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Radial growth response of coniferous forest trees in an inner Alpine environment to heat-wave in 2003

Petra Pichler, Walter Oberhuber *

Institute of Botany, Leopold-Franzens-University of Innsbruck, Sternwartestrasse 15, A-6020 Innsbruck, Austria

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Abstract

The record-breaking heat-wave in summer 2003 was expected to have a strong impact on tree growth, especially where trees occur at their ecological limits. We studied radial growth response of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abie*s (L.) Karst.) exposed to dry inner Alpine climate (Tyrol, Austria) to extreme hot and dry conditions in 2003. Tree ring chronologies from two stands comprising different social status, i.e. dominant, co-dominant and suppressed trees, on a south- and north-facing slope, which represent xeric and dry-mesic site conditions, respectively, were analysed. Growth–climate relationships were explored using response function analysis and Pearson correlation coefficients. Major findings of our study were: (i) radial growth in 2003 was strongest reduced in suppressed *P. sylvestris* growing on a xeric site and in dominant *Picea abies* growing on the dry-mesic site, (ii) median reductions in annual increments reached 35% compared to previous years (1998–2002) and were caused by early stop of cambial activity as indicated by pronounced decrease in latewood width and (iii) April through June precipitation was the environmental factor most strongly associated with growth of both species. Ring width of *P. sylvestris* and *Picea abies* was additionally limited by hot late spring and hot late spring/summer months, respectively. The minor impact of the 2003 summer heat-wave on growth of drought exposed forest trees might find its explanation in strong dependency of radial stem growth on precipitation during late spring and preconditioning of tree vigor in previous years. Results demonstrate that impact of climate extremes on radial tree growth can vary within site and canopy position and strongly depend on species-specific response to climate factors.

Keywords: Extreme climate; Summer heat-wave; Inner Alpine; Radial growth; Tree rings

1. Introduction

Extreme weather events have become more frequent in Europe during the last decades (Klein Tank and Können, 2003) and the year 2003 was an extraordinary year. Central European mean summer temperatures exceeded the 1961–1990 mean by *ca*. 3 °C (Beniston, 2004; Luterbacher et al., 2004; Schär et al., 2004). In the Eastern Alps no comparably hot and dry summer period was measured during the last 200 years, when climate data have been consistently recorded (Böhm et al., 2001) and it was probably the hottest summer in Europe since at least AD 1500 (Pfister et al., 1999).

Ecological relationships between tree species, climate, site conditions and biotic factors are frequently performed by analysing annual growth increments (Fritts and Swetnam, 1989; Dean et al., 1996). Especially at the boundary of tree existence, e.g. at the Alpine and drought-caused timberlines, radial growth of trees is sensitive to year-to-year climate variation (Fritts, 1976). Several authors found that within dry inner Alpine valleys periods of extensive drought limit radial growth and influence mortality of Scots pine (*Pinus sylvestris*) stands (Kienast et al., 1987; Oberhuber et al., 1998; Oberhuber, 2001; Rigling et al., 2002; Jolly et al., 2005; Bigler et al., 2006). Radial growth indices are known to be valuable long-term measures of overall tree vigor and are frequently used in modelling mortality processes of trees (e.g. LeBlanc, 1990, 1992; Pedersen, 1998a; Bigler and Bugmann, 2003; Dobbertin, 2005), which play a key role in predicting forest decline during climate change (Loehle and LeBlanc, 1996).

The most significant long-term effect of climate change on forest ecosystems is suggested to be changes in disturbance regimes, like the duration and frequency of drought events (e.g. Overpeck et al., 1990; Ayres and Lombardero, 2000; Hanson and Weltzin, 2000). The 2003 summer heat-wave and drought

* Corresponding author. Tel.: +43 512 507 5948; fax: +43 512 507 2715.
E-mail address: Walter.Oberhuber@uibk.ac.at (W. Oberhuber).

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may serve as an example of what may become a more common disturbance event resulting from global warming (Beniston and Diaz, 2004; Schär et al., 2004). Therefore, assessing susceptibility and response of *P. sylvestris*, which forms widespread forest ecosystems within inner Alpine dry valleys of the Alps, to future climatic stresses is urgently needed (Beniston and Innes, 1998). Drought is known to have a large influence on forest health and to be one of the most important factors triggering both temporary declines and the mortality of susceptible species in temperate forests (Innes, 1994; Jenkins and Pallardy, 1995; Villalba and Veblen, 1998; Ogle et al., 2000; Adams and Kolb, 2005; Dobbertin et al., 2005). Rebetez and Dobbertin (2004) reported that in the Swiss Rhône valley drought periods associated with climate warming may be responsible of increased mortality of *P. sylvestris* during recent decades.

Tree growth response to climate should be most obvious under limiting ecological site conditions (Fritts et al., 1965). A natural experiment approach was used to study how drought exposed stands within an inner Alpine dry valley, dominated by *P. sylvestris* and Norway spruce (*Picea abies*), responded to the exceptional heat-wave that Europe experienced in 2003. We are aware of no studies which have examined radial growth responses to drought of trees of different social status, i.e. crown classes, in a closed-canopy *P. sylvestris* forests. Therefore, this study was designed (i) to assess the impact of summer heat-wave in 2003 on radial growth of tree species, which are widely distributed on lower slopes of inner Alpine dry valleys and (ii) to determine how extreme climate conditions affect radial growth of trees belonging to different canopy positions on a xeric and dry-mesic south- and north-facing slope, respectively.

2. Materials and methods

2.1. Study area

The study site (for the geographical location see Oberhuber et al., 1998) is part of a postglacial rock-slide area situated in the montane belt (*ca*. 750 m a.s.l.) within the inner Alpine dry valley of the Inn River (Tyrol, Austria; 47°14′00″N, 10°50′20″E) and has a relatively continental climate with mean annual precipitation and temperature of 716 mm and 7.3 °C, respectively (long-term mean during 1911–2004 at Ötz, 812 m a.s.l., 5 km from the study area). The widespread plant community in the study area is a Spring Heath-Pine wood (*Erico-Pinetum typicum*; Ellenberg, 1988), whereby stunted growth forms of Scots pine (*P. sylvestris* L.) dominate the tree-layer. On the steep south-facing slope pioneer vegetation prevails in the ground flora, whereas crowberry (*Vaccinium vitis-idaea* L.) and a thick moss layer dominate the understory at the north-facing slope, which indicates slightly moist conditions at the latter site. A more favourable water budget at the north-facing plot is also indicated by invasion of stunted Norway spruce trees (*Picea abies* (L.) Karst.). Human impact in this area was generally restricted to sporadic gathering of firewood and livestock grazing.

The study site has shallow soils, predominantly of protorendzina type, i.e. rendzic and lithic leptosols according to the FAO classification system (FAO, 1998) and consists of unconsolidated, coarse-textured materials with low water holding capacity. Distinct soil horizons are hardly ever developed and are restricted to small-scale areas within deep hollows. Soil depths at selected south- and north-facing slopes reach *ca*. 5 and up to 15 cm, respectively.

2.2. Field collection, sample preparation, chronology development and statistics

Previously, it was reported that *P. sylvestris* stands within the study area respond quite differently to identical climatic conditions depending on the interaction of soil condition and topographic features on water availability (Oberhuber and Kofler, 2000). Therefore, within two stands facing south and north, trees of different diameter classes at breast height (>25 cm, 10–25 cm, <10 cm), which were assumed to belong to different social status (dominant, co-dominant and suppressed trees, respectively) were selected. This classification procedure proved suitable since it corresponded well with stratification based on the competition status of trees in the crown layer, i.e. tree height and mean radial growth, but was easier and more reliable to assess at steep slopes. *Picea abies* was scattered within the north-facing *P. sylvestris* stand, whereby number of samples (stem cores) was insufficient ($n < 5$) for the smallest diameter class (<10 cm), which therefore was omitted from the analysis. Stands growing on different aspects were located within less than 200 m in linear distance.

Within each stand and canopy position >10 trees free of major stem or crown anomalies were randomly selected and two core samples were extracted with an increment borer at 1.3 m from opposite sides of each tree and parallel to the contourline, mounted on a holder and the surface prepared with a sharp razor-blade (Pilcher, 1990). Ring widths and latewood widths were measured to the nearest 0.001 mm using an incremental measuring table. The earlywood–latewood transition within an annual ring is generally abrupt in *P. sylvestris.* However, gradual transitions occur in *Picea abies* making accurate determination of the boundary between earlywood and latewood cells more difficult (Schoch et al., 2004). The earlywood–latewood boundary was set as soon as the radial diameter of tracheids along the annual increment was ≤50% of the radial diameter of earlywood tracheids. Since the formation of latewood involves both, cessation of radial enlargement and cell wall thickening of tracheids, some transition latewood was qualified as true latewood (see Jagels and Telewski, 1990).

The dating of tree ring series was checked (i) again existing *P. sylvestris* and *Picea abies* chronologies from the study area (Oberhuber et al., 1998) and/or other locations within this inner Alpine dry valley (see Oberhuber and Kofler, 2002) and (ii) using COFECHA program (Holmes, 1994; Grissino-Mayer, 2001), which identifies segments within each ring series that may have erroneous crossdating or measurement errors. Due to occurrence of missing rings and/or individual growth