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Quantitative analysis of ring growth in spruce roots and its application towards a more precise dating

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ABSTRACT

Missing and wedging rings are common features of tree growth. They occur more frequently in roots than in stems and were reported for various species and sites. These rather frequent irregularities in roots make dendrochronological analysis and cross-dating of roots more challenging. The goal of this study was to present a compiled method for a quantitative analysis of ring-growth irregularities. The analysis was conducted on ten spruce (*Picea abies* L. Karst) roots taken from the Gorce Mountains (Southern Poland). A four-step cross-dating of these root samples was applied. Three to six cross-sections were analysed within each root and cross-dated with a corresponding stem and site chronology. All ring-growth analyses were conducted on micro sections. Finally, the dating method was evaluated using three control indicators. The study revealed that wedging rings occurring in both, cross-sectional and longitudinal profiles were observed in 17.3% of the rings analysed. The application of a combined zig-zag segment tracing and serial sectioning allowed to significantly reduce, compared to previous methods, the amount of undetected missing rings and revealed them as cross-sectional or longitudinal wedging rings. Thanks to the application of control indicators the irregularities occurring in rings of roots were quantified and compared with different environmental factors such as droughts, air pollution, insect outbreaks and geomorphological processes. Significant positive correlation between root age and the number of radial growth irregularities in roots was demonstrated. A detailed investigation of multiple cross-sections per root enabled to trace all types of ring irregularities in the roots and substantially reduced cross-dating subjectivity.

1. Introduction

Missing and wedging rings are common in roots due to the differences in cambial activity along the root and within the whole tree (e.g., Fayle and Farrar, 1965; Fayle, 1968; Schweingruber, 1996; Savidge, 2000; Schrader et al., 2003; Novak et al., 2011). Heterogeneity of growth in roots has been reported for miscellaneous coniferous and deciduous species mainly in the temperate climate zone (Wilson, 1964; Fayle, 1968, 1975a,b, 1976; Krause and Morin, 1995, 1999). Moreover, missing rings are more frequent in roots than in a stem (Schacht, 1858 vide Fayle, 1968; Krause and Morin, 1995) and their number tends to increase with increasing distance from the stem base (Fayle, 1975a,b; Krause and Morin, 1995, 1999).

Besides auxin internally controlling directional growth of roots, various external factors belowground as temperature, oxygen content, moisture, soil compaction and mechanical stress along the roots influence their growth pattern (Rowe, 1964; Fayle, 1968, 1975a,b; Shea, 1973; Schrader et al., 2003). According to Fayle (1968) a higher number of complete rings, and for this a reduced number of wedging rings, depends on the root age and is mostly controlled by an intrinsic regulation of secondary growth. Nevertheless, external factors as droughts, pollution concentrations and pest outbreaks are considered as one of typical factors diminishing root growth (Fayle, 1968, 1975b; Fritts, 1976; Krause and Morin, 1995, 1999; Schweingruber, 1996; Feliksik and Wilczyński, 2003; Wertz, 2012).

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Cambial activity in roots and stems is divergent and depends on various above- and belowground factor (Fayle, 1968; Savidge, 2000; Pelfini and Santilli, 2006). As a result problems related to the correlation of ring growth in roots and the stem of the same tree were observed (Pelfini and Santilli, 2006; Bodoque et al., 2005). It was noted that the response of tree stems and roots to the same environmental factors is often temporally delayed (Krause and Morin, 1995). Moreover, depending on the activity of a given erosional process, annual growth in stem and root may differ, because exposed roots develop wider rings (Alestalo, 1971; Bodoque et al., 2011), while ring width in the stem and unexposed roots potentially stay narrow. In fact the synchronicity of annual growth variations between roots and stems was observed in various species, however it applies exclusively to root sections located close to the stem (i.e. at a distance of less than 0.4 m from the stem) (Schulman, 1945; Fayle, 1968; Krause and Morin, 1995, 1999; Rybniček et al., 2007).

Analyses of radial root growth focused on the occurrence of wedging rings in single cross-sections (e.g., Schulman, 1945; Lyford and Wilson, 1964; Fayle, 1968, 1975b; Krause and Morin, 1995; Rybniček et al., 2007). Specifically, Studhalter et al. (1963) emphasised that discontinuous growth in a root results in the form of permanent lenses, half-lenses (3D perception) as well as arcs (2D perception) which can be inspected in the morphology of its ring growth. Therefore any study of radial growth of roots must take into account the occurrence of such three-dimensional irregularities (Fayle, 1968).

Due to the commonness of ring irregularities in the roots Fayle (1968) as well as Krause and Morin (1995, 1999) used multiple sectioning and cross-dating along the main root axis every 10–15 cm. They proposed to sample roots starting from the root-stem base following the root towards the tip. This procedure involved the basal 50 cm of the root axis in which, according to Fayle (1975b), false rings are common. They are very poorly defined beyond one meter from the stem base (Fayle, 1975b). Moreover, the annual rings at a root-stem base are wider due to the mechanical stress resulting from stem sway (; Fayle, 1975b, 1976) and should therefore be handled with care or even excluded from dating purposes.

In response to commonly discussed issues of root dating, we took the challenge to accurately date the age of exposed and unexposed roots collected from a site prone to geomorphic activity. We hypothesized that in a particular root cross-section, rings tend to wedge in different directions and even the measurements performed along the most complete radius will not include all growth rings, i.e. totally missing rings need to be detected. In order to detect a complete sequence of annual rings within a single cross-section its entire surface has to be taken into consideration. Therefore, the main goal of the study was to present a method which allows to trace highly irregular patterns in roots' annual growth. The method proposed here includes (i) an analysis of the number of growth rings and ring-width measurement within four radii of an entire cross-section by applying a new Zig-Zag Segment Tracing (ZZST) method, (ii) serial sectioning and (iii) visual cross-dating of growth curves obtained from different parts of the roots. This quantitative analysis of radial growth irregularities was then used as base towards a more precise dating of spruce roots. The applicability of this cross-dating technique was finally evaluated by introducing three control indicators which quantitatively evaluate the roots irregularities.

2. Material and methods

2.1. Study area

The research was conducted in the Gorce Mountains (the mid-mountain part of the flysch Western Carpathians, Southern Poland). The root sampling plots were located at an elevation of 1000–1150 m a.s.l., (49°32′37.4"N 20°09′00.7"E) represented by a subalpine forest zone (Carpathian spruce forest – *Piceetum excelsae carpaticum*) (Medwecka-Kornaś, 1955; Chwistek, 2001) with an average annual temperature ranging from 2 °C to 4 °C (Hess, 1965). The growing season in the Gorce mountains lasts less than 170 days. Average annual precipitation amounts 1230 mm, with an average monthly precipitation in the growing season ranging from 73 to 138 mm (Cebulska et al., 1981). Minimum monthly precipitation of the last 50 vegetation periods was 25 mm, the maximum 345 mm. In average every five years an extremely dry month occurs in the vegetation period, when less than 25% of an average annual precipitation considered for the particular month is reported. Similarly, 20-day periods without rainfall tend to occur once every five years. Extremely wet months (i.e., above 200% of the average total monthly precipitation) occur on average once every four years.

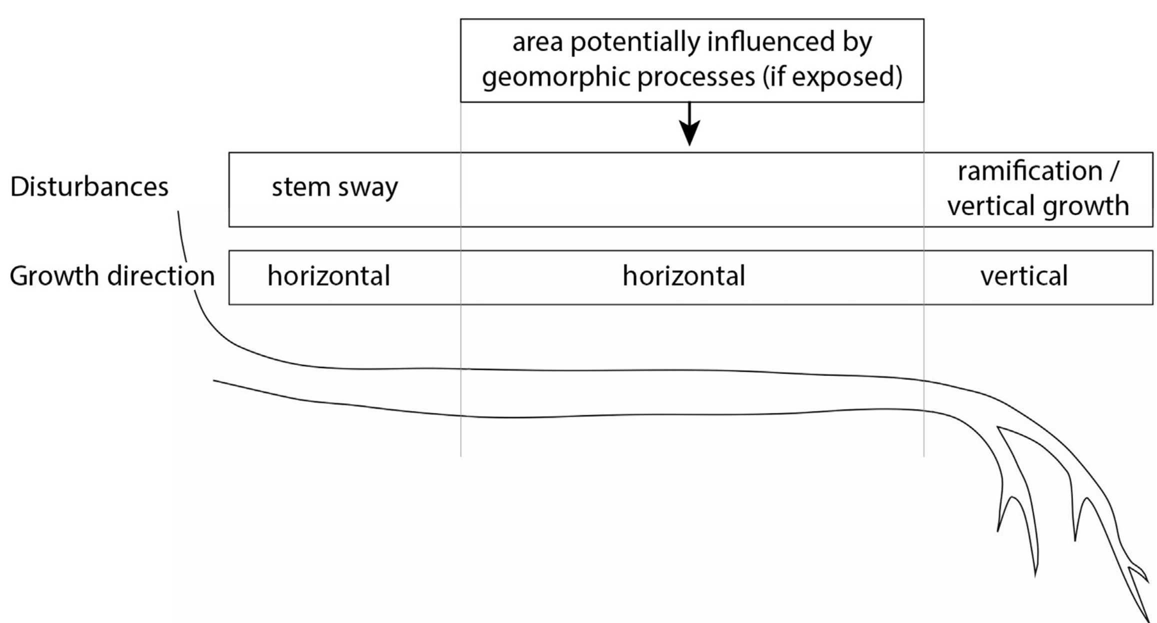

Fig. 1. Tree-root growth disturbances (based on Wilson, 1964; LaMarche, 1968; Fayle, 1975a,b; Gärtner et al., 2001).