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ORIGINAL ARTICLE

Degraded temperature sensitivity of a stone pine chronology explained by dendrochemical evidences

Zoltán Kern[a,*], Ionel Popa[b], Zsolt Varga[c], Éva Széles[c]

[a]Institute for Geochemical Research, Hungarian Academy of Sciences, Budaörsi út 45, H-1112, Budapest, Hungary
[b]Experiment Station for Spruce Silviculture, Forest Research and Management Institute, Calea Bucovinei 73 bis, 725100, Cimpulung Moldovenesc, Romania
[c]Institute of Isotopes, Hungarian Academy of Sciences, Konkoly-Thege M. út 29-33. H-1121, Budapest, Hungary

Abstract

Fluctuations in sulphur (S) content in tree rings were analysed for a 93 years long period (1915–2007) by laser ablation system coupled to an inductively coupled plasma mass spectrometer from three Swiss stone pine (*Pinus cembra* L.) trees grown in the Rachitis Cirque, Calimani Mts, Eastern Carpathians. Investigated domain envelops the period of degraded climatic sensitivity of pines' growth. Chemical data were standardized for sapwood and heartwood separately. The averaged sulphur record calculated from the three individual records unequivocally presents anomalously high S content for the tree rings dated to 1970s and 1980s. Ring-width fluctuation portrays changes of summer temperature but from 1966 to 1986 pines produced apparently larger rings than the corresponding summer temperatures can explain. This deviating interval coincides with the period of exploitation in the nearby sulphur mine. The elevated S content in tree rings refers probably to the dispersion of S-rich dust around the mine owing to the opencast type of exploitation. The divergent growth trend and degraded climatic signal likely due to the anthropogenic altered nutritional status of the site, as residues from nitrogen fertilizer, applied as a compound of explosive in the opencast sulphur exploitation, could be deposited on the surrounding forest.

Keywords: *Pinus cembra* L.; Climate signal; "Divergence problem"; Dendrochemistry; Anthropogenic fertilization

Introduction

Increasing number of dendroclimatological investigation had reported worldwide since the late 1990s about decreasing climate sensitivity of tree-ring chronologies and divergent growth trend for the recent decades. This phenomenon strongly biases large-scale tree ring based temperature reconstructions (D'Arrigo et al., 2006, 2008). There is no uniform explanation for this phenomenon.

Potential explanations are changed sensitivity (Wilmking et al., 2005; Büntgen et al., 2006); changed seasonality (Vaganov et al., 1999); enhanced UV-B radiation (Briffa et al., 1998, 2004); environmental pollution (Wilson and Elling, 2004) but mostly no clear explanation has been found (Smith et al., 1999; Brázdil et al., 2002; Buckley et al., 2004; Wilmking and Myers-Smith, 2008). To assess and understand the nature of changing growth–climate relationships is important due to many reasons for instances, (i) to see if a shifted sensitivity is behind the recent decline (e.g., June temperature vs. July temperature); (ii) a substantial change is in progress in main growth regulator climatic factors (e.g., temperature sensitivity vs. drought

*Corresponding author. Tel.: +0036 1 3092600x1106; fax: +0036 1 3193137.
E-mail address: kern@geochem.hu (Z. Kern).

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sensitivity) or (iii) we are facing with a general tree-growth/climate decoupling (e.g., increasing tropospheric ozone affects photosynthesis apparatus all around the world).

In addition, there is strong pressure from a paleoclimatological viewpoint that new temperature sensitive proxies are needed to develop to derive independent large-scale temperature reconstructions but their stable climatic sensitivity needs to explore and verify on local/regional scale (Büntgen et al., 2008; Wilson et al., 2007).

The first millennium long Carpathian tree-ring chronology was developed recently from the Calimani Mts (Popa and Kern, 2009). The ring-width fluctuation portrays changes of summer temperature over the major part of the 20th century but the chronology presents significantly larger rings from 1966 to 1986 than corresponding summer temperatures can explain. This bidecadal deviation significantly biased the verification of the temperature reconstruction.

Another fact giving additional interesting aspect to the degraded climatic sensitivity of the Calimani's stone pine ring-width chronology is that in the Alps particular stone pine stands were determined to suffer some weakening/alteration in temperature signal in their ring-width fluctuation since late-20th century (Oberhuber et al., 2008) whereas other stands were proved to carry stable temperature signal (Büntgen et al., 2005).

The aims of present work are searching for experimental evidence by dendrochemical analysis to determine the cause of the degraded growth–climate relationship of pines and develop strategy to save and improve the ability of the longest Carpathian tree-ring chronology for climate reconstruction.

Materials and methods

Site description

Study site is located in the Calimani Mts, northern part of the Eastern Carpathians (Fig. 1). Timberline (~1750 m a.s.l.) is characterized by Norway spruce (*Picea abies* (L.) Karst) and Swiss stone pine (*Pinus cembra* L.). The pine forests of the Eastern Carpathians are at the eastern boundary of the European distribution area of stone pine. Largest stand of the region grows in the Calimani Mts, at the northern slopes of Rachitis Peak and Pietricelu Peak (Höhn, 2001) smaller but significant stone pine populations grow in the Rodna Mts (Lala Valley near Ineu Peak and Zanoga Cirque near Pietrosul Peak) (Fig. 1). The Calimani site is situated in the vicinity of the largest opencast mine of the Eastern Carpathians, exploited material was sulphur. The mining activity had started in the Negoiu Romanesc region from 1965 and exploitation have taken higher proportions since 1970 (Brâdus and Cristea, 2004). Reliable quantitative data are not available about the annual product rates, but sparse and dominantly qualitative descriptions report that sulphur exploitation became most intensive between 1974 and 1986. The average annual production abruptly decreased after 1986 due to the changes in economical circumstances. The mine was closed officially only in 1992, however, from practical point of view 1986 can be regarded as the end of mining activity.

Sampling for dendrochemistry

Three healthy stone pine specimens were selected for dendrochemical investigation from the Rachitis area at 28 November, 2007 (Table 1). Site elevation was *c.* 1550 m a.s.l. Sampling was carried out after winter dormancy had already started to prevent detection of any false signal due to the potential seasonal variations in trace element concentrations (Hagemeyer and Schäfer, 1995). Trees with pathogen activity or mechanical damage on their surface were avoided (Smith and Shortle, 1996).

One core was extracted from each tree by increment borer on the mine-facing side of the bole to maximize the potential to detect the chemical signal related to mining activity (Watmough, 1999). A part of the bark was peeled by a stainless steel knife to prevent the supra contamination of the wood by accumulated airborne dust from bark surface (Schulz et al., 1999). Samples were packed in plastic tubes and were stored in frozen temperature until analysis to protect samples from fungal activity (Smith and Shortle, 1996) and prevent sap migration (Pearson et al., 2006).

Samples were sectioned into 2 cm long subsamples and their surface was trimmed, perpendicular to fibres, by hand-operated teflon-coated razor blade.

Sapwood/heartwood boundary was recorded due to its important physiological divisional role (Smith and Shortle, 1996), on the one hand it was demarcated by visual inspection after thawing when sap was still humid; on the other hand it was further confirmed on the basis of colour difference between sapwood and heartwood in dried samples.

First chemical analyses were achieved (see below) then LINTAB digital positioning table and TSAPWin 0.55 software were used for measuring the annual ring widths with a precision of 0.01 mm (Rinn, 2005), as well as for cross-dating the growth series by graphical comparison against the local stone pine master chronology (Popa and Kern, 2009). The results were checked for missing ring and dating error using the COFECHA software (Holmes, 1983; Grissino-Mayer, 1997).