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Constraints on dendrochronological dating of *Salix polaris* from central Spitsbergen

Short communication

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Abstract

Application of tundra shrubs in dendrochronological studies is recently increasing. However their growth rings are characterized by high irregularity which cause a common tree-ring dating problems. The goal of the study is to demonstrate a dendrochronological potential of common tundra species *Salix polaris* from central Spitsbergen (Ebbadalen, Petuniabukta) while (i) presenting its radial growth pattern and irregularities and (ii) discussing on its example a common problems of Arctic shrubs radial growth cross-dating. The results revealed that in average 25% of growth ring measured per single shrub was irregular and therefore might be problematic to detect and cross-date. It was found that even on a short distance (*i.e.*, along a main root axis) cambial activity is not equal and missing and partially missing rings occurred alternately in a longitudinal profile. Common growth irregularities, such as missing and wedging rings, must be taken into account while measuring and cross-dating such a difficult dendrochronological woody material as shown on the example of a *Salix polaris* dwarf shrub. The study revealed a high importance of serial sectioning and intra-plant cross-dating in dendrochronological studies of tundra shrubs.

Key words: tundra shrubs, radial growth, cross-dating, serial sectioning, *Salix polaris*

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Introduction

Tundra shrubs become more and more important for dendrochronological studies in the last two decades. Annual radial growth of shrubs, analogically like in the trees, provide a great opportunity for a tree-ring based studies and high-resolution dating. The use of so called "shrub-rings" (alternatively named as "tree-rings") has been widely demonstrated in both dwarf and erect shrubs species across a vast Arctic area, *i.e.*, from Canadian Arctic (Woodcock et Bradley 1994, Rayback et Henry 2005, Au et Tardiff 2007); Alaska (Tape et al. 2012) or Greenland (Schmidt et al. 2006, Schweingruber et al. 2013). Recently we observed a deep interest in dendrochronological studies in Spitsbergen, were dominant tundra species like *Cassiope tetragona* (Weijers et al. 2010) or *Salix polaris* (Buchwal et al. 2013, Owczarek 2009, Owczarek et al. 2014) and *Salix reticulata* (Owczarek 2009, Owczarek et al. 2014) are used for tree-ring dating with an annual resolution. This is happening because the highest interest of climate change studies is located in the polar regions where, as predicted, the warmer conditions will influence a terrestrial environment significantly (*i.e.*, IPCC 2013). Since shrubs can become old (more than 100 years old) and its annual ring growth register valuable environmental information, dendrochronological studies on tundra shrubs are expected to be of great importance in the future polar studies (Myers-Smith et al. 2011).

Although a great application of shrubs in dendrochronological studies has been indicated so far all studies have deeply stressed a common problems in ring-width measurements of tundra shrubs. This limitation is mainly linked with a radial growth irregularities, such as partially and completely missing rings, which make an accurate ring-width dating of shrubs very problematic. Thus a high dendrochronological potential of tundra woody plants is contrasting with its limitations and requires a closer look.

The goal of the study is to demonstrate a dendrochronological potential of common tundra species *Salix polaris* from central Spitsbergen while (i) presenting its radial growth pattern and irregularities and (ii) discussing on its example a common problems of Arctic shrubs radial growth cross-dating.

Material and Methods

The study material was collected in Ebbadalen located at the Petuniabukta in central Spitsbergen. Sampling plot was situated ca. 1,5 km apart eastwards from the Adam Mickiewicz University Polar Station. The study area represents *Dryas octopetala* community (Elvebakk 1999, Prach et al. 2012) with *Salix polaris* as a co-dominant shrub species (Fig.1A). Ten entire below-ground and above-ground parts of *Salix polaris* shrubs were sampled. The material was collected from a valley bottom and were assign to represent a rather stable growth conditions for *Salix polaris* in the post-glacial valley. Such High Arctic location was recently found to represent rather opportunistic vegetation change response to a warming climate (Jónsdóttir 2005), associated with limited succession of new species (Prach et al. 2010, Prach et Rachlewicz 2012). However the study area is characterized by high geomorphic activity (Rachlewicz et al. 2013) lately characterized by almost triple higher mechanical over a chemical denudation rates (Szpikowski et al. 2014).

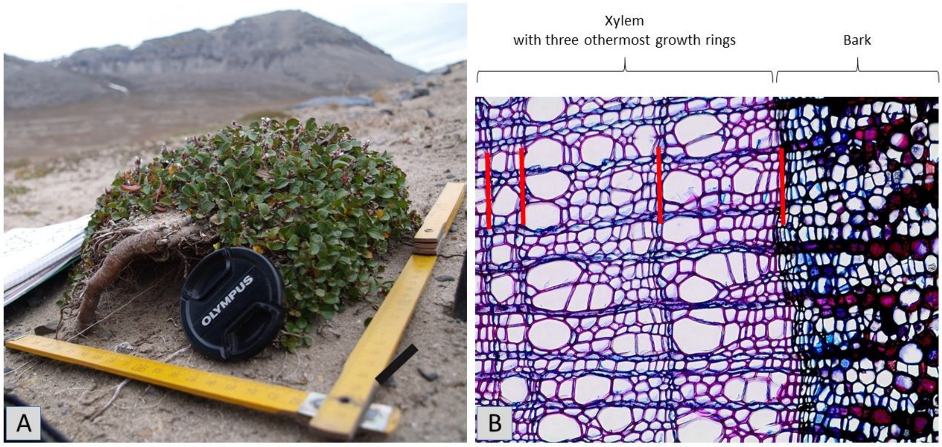

Fig. 1. 50-years old *Salix polaris* Wahlenb. shrub from (Ebbadalen, vicininity of Petuniabukta, central Spitsbergen) with a main root exposed due to an intense wash-out and wind erosion (**A**); cross-sectional view of three regular annual growth rings of the main root of *Salix polaris* with well-developed vessels and fibers visible on the thin-section; ring boundaries marked with red line (**B**).

Climate conditions of the study area are characterized by high continentality (Przybylak et al. 2014). Recent studies from the study area revealed that snow cover usually last from October to mid-June (Láska et al. 2012), whereas a permafrost thaw exceed 1 m thickness in late July (Rachlewicz et Szczuciński 2008).

To understand radial growth patterns in Arctic tundra shrubs an extended serial sectioning method was applied based on principals proposed by Kolishchuck (1990). Annual growth rings were investigated both within above-ground (*i.e.*, dominant branches) and below-ground plant parts, including main root and tap roots if available. From rather straight and not injured plant parts a sequence, *i.e.* in average more than 10 specimens were sectioned.

From each specimen a thin-section was prepared by using a sledge microtome. Each section was 15-30 μm thick and after cutting was stained with a mixture of Astra Blue and Safraning to highlight unlignified and lignified anatomical structures. A detailed instruction of micro-sections preparations followed the methods presented by Schwiengruber et Poschlod (2005).

In order to increase a confidence in annual date assignment ring-width measurements were conducted both within above-ground and below-ground shrub parts. Radial growth of *Salix polaris* was investigated in details tracing annual growth rings within whole cross-sections. Measurements of ring widths was performed along four radii using manual path analysis in WinCell (Regents Instruments). To precisely date the woody material into calendar years and to ensure a reliable chronology development cross-dating procedure is highly required (Fritts 1976, Schweingruber 1988, Cook et Kairiukstis 1990). A cross-dating procedure of *Salix polaris* dwarf shrubs was performed in three stages: i) cross-dating of four-radii tree-ring widths measurements within one cross-section and computing a mean growth series; ii) cross-dating between mean growth-series of all cross-sections taken from one individual shrub, including below-ground and above-ground parts and computing a mean growth-curve of a single shrub; iii) cross-dating between the mean growth-curves of each shrub and establishing a site chronology. Final tree-ring chronology was presented previously in Buchwal et al. (2013).

Results and Discussion

Annual ring structure of *Salix polaris* shrub is very distinguished with a ring boundary usually consisting of 1-2 rows of thick-walled fibers (Fig. 1B). However a tree-ring structure vary from ideally regular and complete rings (Fig. 1B) to irregular and erratic configuration completed with wedging rings (Fig. 2). Detailed serial sectioning studies on *Salix polaris* sampled from the Petuniabukta area indicated high intra- and inter-plant variability in its radial growth. It was specified that mean missing rings ratio per individual shrub was 24.8% (Buchwal et al. 2013). This amount included both completely missing rings, which were not visible in a whole cross-section and not detected either in some part of the plant or in a whole plant, as well partially missing rings (*i.e.* wedging rings) detected only in comparison between four-radii measurements within a single cross-section. The oldest part of the plant was always found below-ground, *i.e.* in the main root and up to 10 cm below the root collar. However the upper part of the root was representing the longest records, it was always associated with a numerous irregular rings formed as wedging or missing rings (Fig. 2) and detectable only by applying three steps in a cross-dating procedure. It has to be noted that all analyzed cross-sections were consisting of some wedging rings and a proper calendar dating of this woody material would not be possible without serial sectioning and cross-dating between tree-ring growth of different parts of the plant. Irregularity of growth ring formation was traced within both radial measurements of a single cross-section and between the adjacent cross-sections. This step ensured confidence in complete detection of growth rings and shrub dendrochronological dating.

A comparison of raw ring-width measurements taken at a different root depth and above-ground shoots length revealed high incompatibility (Fig. 3). This was true while considering each shrub and its above-ground and below-ground cross-sectional measurements of growth rings. Moreover measurements of growth rings between two consecutive cross-sections taken at a short distance (*i.e.*, 3 cm apart) along a main root axis revealed high discrepancies in annual ring formation along the main root axis (Fig. 2). Missing rings and wedging rings were very common and occurred alternated, making a successful cross-dating very challenging. Annual ring boundaries were often hard to distinguished and in some parts were overlapping with the following year ring boundary. Therefore a comparison between growth patterns of different parts of the plant (Fig. 2 and 3) revealed a crucial need for intra-plant cross-dating.

Annual growth constraints (*i.e.*, missing and wedging rings) result of cambial activity failure and were often reported in previous shrub dendrochronological studies (*e.g.*, Polunin 1955, Beschel et Webb 1963, Bär et al. 2006, Wilmking et al. 2012). Due to low replication of long, *i.e.* old growth series of tundra shrubs these constraints need to be taken into account in respect of possible ring-width chronology underestimation.

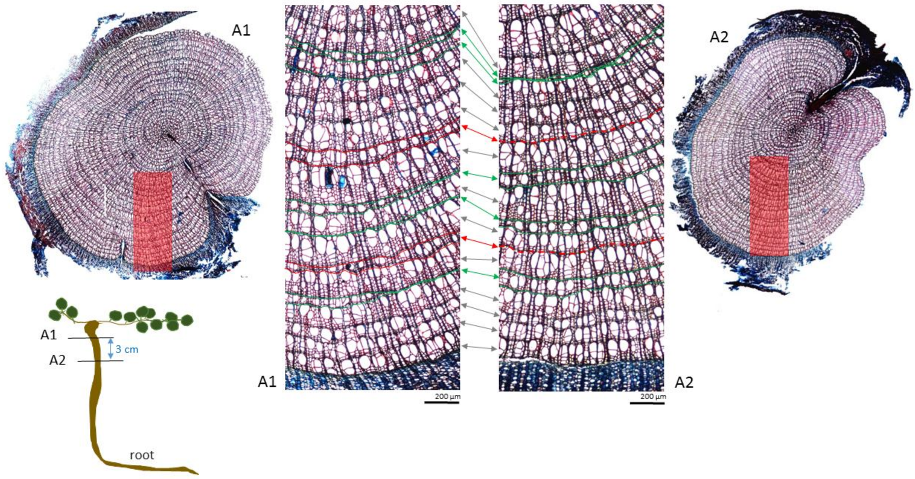

Fig. 2. Comparison of annual growth rings of one individual *Salix polaris* shrub from central Spitsbergen, Ebbadalen. Two consecutive main root cross-sections are compared: (A1) upper part and (A2) lower part of the root. A sequence of regular rings (grey arrows) and wedging rings (green lines and arrows) and missing rings (red lines and arrows) are marked on the enlarged parts of the sections. Cross-section A1 was cut 1 cm below the root collar.

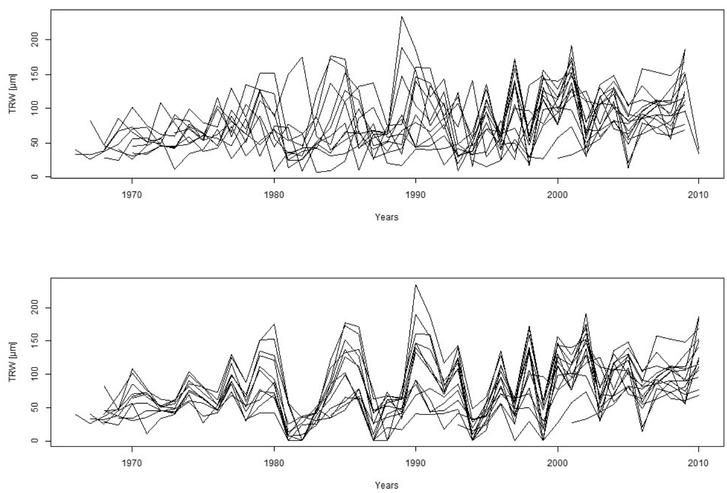

Fig. 3. Comparison of (A) raw and (B) cross-dated ring-widths measurements from 18 cross-sections taken from one *Salix polaris* shrub from Ebbadalen, central Spitsbergen. Each curve represents a mean of four-radii ring-widths measurements per cross-section. The longest series represent main root annual growth.

Summary

The study revealed that although *Salix polaris* shrub from central Spitsbergen presents a high potential for dendrochronological studies its radial growth pattern was found to be very irregular and asynchronous making ring-widths measurements very challenging. Missing and partially missing rings occurred alternately and were hardly possible to detect along a single radius growth rings measurements. Only cross-dating of raw growth-series measured along four radii within a single cross-section acted as a crucial step for wedging rings detection. These are often omitted in a one-radius measurements and are fundamental for a reliable cross-dating of growth-series within a single shrub. Whereas a cross-dating between all cross-sections from one shrub and between the shrubs enabled detection of missing rings. Both steps of cross-dating revealed an obligation of serial sectioning and its application in reliable dendrochronological dating of *Salix polaris* dwarf shrub from a High Arctic.

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