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Tree rings indicate different drought resistance of a native (*Abies alba* Mill.) and a nonnative (*Picea abies* (L.) Karst.) species co-occurring at a dry site in Southern Italy

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ABSTRACT

Climate changes induced by the anthropogenic alteration of the atmospheric radiative balance are expected to change the productivity and composition of forest ecosystems. In Europe, the Mediterranean is considered one of the most vulnerable regions according to climatic forecasts and simulations. However, although modifications in the inter-specific competition are envisaged, we still lack a clear understanding of the ability of the Mediterranean vegetation to adapt to climate changes. We investigated how two co-occurring tree species commonly used in afforestation programmes, the native *Abies alba* Mill. and the nonnative *Picea abies* L. Karst., adapt to climate change by assessing their growth performance and physiological responses in relation to past climate variability. Growth was addressed by analysing tree-ring width and carbon and oxygen stable isotopes. Statistical relationships between isotopic value and monthly climate data suggest that the two species underwent ecophysiological adaptation to Mediterranean climatic constraints. These adaptations are also expressed in the ring-width data. Based on the carbon isotope ratio reflecting the stomatal response to drought, we found that the precipitation in the first period of the growing season, i.e. early spring, is a major factor influencing the annual growth of *A. alba*, which although native, proved to be sensitive to drought. *P. abies*, on the other hand, showed a higher tolerance to summer drought stress. These findings should help define criteria for sustainability and effective forest conservation in the Mediterranean region.

1. Introduction

Mediterranean forests are particularly sensitive to climate changes (Scarascia-Mugnozza et al., 2000). Hence, forest management can play a key role in mediating the adaptation of vegetation and preventing ecosystem degradation in the Mediterranean region and has priority on the agenda of European forest policy. Natural regeneration is generally preferred in managing European forests, but in a changing environment it is important to identify the acclimatization and adaptation capability of each tree species to improve a forest ecosystem's resilience and productivity without reducing its complexity and the provision of goods and services. Climate change scenarios predict a likely increase in drought stress (with increased temperature and decreased precipitation) throughout Europe, with the Mediterranean region being particularly affected (IPCC, 2007). Already, the climatic trends in the Mediterranean basin during the last 50 years have been characterized by a rise in mean temperature (2–4 °C), and an increase in both the frequency and intensity of severe droughts (IPCC, 2001, 2007). In this context it is essential to study the abilities of plants at the species and individual levels to respond to climate change by modifying their wood anatomical and physiological response patterns (e.g., Baas, 1976; Gartner, 1995).

Tree-ring analysis offers a unique opportunity for understanding the response of trees to drought stress over decades, and over centuries and millennia. Trees in temperate and boreal forests (but not in the tropics) form a new wood growth layer every year (annual ring). The physical and chemical characteristics of the wood cells formed in each particular year reflect the environmental conditions in which the tree grew during that year, and can

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be used to reconstruct past environmental conditions (climatic conditions included). Moreover, the analysis of natural variation in stable isotopes in tree-ring wood offers a useful tool for such studies since physical, chemical and biological processes result in distinctive isotope fractionations and thus the external factors causing these isotope effects can be traced. The carbon isotope ratio in plant material has been successfully used to estimate the drought response and water use efficiency (WUE) of C_3 plants (Farquhar and Richards, 1984; Farquhar et al., 1989; Ehleringer and Dawson, 1992; Saurer et al., 1997a). In addition, the oxygen isotope ratio provides information on water source (Dawson, 1993), relative humidity (Roden and Ehleringer, 1999, 2000) and air temperature (Saurer et al., 1997b, 2000) since it is determined by (i) the soil water isotopic composition, (ii) evaporative enrichment at the leaf level, due to stomatal transpiration, and (iii) biochemical fractionation. A combined analysis of carbon and oxygen isotopes can be used to assess changes in photosynthesis and stomatal conductance (Scheidegger et al., 2000; Battipaglia et al., 2007; Voltas et al., 2008).

In this project we analysed *Abies alba* Mill., which is native to the southern Italian Apennines and *Picea abies* L. Karst., which is nonnative. The two tree species are often used in reforestation and, although it has been reported that the habitat of both species is quite comparable (Becker et al., 1995; Ausennac, 2002), the nonnative species may be invasive under water stress condition. We want to investigate the degree to which the two species show sensitivity in the radial growth in response to drought and to changes in seasonal distribution of precipitation. In particular, if a species is drought sensitive, it is expected that ring width and isotope variability is high, and correlation with climate should be stronger compared to a less-sensitive species (Schweingruber et al., 1990; Saurer et al., 1995). From an ecophysiological point of view, the shade tolerant *A. alba* species appears to be rather a more frost and drought sensitive species than *P. abies* which behaves as a pioneer species (Becker, 1970; Guehl, 1985; Berger and Herbert, 2000).

Thus, the aim of this study is to assess the climatic sensitivity of *A. alba* and *P. abies* and to predict these species ability to adapt to forecasted climate changes, in order to provide indications for future forest management in the Mediterranean region.

2. Materials and methods

2.1. Study site and meteorological data

The study was carried out in a forest plantation, which was established at the beginning of the 20th century. The forest is characterized by silver fir (*A. alba* Mill.) and Norway spruce (*P. abies* L. Karst.), on Mount Taburno, 1300 m a.s.l. (41°08′N, 14°35′E) located 40 km south-east of Naples, in Southern Italy. The Taburno geological substrate is limestone with a deep pyroclastic cover. The area has a typical Mediterranean climate with a pronounced summer drought period between June and August. We used temperature and precipitation data recorded at the Montesarchio weather station (460 m a.s.l., about 15 km from the study site) from 1950 to 2003. The average annual precipitation was approximately 1200 mm and the mean annual temperature 20 °C. Since the altitudinal difference between the study site and the meteorological station could affect the results, we compared all the annual data with another meteorological station, Montevergine, located at 1287 m a.s.l. around 50 km from the site but with similar geographic and climatic conditions. The recorded temperature and precipitation data were consistent between the two stations ($r = 0.83$; $P < 0.001$), with no significant differences, so that potential climatic data errors were not significant. Therefore we considered the climate data of the nearby weather station to be representative for our study site.

2.2. Sampling

In January 2003 four dominant *A. alba* trees and four dominant *P. abies* were sampled. Four has been shown to be a satisfactory number of replicates to develop a representative isotope site record (Leavitt and Long, 1984; McCarroll and Loader, 2004; Gagen et al., 2004; Treydte et al., 2001, 2006). Dominant individuals are preferred for dendrochronological analyses to reduce the influence of competition on growth ring width. Since these trees were growing in a plantation, we assume that trees, that are currently dominant, will have been always dominant during their life times, and therefore not significantly affected by competition. Trees were cored with increment borers 5.15 mm diameter. One full-diameter core, including two opposite radial cores, was taken at approximately 0.3 m above the ground to obtain as many growth rings as possible.

2.3. Ring-width measurement

The cores of each tree were mounted on a channelled wood, dried and sanded a few days later. Ring-widths were measured to the nearest 0.01 mm on each core, using LINTAB measurement equipment (Frank Rinn, Heidelberg, Germany) fitted with a Leica MS5 stereoscope and analysed with TSAP software package (Frank Rinn, Heidelberg, Germany). The program COFECHA was used to do a data quality control as well as to check for crossdating among the trees within available chronologies (Grissino-Mayer, 2001). For this study we used only the successfully crossdated cores, with a significant ($P \leq 0.05$) "*Gleichläufigkeit*". This is a statistical measure of the year to year agreement between the interval trends of the chronologies, based upon the sign of agreement (Kaennel and Schweingruber, 1995) and Student's *t*-test, which determines the degree of correlation between curves.

2.4. Isotopic analysis

After dating and ring-width measurement, the two cores per tree were used for isotopic analysis. Previous results (Lipp et al., 1991; Hill et al., 1995; Robertson et al., 1996; Switsur et al., 1996; Jäggi et al., 2003) suggest that early and latewood can have significantly different isotope abundances, and that latewood has the strongest signal related to the current year of formation. This is why only latewood of each year, carefully separated from earlywood, was used for the analyses. In some rings of the *P. abies* samples (≈10%), the early and latewood could not be separated because the ring was too small (<1 mm) and the two wood types were not distinguishable with the earlywood covering a small percentage of the total ring. In these cases the whole annual ring was used and we assume that the contribution of the earlywood to the isotope values is negligible.

All sampled trees were over 80–100 years old, but only rings formed after 1950 were analysed, which is likely to eliminate any influence of the "juvenile effect" observed in young trees (Freyer, 1979; Francey and Farquhar, 1982). Whole wood was milled, an aliquot of 100 mg was packed in porous bags and used for cellulose extraction according to a slightly modified version of the method described by Loader et al. (1997). In brief, the samples were washed in 5% NaOH solution twice for 2 h at 60 °C in order to remove fats, oils, resins and hemicellulose. In a second step the lignin was removed with $NaClO_2$ 7% for 36 h (Battipaglia et al., 2008). After each treatment the samples were washed with distilled water and then finally dried overnight at 60 °C.