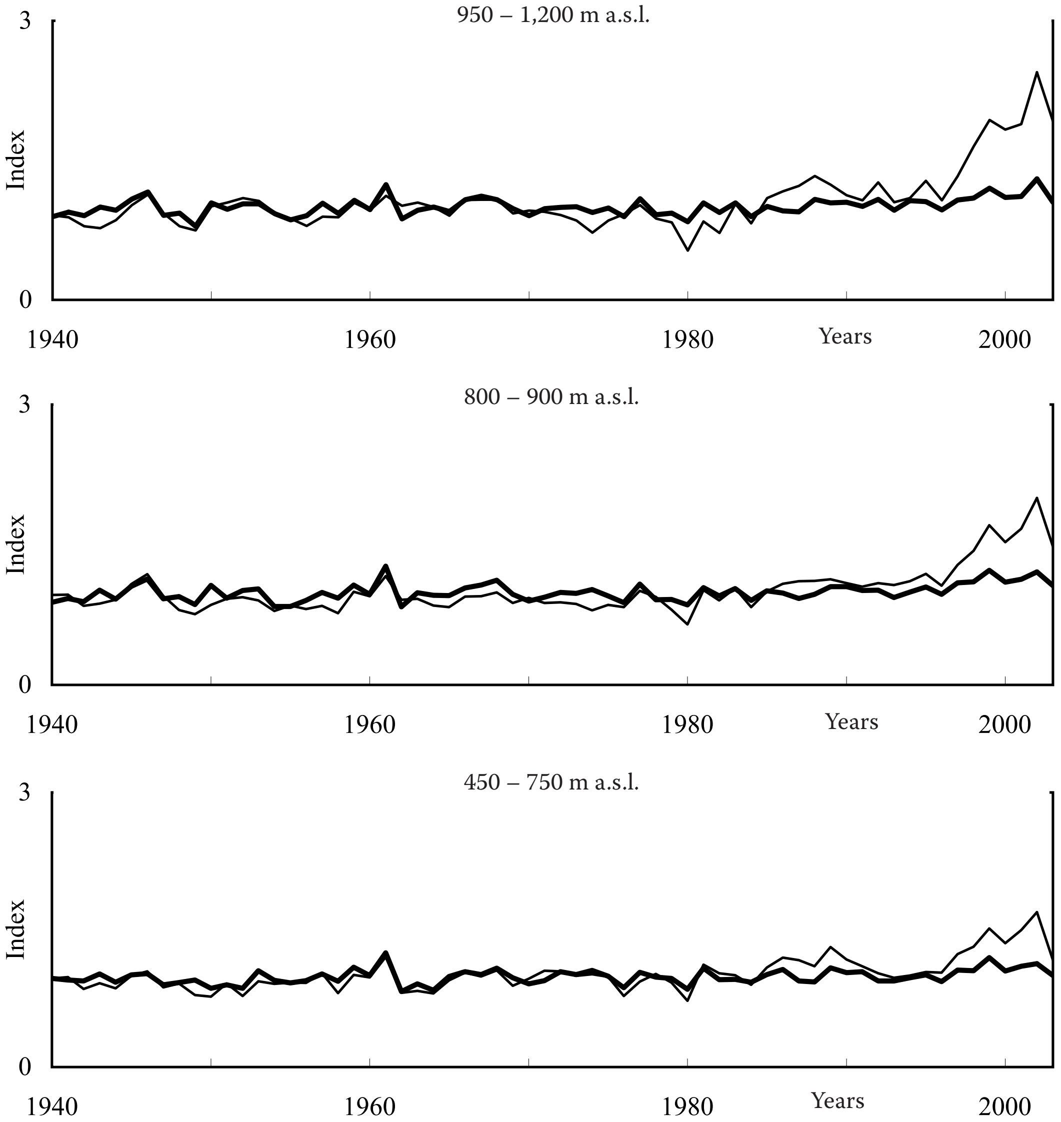

Fig. 8. Comparison of the indexed tree-ring chronology (thin line) and estimated tree-ring chronology (thick line) of spruce trees from three altitudinal zones

changes in radial increments was different at the respective altitudinal levels. The greatest increase in annual increments during that period of time took place in Norway spruce of the highest part of the lower mountain zone, i.e. 950–1,200 m a.s.l., while the smallest one in its lowest part, i.e. 450–750 m (Fig. 8). A similar distribution was observed in the amplitude of ring width changes from year to year. It was greater than in the previous years, and the greatest in the highest parts (Fig. 8). It seems that the cause of this type of increment responses of the investigated trees could have been a high variation of meteorological conditions in the Beskids during that period of time. For example in the Beskid Śląski the thermal conditions at the turn of winter (February, March) were changing from year to year in the second half of the 1990s. Similar variation was observed in the case of precipitation and pluvial and thermal indexes during summer months (June, July, August) (Feliksik, Durło 2004). The earlier dendroclimatic research showed that the thermal and pluvial conditions of these seasons had a considerable effect on the wood forming activity of Norway spruce of the Beskids (Feliksik, Wilczyński 2000, 2001).

DISCUSSION

As it has been pointed out in forestry literature many times, air pollution is one of the frequent causes of disturbances in the growth of trees. Its effect on forests is manifested as a rule by the weakening of trees and checking of their metabolic processes, and this causes a long-term depression in radial growth (Pollanschütz 1987; Eckstein, Saß 1989; Oleksyn et al. 1993; Schweingruber 1993; Feliksik 1995; Kobayashi et al. 1997; Juknys et al. 2002; Wilczyński, Feliksik 2004).

The uneven distribution of industrial emissions in the forest environment and different strength of responses of individual trees are expressed by marked disturbances in similarity of growth rhythms of trees which are normally regulated by weather conditions (Fritts 1976; Kairiukstis et al. 1987; Wójcik, Buczkowski 2002; Feliksik, Wilczyński 2003b; Wilczyński et al. 2004a). We probably deal with such phenomena in the Western Beskids. In the early 1960s, due to a rapid development of industries in Moravia and Silesia the emissions of pollutants gradually increased to reach the culminating point in the late 1970s (Szdzuj et al. 2001; Świątczak 2002). This was reflected in disturbances in the growth rhythm of trees investigated during this study.

The harmful effect of emissions contributed to the weakening of Norway spruce in this region with the culmination point at the turn of the 1970s. A radical decrease in air pollution occurred in the second half of the 1980s (Szdzuj et al. 2001; Świątczak 2002). It was immediately reflected in increasing diameter increments of Norway spruce trees, which meant their revitalisation. In recent years the decrease in air pollution has been accompanied by climatic changes. Warmer winters have been more and more frequent while the winter and spring precipitation has increased. Such conditions could favour Norway spruce. They could intensify the tree revitalisation process. However, the disturbances in thermal and pluvial balance during the growing season were observed during the last few years (Feliksik, Durło 2004; Wilczyński et al. 2004b,c). The most recent summers in the area in question were alternately dry and hot or cold and moist. This probably disturbed the balance in tree growth responses. The weakened Norway spruce trees were attacked by *Armillaria* spp. and *Ips typographus* (Szabla 2003), and their defoliation also increased (Modrzyński 2001; Godzik et al. 1997; Szdzuj et al. 2001).

The lower mountain zone in the Beskids is not the area of natural occurrence of pure stands of Norway spruce. Presently these artificial monocultures have entered the phase of stand break-up, caused not only by air pollution but also as it seems in the first place by unfavourable climatic conditions of the summer period. Thus they should be converted as soon as possible.

CONCLUSIONS

The decrease in air pollution in the 1980s resulted in the initiation of the process of revitalisation of Norway spruce growing in the lower mountain zone of the Western Beskids. Radial increments increased considerably although the degree of defoliation was still relatively high. In the 1990s favourable weather conditions during winters and springs promoted the formation of large wood increments.

In recent years, however, rapid changes in thermal and pluvial conditions of summer may be observed every year. Wet summers are followed by dry and hot ones, particularly unfavourable for Norway spruce, which is very sensitive to a moisture deficit. In consequence the growth response of trees became uneven, and the amplitude of changes in ring width increased. Such a strong and variable increment response of old trees is probably one of the very important causes of their weakening and dying.

The initial symptoms of break-up of Norway spruce stands in the Western Beskids, observed at the present time, force the foresters to undertake a quick conversion of pure stands of this species. Norway spruce may remain there as an admixture in natural beech-fir stands of the lower mountain zone.

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Poruchy kolísání šířky letokruhů smrku ztepilého v polských západních Beskydech

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ABSTRAKT: Ve 25 porostech smrku ztepilého ve věku 100 let byly analyzovány změny tloušťkového přírůstu. Porosty rostly v polských západních Beskydech na lokalitách s různou expozicí v nadmořské výšce 450–1 200 m. V polovině devadesátých let byl zjištěn významný nárůst šířky letokruhů. Největší nárůst se vyskytoval u stromů rostoucích ve vyšších nadmořských výškách. Tento jev nastal po dlouhém období poklesu přírůstu okolo sedmdesátých let. Po roce 1990 se šířka letokruhu zvětšovala, kolísání a amplituda se zvětšily také. Příčinou dlouhodobého zvyšování tloušťkového přírůstu bylo zlepšení teplotních a srážkových podmínek v pozdní zimě a brzy na jaře, což mělo značný vliv na růst smrku. V devadesátých letech začalo období významných změn teplotních a srážkových poměrů v létě. Po vlhkých a chladných létech následovala léta horká a suchá. To se promítlo do zvýšeného kolísání a amplitudy přírůstové reakce smrku a přispělo k oslabení stromů starších 100 let. Zvyšující se rozpad smrkových porostů rostoucích v nižší horské zóně polských západních Beskyd, pozorovaný v posledních letech, je konečným výsledkem tohoto procesu.

Klíčová slova: letokruh; kolísání šířky letokruhů; smrk ztepilý; polské Beskydy

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