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Original article

Straight lines or eccentric eggs? A comparison of radial and spatial ring width measurements and its implications for climate transfer functions

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ABSTRACT

Shrub dendrochronological investigations are recently gaining more and more importance within the dendro-scientific community. As being a rather young discipline, many means of shrub dendrochronology lean on established methods that have been developed for trees. Although shrubs as trees are woody plants, it seems likely that they express differing growth characteristics due to their often multi-stemmed and prostrate stature. Yet, the majority of shrub dendrochronological investigations have measured shrub ring widths along two radii within one (sometimes several) stem disk(s) per individual. To our knowledge only one study so far has undertaken the approach to measure complete area increments (e.g. basal area increments, if applied to the basal stem disk of a shrub), however not focusing in detail on a comparative evaluation of this new approach with respect to radial measurements. To fill this knowledge gap our study focuses on the comparison of stem disk area increment measurements with radial measurements in the context of shrub growth representation and response- and transfer-function analyses. Our results indicate that for eccentric shrubs a minimum of four radial measurements per stem disk should be obtained for a good representation of the average stem disk growth. Inter-stem-disk comparisons showed that growth differences between individuals were often misestimated when only based on one or two radial measurements per stem disk. Response- and transfer-function analyses suggested, that the investigated shrubs reflect different environmental signals within different sectors of stem discs. This implies to carefully select radial measurements and individuals to increase the strength of environmental signals within transfer functions.

Introduction

In the recent decade, the number of shrub dendrochronological investigations has increased rapidly (e.g. Schweingruber and Poschlod, 2005; Baer et al., 2008; Hallinger et al., 2010; Weijers et al., 2010; Hallinger and Wilmking, 2011; Myers-Smith et al., 2011; Tape et al., 2012; Wilmking et al., 2012). One of the reasons for this is that shrubs may provide information on past environmental conditions in regions where trees are not growing due to environmental constraints (e.g. Arctic and Alpine Tundra, Deserts). Several investigations have shown that shrubs – as trees – are suited to reconstruct past environmental parameters, such as summer temperature (e.g. Baer et al., 2008; Hallinger et al., 2010; Weijers et al., 2010; Hallinger and Wilmking, 2011; Myers-Smith et al., 2011) and glacier summer mass balance (Buras et al., 2012).

Due to the rather recent establishment of shrub research, shrub dendrochronological analyses have leaned on methods that originate from tree dendrochronology. However, because of their different stature (in particular multi-stemmed, sometimes prostrate) it might be necessary to apply specific methods for the investigation of shrub growth. For instance, shrub samples are generally taken as stem discs instead of increment cores. Further, some authors suggest to sample several stem discs per stem (Kolishchuk, 1990) to allow for the determination of frequently observed missing outer rings in the lower parts of shrub stems under unfavorable environmental conditions (Wilmking et al., 2012). Another typical feature of shrubs is eccentric growth, often resulting in partly missing rings (also known as wedging rings). This eccentricity likely is the result of their multi-stemmed, often non-vertical but rather prostrate growth form. In contrast to the reaction wood that

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Fig. 1. Juniper (*Juniperus communis* ssp. *alpina*, left) stem disk showing lobed growth and sectorally differing eccentricity.

typically is observed for trees growing on slopes (Schweingruber, 1988) and expresses a rather elliptical shape (Visser, 1995), shrubs may express a combination of lobed growth and multisectoral eccentricity (Fig. 1). Due to these characteristics it seems meaningful to acquire more than the common two radial measurements. Yet, it remains uncertain how many radial measurements deliver a reliable representation of shrub growth.

In general, aging trees tend to exhibit narrower rings in the outer stem areas. Over the majority of a trees lifetime this decrease is mainly caused by a higher amount of wood production needed to acquire equal ring-widths with increasing stem diameters. One way to circumvent this effect is the calculation of basal area increments (BAI, e.g. Visser, 1995) as it better represents the wood production, thus growth. To calculate BAI one can use Eq. (1)

$$BAI_t^{t+1} = \pi(R_{t+1})^2 - \pi(R_t)^2 \quad (1)$$

where R is the radius of the stem at a given time (t; $t+1$).

However, if trees exhibit eccentric growth (e.g. reaction wood), this eccentricity has to be accounted for in the calculation of BAI. Visser (1995) therefore suggests measuring the radii along the respectively shortest and longest axes of the tree. For trees which express a two-directional eccentricity, this seems to be a reliable approach (Visser, 1995). However, this statement is based on two assumptions:

(I) the rings are elliptical in shape, and
(II) consecutive rings are congruent (Visser, 1995).

As can be seen from Figs. 1 and A1 (Appendix), neither of these two assumptions holds for the shown examples, which to our experience (DENDROGREIF laboratory, Greifswald, Germany) – based on juniper samples from five different locations in Northern Europe and Greenland – represent typically occurring anatomical features of old-grown junipers. It remains an open question how the effects of non-elliptical shapes and incongruence of consecutive rings affect the quality of radial measurements regarding their potential as growth proxies.

In 2006, Baer et al. (2006) started a first approach to elucidate these effects by directly measuring BAI of crowberry (*Empetrum hermaphroditum*) sampled in Norway. However, these authors did not in detail perform a comparative evaluation between that new approach and radial measurements. In our opinion they also did not choose the most suited statistics to compare radial and areal measurements, as they simply z-standardized their measurements for comparison instead of calculating an ideal ring-width-series that would directly represent the areal measurements (but see ‘Extracting ring-width-series from raster files’). Finally, they came to the conclusion that the error of radial measurements in comparison to areal measurements was negligible (but see Baer et al. (2006) and ‘Representation of rws_∞ by rwsM’ for further details). However, Gričar et al. (2006) showed by artificial experiments that cambial activity of trees differed in relation to temperatures to which the tissue was exposed. In their study the authors could not find significant differences regarding ring-widths of treated and non-treated tissue. Nevertheless it seems possible that sectorally differing environmental conditions result in differing ring-widths over the different sectors of stems if these differences prevail over one complete or several seasons (but see ‘Environmental signals’ for a detailed discussion). It has been shown by Körner (2003) that shrubs growing in alpine or arctic environments experience strong temperature gradients within the plant. As a consequence this may result in sectorally different growth as well as differing strengths of environmental signals. By this it theoretically seems possible that different environmental signals are recorded in the differing growth signals. Based on this it seems necessary to further investigate on the causes and analytical effects of eccentric rings in woody plants.

Another problem that arises from eccentric growth and dendrochronological analyses is comparison between individuals. Theoretically it is possible to find significantly differing growth of two individuals despite comparable growth rates, if for instance the widest and respectively narrowest rings along each one radius were measured for the two specimens. Including further radial measurements will diminish the difference between the two specimens. Yet, the number of radial measurements needed to represent their equal growth will depend on eccentricity, the question is how many radial measurements account for a given eccentricity.

Based on these open research questions, it seems necessary to further elucidate the relationship between ring width measurements (RWM) and BAI of shrubs. Therefore, this study focuses on the relationship between RWM and stem disk area increments (SDAI as not only measured for the basal stem disk but several stem discs along the shrub stems) and addresses the following questions:

- Q1: How many radial measurements are needed for reliable estimates on SDAI and thus for reliable inter-individual comparisons (reliable assumed as correlation between average RWM and SDAI above 0.95 and glk above 0.9)?
- Q2: Are specific RWM combinations better suited to represent SDAI in comparison to others?
- Q3: Does the strength of environmental signals differ over RWM within stem discs?
- Q4: Is it possible to detect different environmental signals in different sectors of stem discs?
- Q5: Is the strength of an environmental signal higher in SDAI or RWM?
- Q6: Is there a particular combination of RWM that delivers a stronger environmental signal?

These research questions shall accompany the reader throughout the manuscript and will be referred to in the corresponding sections. For a general overview on the methodological treatment as well as the results, we refer to the Appendix Tables A1 and A2.