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Original article

Spruce tree-ring reductions in relation to air pollution and human diseases a case study from Southern Poland

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ABSTRACT

The study was conducted in two small municipalities in Małopolskie voivodeship in Southern Poland. Both municipalities are located in mountain basins in the Western Beskids mountain range.Cores were taken from trees growing near the centre of Rabka-Zdrój and Sucha Beskidzka in order to analyse the impact of contemporary air pollution on the health of tree stands. Annual tree rings developed during the era of high atmospheric pollution are usually narrower than the others. These municipalities were chosen due to their current air pollution problems despite their relatively small population.Local chronology, skeleton plots and calculated ring reductions were created for the sample trees. Temporal relationships between air pollution and a negative health reaction in trees and in people were also examined. To fulfil this objective the dates of occurrence of tree-ring reductions were compared with the concentration of particulates (PM10) in the atmosphere and also lung disease morbidity in the local population. Two periods of reduced annual tree rings were detected: first from the 1960s to the end of the 1980s (associated with industrial pollution) and more recently the years since 2003. Since 2003 reductions of annual tree rings have increased in parallel with increases in dust pollution. This reaction of trees to dust pollution was immediate. The negative reaction of trees preceded several years of increasing lung disease morbidity. This gives basic evidence to support the argument that tree ring reductions could be used as an early bioindicator for warning against the risk of air pollution. The aim of this work was to determine the periods of reduction in the annual growth of spruce growing near the centre of Rabka-Zdrój and Sucha Beskidzka. In addition, potential associations were sought between the time of occurrence of these periods and changes in air pollution and human disease.

KEY WORDS: wood cores, dendrochronological data, Rabka-Zdrój, Sucha Beskidzka

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1. Introduction

Air pollution is considered a key stress factor affecting the annual ring widths of trees, especially those growing in industrialised areas (DANEK, 2007). Coniferous species are especially susceptible to pollution. The effect of air pollution on coniferous trees can be manifested in the reduction of cambium division activity; trees produce fewer cambial derivatives, there is acceleration of the aging processes, death of dwarf shoots, and faster death of needles. Air pollution accelerates the process of surface cell death in the basal part of the apex (KURCZYŃSKA ET AL., 1994). The influence of pollution also contributes to a decrease in the length and slenderness of late wood coils and a decrease in the strength of the wood when being bent (SPŁAWA–NEYMAN, 1994). Emission of pollutants may also cause general damage and reduction of the assimilation apparatus (SZYMAŃSKA ET AL., 1994). Annual tree rings developed during a period of high atmospheric pollution are usually narrower than those from other periods (BORECKI, 1993). In extreme cases large areas have been completely destroyed (INNES & COOK, 1989). The widths of the annual increments that are produced can be treated as a measure of their response to changing environmental conditions, including the impact of pollution (WERTZ, & WILCZYŃSKI, 2012). Sensitive species and especially coniferous species should be first

choice for the investigation of the impact of industrial pollution on trees (WERTZ, 2012). In terms of air quality, Poland occupies almost last place among the countries belonging to the European Union in the ranking of the European Environment Agency (EEA, 2013). Only Bulgaria presents a worse situation than Poland. However data from the World Health Organization (WHO) demonstrates that among the fifty EU cities with the worst air quality, as many as 33 are located in Poland. After Poland's accession to the European Union in 2004 standards in the field of coal quality were abolished, which resulted in the mass sale and combustion of very low quality fuel. Atmospheric pollution also caused an increase in the number of cases of morbidity and mortality in the population. Epidemiological research shows that the negative health effects among people appear more often with an increasing concentration of pollutants in the air as well as with the time that people are in the contaminated area (MALIK ET AL., 2012). This work was produced as a continuation of publications on tree-ring reductions in Norway spruce in relation to air pollution and on human morbidity based on the example of Zakopane (RUTKIEWICZ ET AL., 2016). This work was also undertaken due to the persistent problem of low emissions and their harmful impact on human health. The aim of this work was to determine the periods of reduction in the annual growth of spruce growing near the centre of Rabka-Zdrój and Sucha Beskidzka. In addition, potential associations were sought between the time of occurrence of these periods and changes in air pollution and human disease.

2. Study area

The study was conducted in two small municipalities in Małopolskie voivodeship in Southern Poland (Fig. 1), Sucha Beskidzka with 9365 inhabitants and Rabka-Zdrój with 12 813 inhabitants. It is worth mentioning that Rabka-Zdrój is a health resort. These municipalities were chosen due to the current problem of air pollution despite their relatively small population. Both municipalities are located in mountain basins in the Western Beskids mountain range. Rabka-Zdrój lies in the Rabczańska Basin, which is of upland character with significant relief, lying at an altitude of 500-600 m a.s.l. and is crossed by the rivers Skawa and Raba, surrounded on all sides by mountain ranges with a maximum altitude of 820 m a.s.l. to the south, 644 m a.s.l., to the north and 679 m a.s.l. to the east. The surrounding mountain ridges are formed of Magurski sandstone, while soft shales occur in depressions. The climate of Rabka-Zdrój is determined by the conflicting influences of polar-continental and polar-sea air masses. The winds blow most frequently from the south-west. A characteristic feature of the climate of the study area is a high degree of insolation and a small amount of precipitation. The average annual air temperature is 7.3°C, with the warmest month in July and the coldest month in February. Diurnal temperature fluctuations are small, both in summer and in winter. Snow cover occurs from December to March. The average annual precipitation is around 949 mm and is typical for areas located at a similar altitude in mountain areas (CHRZĄSTOWSKI, 1965; KONDRACKI, 1998; TURZAŃSKI ET AL., 2008).

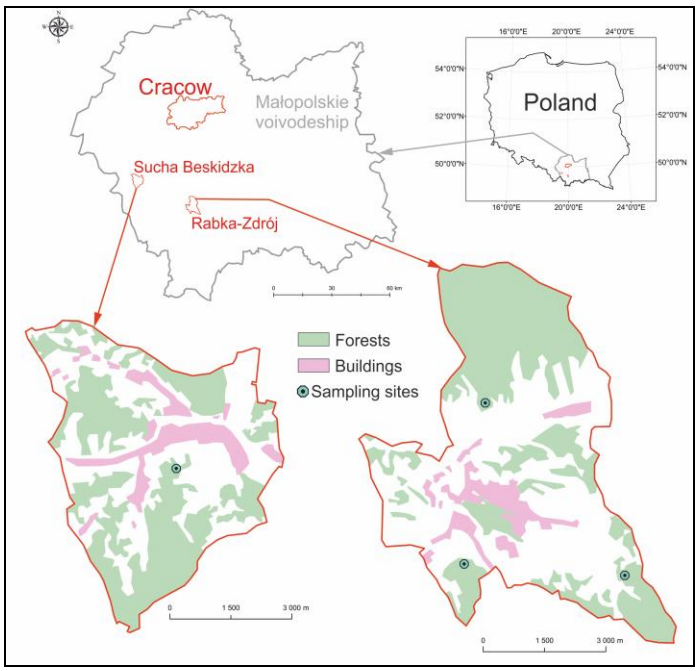

Fig. 1. Location of the study sites

Sucha Beskidzka is located in the Makowski Beskids, which consist of many fragmented ranges made up of sandstones with alternating layers of shales, in which valleys are dissected. The municipality lies in an area that is characterised by a very large diversity of terrain - from flattened areas located in the bottoms of valleys, through gentle slopes to steep slopes (ROZENAU-RYBOWICZ ET AL., 2012). Directly above the valley and the town are the highest points of the high ground: 625.2 m a.s.l. and 521 m a.s.l., to the north, 871.5 m a.s.l. and 744 m a.s.l. to the south, and 744 m a.s.l. to the east. The municipality is located in a zone of moderately warm climate zone (up to 700 m above sea level), while its south-western borders can be classified as a moderately cold climate zone. The prevailing wind directions are west and south-west and correspond to the morphology of the area. Locally, the impact of mountain winds is apparent. The intensity of precipitation rises from the foothills (river valleys) to the mountain peaks from 800 to 900 mm respectively. The average annual air temperature is about 8°C (in the Valley bottoms) and about 6°C in mountainous areas. Snow cover lasts from December to March and on the northern slopes of the mountains until the second half of April (KONDRACKI, 1998; ROZENAU-RYBOWICZ ET AL., 2016).

3. Methods of study

Cores were collected at the end of the 2016 growing season. In all 35 cores were collected from spruce (*Picea abies*) growing near to Sucha Beskidzka (20 cores) and Rabka–Zdrój (15 cores) town centres. The cores were taken from available trees, where possible close to built-up areas. Areas located on steep slopes were excluded to eliminate the possible impact of mass movements on tree growth. Therefore we selected sites located on as flat an area as possible and collected cores at breast height using a Pressler borer. One core was taken from each tree on the same, south side of the stem to ensure as uniform a tree-ring pattern as possible. We excluded tilted or injured trees. We have sampled all suitable trees which met the above described criteria. As in previous investigations samples of wood were glued into wooden holders and sanded to expose the wood's anatomical structure. An initial skeleton plot development was carried out for each core. These allowed quick dating of the periods of reduction in radial growth for each tree, and the identification of the beginnings of the periods of reduction. Next we measured the widths of annual tree rings and created local raw chronologies. The widths of annual rings were measured with a precision of up to 0.01 mm. The tree ring patterns were unusual. A characteristic tree ring growth pattern was not observed in the individual trees which excludes the application of detrending (negative expotential curve). We used the methodology of tree-ring reduction periods based on SCHWEINGRUBER ET. AL.'S methodology (1985). We assumed reduction periods were then determined for a particular tree and they were divided into two categories: weak and strong reductions. The values of reductions were calculated as the ratio between the sum of tree-ring widths of all rings in a reduction period and the sum of tree-ring widths of the same number of rings from the period before the reduction. Strong reductions were recognised when the average width of the series of at least three annual rings was less than 50% of the average width of the same number of tree rings preceding the reduction period. A similar rule was used for weak (30-50%) reductions (RUTKIEWICZ ET. AL., 2016). We also compared the reduction graphs which were created with the data on air pollution in Rabka-Zdrój and Sucha Beskidzka over the period 2000-2014 from the Regional Inspectorate for Environmental Protection in Cracow. This is a period for which there is data available to the public. We analysed the concentration of dust (PM10). For the same period statistical data were collected on lung disease morbidity for the Małopolskie voivodeship (Central Statistical Office of Poland – GUS) (www.stat.gov.pl). Detailed epidemiological data for each town were not available. Comparison of temporal patterns of the study data was carried out in a search for common trends and relationships between the reduction of annual tree-ring widths, air pollution and the number of patients with lung diseases.

4. Results

The oldest tree examined from the Rabka-Zdrój area was 104 years old and the youngest was 25 years old. The average age of the trees examined was 69 years. The oldest tree examined from Sucha Beskidzka was 87 years old and the youngest was 31 years old. The average age of the trees examined was 63 years. Tree-ring data gathered in Rabka-Zdrój shows two reduction periods while one period was found in trees growing in Sucha Beskidzka. In Rabka-Zdrój these are from the 1960s to the end of the 1980s, with predominant strong reductions occurring gradually during the whole period, and in the period since 2003 (60% of all trees). Particularly strong and common reductions were found in 2003 (Fig. 2). In Sucha Beskidzka clear and common tree-ring width reductions

(55% of all trees) started in 2003 and continue to the present (Fig. 3). In all the periods observed, both in Rabka-Zdrój and in Sucha Beskidzka, strong reductions predominate, while in other periods they are rare. The largest number of trees with strong ring reductions in one year was identified in 2003 in both Rabka-Zdrój and Sucha Beskidzka (Fig. 2, 3). During the period 2000-2014, concentrations of dust (PM10) increased in both study sites, reaching particularly high values in 2005 (Rabka-Zdrój) and in 2009 (Sucha Beskidzka). The morbidity data for the whole of Małopolskie voivodeship shows a slight increase in the 2001-2007 period and a significant rise since 2008 (Fig. 2, 3).

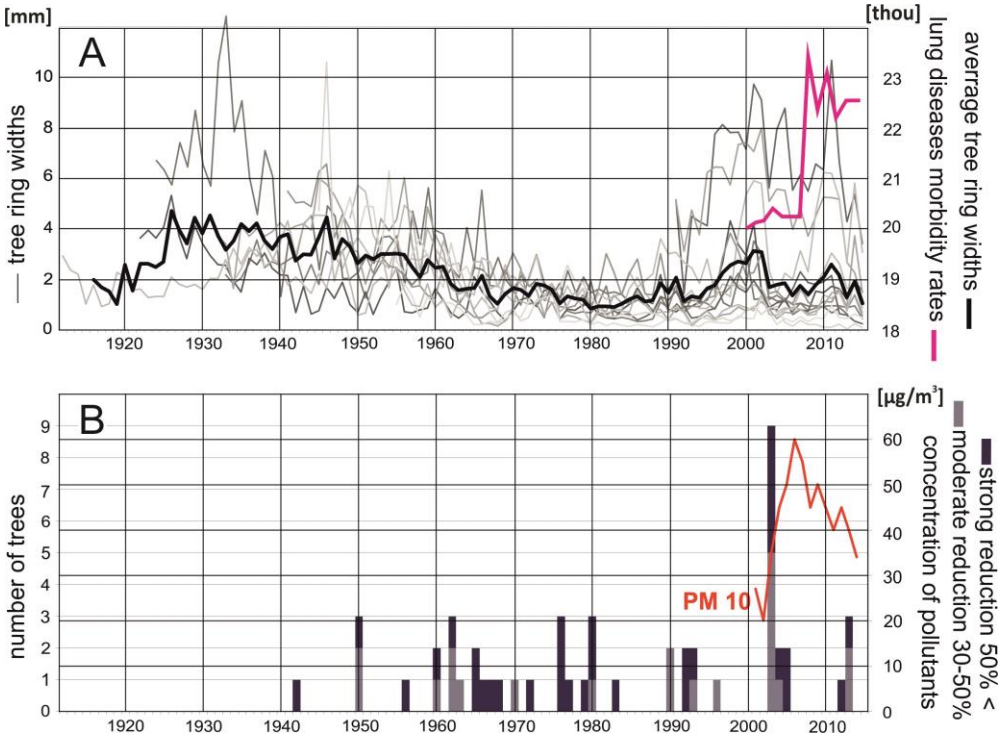

Fig. 2. Dendrochronological data for the Rabka-Zdrój study site: tree-ring widths (A) and number of trees showing the beginnings of ring reductions (B) compared to lung diseases morbidity rates and air pollution level in Rabka-Zdrój

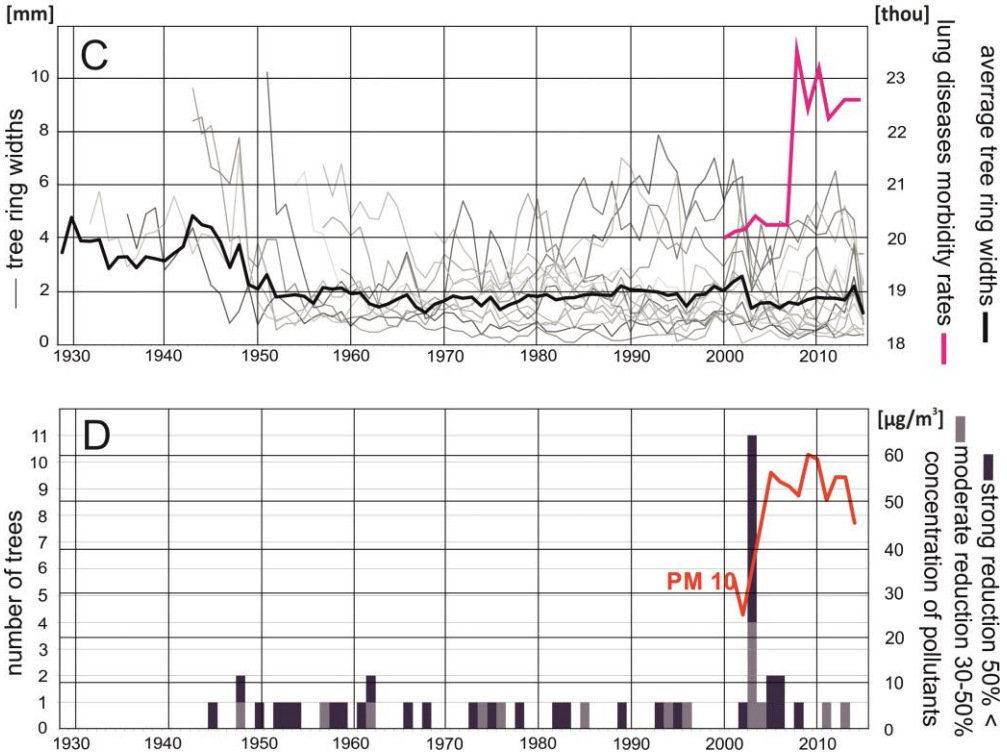

Fig. 3. Dendrochronological data for the Sucha Beskidzka study site: tree-ring widths (C) and number of trees showing the beginnings of ring reductions (D) compared to lung diseases morbidity rates and air pollution level in Sucha Beskidzka

5. Discussion

When Poland joined the European Union in 2004 quality standards for the combustion of coal were abolished. The combustion of low-quality coal in domestic boilers has caused a severe increase in emissions of PM10, benzo [a] pyrene, volatile organic compounds, soot, carbon monoxide, dioxins and heavy metals (www.polishsmogalert.org). According to data from global organisations, Poland is in almost the lowest position in terms of air quality among countries belonging to the European Union (GINALSKI, 2017). About 8-9 million tons of coal are burned every year in individual households and about 7-7.5 million tons of wood, as well as plastics and chopped-up tyres (GRABOŚ, 2014). The oldest of the periods of tree-ring reduction identified – from the 1960s to the end of the 1980s – could be associated with the intensive development of industry in the Upper Silesian Industrial District (Southern Poland). Western and south-western winds occurring in the study area could have caused the displacement of contaminated air masses from the Upper Silesian Industrial District. However, this is not certain because research conducted in the very heterogeneous Sudetes Mts. indicates that air pollution from distant industry is only visible in trees growing on windward slopes (DUSZYŃSKI, 2014). The second period observed in Rabka-Zdrój and Sucha Beskidzka, since 2003, is associated with the combustion of materials mentioned by GRABOŚ (2014).

The smog problem in the chosen municipalities also results greatly from the geographical location which is a factor that strongly and permanently limits an effective battle against air pollution. The air circulation system in mountainous valley areas is particularly difficult. Air exchange within these municipalities mainly takes place through the valley areas, which are natural ventilation corridors. Previously, the negative impact of air pollution on the annual tree rings of trees growing in mountainous areas has been demonstrated by WILCZYŃSKI (2006) in his research in the foothills of the Sudetes (southern Poland). According to the author's research, the decline of trees during periods of air pollution is mainly evidenced by a great variation in the width of annual rings. The phenomenon of contemporary tree-ring reductions related to the problem of low emissions is common in Poland. Trees in numerous forest stands, mainly coniferous, show signs of disease and there is even an increased tree mortality (STARZYK ET AL., 2005). The reductions in tree rings which have occurred since 2003 among trees growing in Rabka-Zdrój and in Sucha Beskidzka, are stronger than tree-growth suppressions from the oldest period. This is due to the fact that industrial air pollution in the former period came only from long-distance transport and thus is not strongly recorded in tree rings. It is worth mentioning that neither Rabka-Zdrój, nor Sucha Beskidzka are industrial towns and Rabka-Zdrój is also a health resort. Comparison of the tree-ring reductions in Rabka-Zdrój and in Sucha Beskidzka with pollution data suggests that PM10 dust is responsible for the recent deterioration in tree health and radial growth.

According to the study of MALEC ET AL. (2016), in winter the relationship between dust concentrations PM10 and PM2.5 in the inhaled air and the number of reports to the Admissions Department due to acute conditions associated with the respiratory system in children, was statistically significant. The same study confirmed the significant impact of smog on the health of the youngest residents of Cracow. The study confirmed also that the concentration of PM10 and PM2.5 leads directly to the number of instances of intensification of chronic diseases and new diseases in the respiratory system (MALEC ET AL., 2016). The reductions of annual tree rings that started in 2003, and an increase in dust pollution occur at the same time. The negative reaction of trees and increasing dust content in the atmosphere preceded increases in lung disease morbidity by several years. Previous studies conducted in Zakopane indicated a very similar and in the case of Nowy Targ, identical delay of human reaction to pollution compared to the effects observed in trees (RUTKIEWICZ ET AL., 2017). This may mean that there is a cause-and-effect relationship between air pollution and growth suppression in Norway spruce, as well as between air pollution and its adverse health effects on the human population. That could also give basic support to the argument that tree ring reductions can be used as an early bioindicator in warning against the risk of air pollution. However, to confirm the harmful effect on human health there is a need to collect tree ring data in other locations and to obtain more accurate epidemiological data than only that for the Małopolskie voivodeship.

The prevention of air pollution is also important for economic reasons. The World Health Organisation has estimated that the cost of treating people affected by air pollution in Poland as 101 billion 826 million dollars, it is as much as 12.9% of the gross domestic product (GDP) (www.who.int). Calculated per inhabitant of Poland, that is over PLN 800 per month. The statistics of the Małopolska Marshal's Office are also meaningful, they show that 98% of the Małopolska population breathes air which contains too much carcinogenic

benzo(a)pyrene. In all, 4,000 people die prematurely each year on account of this (GINALSKI, 2017). In the future, studies should be complemented by information on other factors that could cause the observed tree-ring reductions (e.g. climatic factors, site related factors, insect outbreaks). For example, the results achieved by GODEK ET AL. in mountain areas (2015) document a strongly negative dependence of tree ring widths on fog deposition rates. This research has only a contributing character and was carried out mainly to highlight the negative impact of contaminated air on both tree stands and human health.

6. Conclusions

Dendrochronology is a useful tool for spatial and temporal detection of air pollution. Two periods of reduced annual tree rings were detected: from the 1960s to the end of the 1980s and in recent years since 2003. The older period could be related to high emissions of industrial pollution. The period since 2003 is most likely related to harmful, low level emissions from individual houses. Reductions of annual tree rings from Rabka-Zdrój and Sucha Beskidzka have occurred at the same time as an increasing dust content in the atmosphere and the reaction of trees indicates that growth suppression was caused by low level emissions of dust. Since 2003 the size of annual tree rings has reduced and the amount of dust pollution has increased. The reaction of trees to dust pollution was immediate. The negative reaction of trees preceded increasing lung disease morbidity by several lyears. That gives basic support to the argument that tree ring reductions could be useful as an early bio indicator in warning against the risk of air pollution.

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