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Growth dynamics of Scots pine (*Pinus sylvestris*) in the Olkusz Ore-bearing Region

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Introduction

The Olkusz region has been associated with lead and zinc mining since the 12th century. Over time, ore extraction intensified with the development of the steel industry. Industrial production accelerated after World War II, increasing its environmental impact. The mining and processing complex known as ZGH Bolesław in Bukowno became the largest industrial plant in the area (Liszka and Świć 2004; Danek 2008). Centuries of deposit exploitation has left the area surrounding Olkusz largely covered with pits and mining waste heaps. The area has been subjected to reclamation measures, mainly afforestation, and has also undergone spontaneous succession. The air pollution associated with industry became a major environmental concern of the Olkusz region; the vegetation inhabiting areas degraded by industry is exposed to additional stress related to dustfall containing heavy metals and sulfur compounds particularly harmful to plants' assimilation apparatus. Numerous studies have shown the negative impact of industrial air pollution on the annual radial growth of trees. Reduction of that radial increment may therefore serve as an indicator of the impact of pollution (Muzika *et al*. 2004; Aznar *et al*. 2009).

This study investigated the dynamics of change over recent decades in the annual radial increments of Scots pine (*Pinus sylvestris* L.) growing in part of the Olkusz area, the Olkusz Ore-bearing Region (OOR), and correlated those dynamics with the level of industrial emissions coming from ZGH Bolesław in Bukowno.

Study area, materials and methods

Radial growth increments were analysed in Scots pine (*Pinus sylvestris* L.) trees growing on 21 forest research plots demarcated in the Olkusz Ore-bearing Region (OOR) for project EEA FM PL0265, "Vegetation of calamine soils and its importance for biodiversity and landscape conservation in post-mining areas" (Fig. 1). Each plot covered 400 m^2. Cores were taken along two rays at 1.30 m height

Fig. 1. Location of study sites and ZGH Bolesław in the Olkusz Ore-bearing Region
Ryc. 1. Lokalizacja powierzchni badawczych oraz ZGH Bolesław na terenie Olkuskiego Okręgu Rudnego

from 10 trees having the largest diameter at breast height, according to standard dendrochronological methods, using a Pressler increment borer (Schweingruber 1989). The cores were dried and polished, scanned, and the widths of annual increments were measured using WinDendro software. The correctness of dating was verified with COFECHA (Holmes 1983) and then the width of increments along the rays was averaged for each of the trees. Changes in increments were calculated as the ratio of average increments of each decade to the average increment of the previous decade (Nowacki and Abrams 1996).

Results and discussion

The cored trees were in age classes representing the dominant trees on a given plot, but tree age varied between plots. The longest increment sequence (141 years) was obtained from plot 42, and the youngest trees grew on plot 23: their age did not exceed 14 years (Fig. 2). The average age of all studied pine trees was 47 years. Tree age exceeded 60 years on 7 plots (Fig. 2A), and was less on the remaining plots (Fig. 2B). The older pines on all the plots showed a strong incremental depression which started in the mid 1950s and lasted until 1980 (Fig. 3). The average increment in the 1960s and 1970s was 0.8 mm, significantly less than in other decades (Fig. 3). Regardless of the trees' age, the radial increment rapidly increased at the beginning of the 1980s on all plots. A measure of this rapid increase of radial growth is the percentage of increment change (Fig. 4), which on most plots reached maximum in 1980 or the following years. The

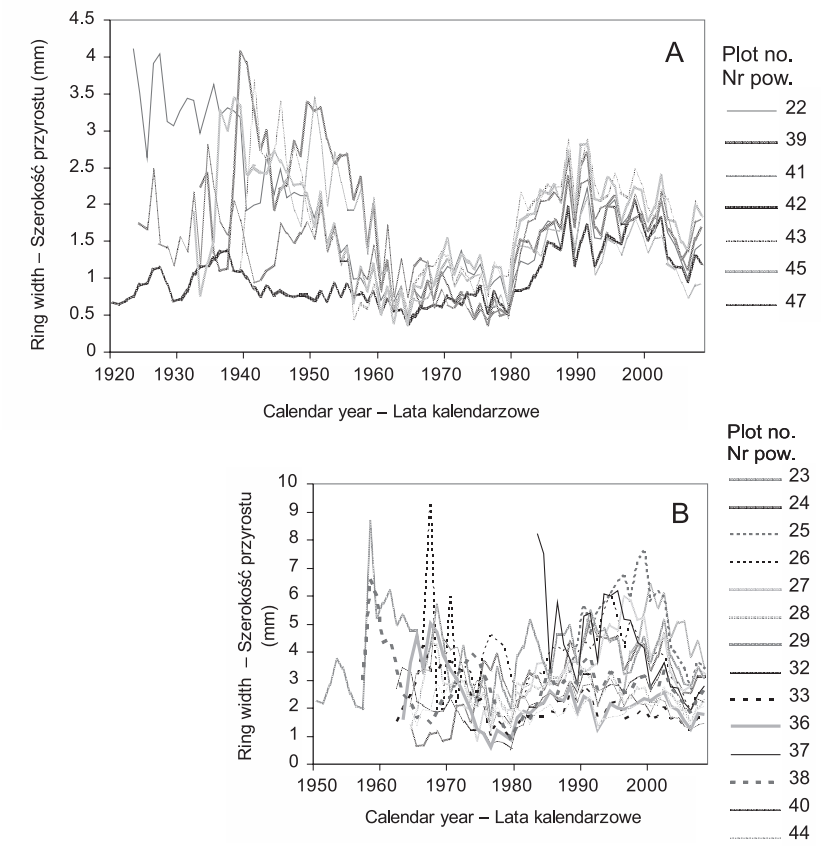

Fig. 2. Average growth of older (A) and younger (B) Scots pine (*Pinus sylvestris*) stands at study sites

Ryc. 2. Średnie przyrosty sosny zwyczajnej (*Pinus sylvestris*) na poszczególnych powierzchniach badawczych dla drzewostanów starszych (A) i młodszych (B)

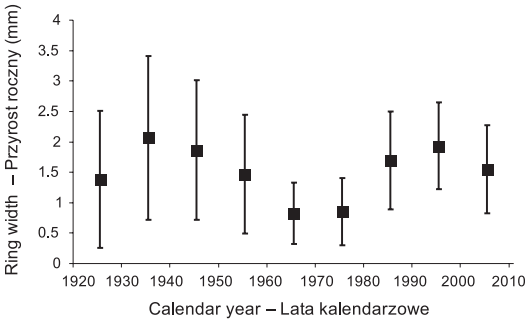

Fig. 3. Average growth (±SD) of Scots pine (*Pinus sylvestris*) trees over 60 years old, by decade

Ryc. 3. Średni przyrost sosny zwyczajnej (*Pinus sylvestris*) dla dekad oraz odchylenie standardowe (dla drzew w wieku powyżej 60 lat)

positive change in radial growth was greater in older trees. Around 1980, those trees increased their increments by between 73% and 321%, depending on the plot (Fig. 4A). Among younger trees the increase of average radial growth ranged from 15% to 162% (Fig. 4B).

We compared these results with the available data on emissions from ZGH Bolesław, the main source of industrial pollution in the Olkusz Ore-bearing Region. Atmospheric emission of harmful dusts and gases from technological processes was one of the company's biggest problems. Continuous data on annual particulate emissions (metallurgical dust, coal

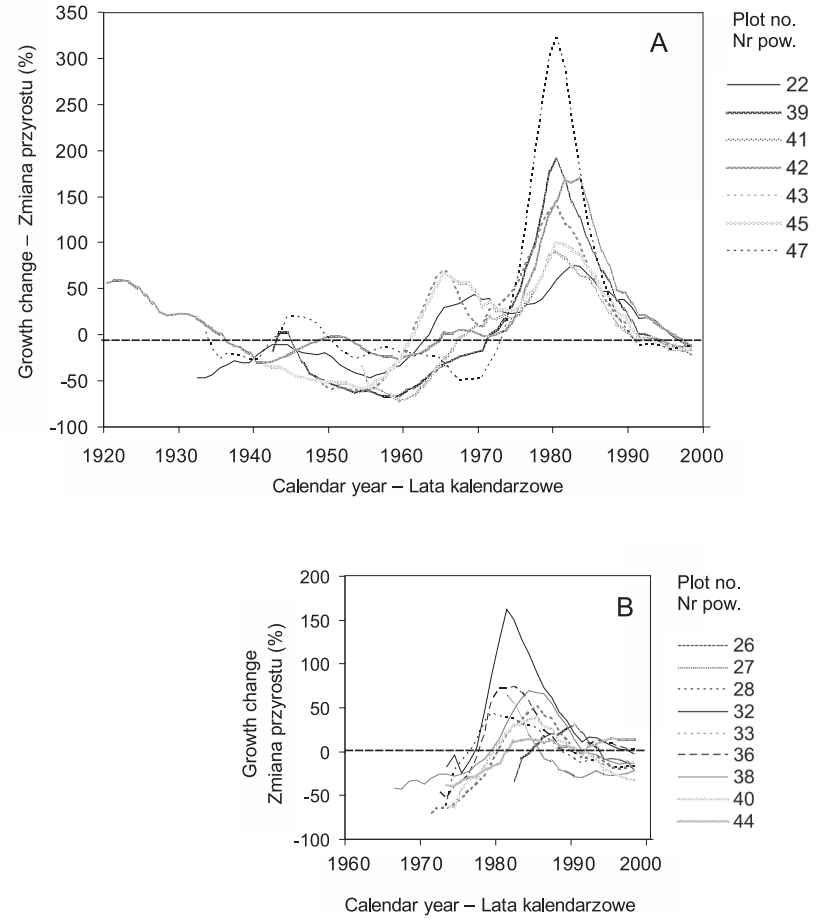

Fig. 4. Growth change (%) of Scots pine (*Pinus sylvestris*) trees over 60 years old (A) and younger (B)

Ryc. 4. Zmiana przyrostu sosny zwyczajnej (*Pinus sylvestris*) dla drzew starszych niż 60 lat (A) i młodszych (B) w procentach

dust, dust from fuel combustion) and on their heavy metal content (Zn, Pb) are available since 1962 (Fig. 5). The pre-dedusting and final dust removal devices placed in the furnaces in the early 1950s were designed according to 1930s air protection technology. The first reliable measurements carried out in 1956 showed annual particulate emissions of 5500 tons. Regular improvement of the dedusting installations gradually decreased those emissions starting in the 1960s. Since 1981, ZGH Bolesław has been covered by the Environmental Protection Act, which imposes heavy penalties for exceeding emissions standards (Liszka and Świć 2004). The depression of radial growth among pines in the OOR covers the period of high industrial emissions in the 1960s and 1970s. We found no significant correlation between the intensity of the depression and the distance of the tree stand from the source of pollution, ZGH Bolesław, probably due to the small size

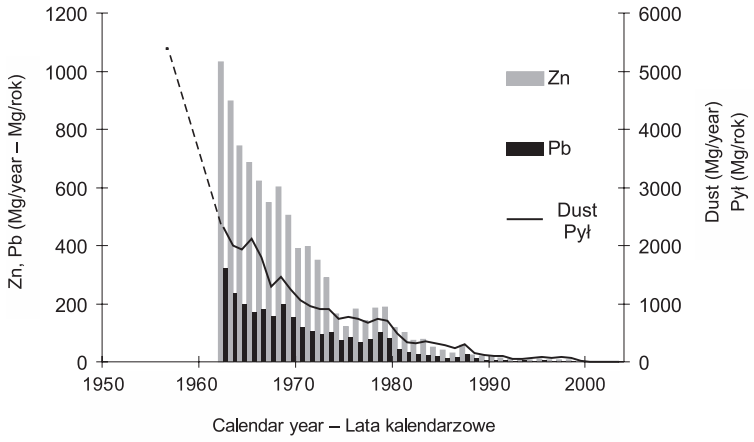

Fig. 5. Dust emissions from ZGH Bolesław and content of lead and zinc in dust. Dashed line indicates interpolation between 1956 and 1962

Ryc. 5. Emisje pyłowe ZGH Bolesław oraz zawartość cynku i ołowiu w pyle. Linia przerywana oznacza interpolacje pomiędzy rokiem 1956 i 1962

of the studied area. The impact of emissions from more distant sources on the growth of the studied trees cannot be excluded. The prevailing winds from the west can transmit contaminants from highly industrialised Silesia, which is not far away. Our methodology for this study cannot separate the effects of near and long-range pollution on the trees, but the proximity of ZGH Bolesław makes it the main source of pollution.

Depression of radial growth was clearly more evident in older trees. The growth increment of younger trees, which were in their juvenile period in the 1960s and 1970s, was not reduced as much. Regardless of age, the trees we studied showed a rapid and simultaneous increase in the width of annual increments in the early 1980s, when emissions dropped considerably.

Air pollution is not the only factor that can decrease radial growth drastically. Soil dehydration and soil pollution can also have a significant impact on radial growth (Schweingruber 1996). The stress caused by dust and gas pollution can be exacerbated by the competition that occurs in earlier stages of tree stand development (e.g. small polewood, high polewood). Our results clearly indicate rapid and significant improvement of growth conditions for all trees, coinciding with the reduction of air pollution. This suggests that the depression of radial growth had been a response to atmospheric pollution rather than to changes in soil chemistry (Aznar *et al*. 2007).

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