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ORIGINAL ARTICLE

# Climate–growth relationships of silver fir (*Abies alba* Mill.) in marginal populations of Central Italy

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ABSTRACT

This study is part of a LIFE+ project on marginal mountain ecosystem conservation. In five mixed European beech-silver fir forests of Central Italy (Tuscany and Marches), classified as priority habitats of the Natura 2000 Network, we analysed the climate–growth relationships of silver fir (*Abies alba* Mill.) along an altitudinal gradient. The aims of this study were: (i) to identify the main spatial patterns in the frequency domain of both silver fir growth and climate variables in five different sites and (ii) to detect the overall climate sensitivity of the target species through time.

Multivariate analysis displayed groups of chronologies with similar growth patterns for each frequency band-pass, discriminating for altitude and geographical location. The spectral density of climate variables at seasonal scale displayed common spatial patterns during late-spring and summer months. In stands where fir grows in optimal conditions, the most significant growth responses to climate were the positive influence of late-spring and summer precipitations of the previous year and the negative effect of summer temperatures of both previous and current year, although decreasing during the last decades. On the other hand, the site at lowest altitude shows a low and not very consistent climate sensitivity as compared to the preferred altitudes. At the highest site (1375 m asl) the positive effect of previous year spring–summer precipitation and summer temperature of both previous and current year disappears.

Results suggest that in the studied areas a water-use increase in summer is a possible response of silver fir to the significant reduction of spring precipitation and general temperature increase throughout the 20th century.

These findings provide additional information on silver fir responses to climate variability at different altitudes, useful for calibrating silvicultural treatments to apply for conservation of sensitive ecosystems and of tree species in mountain areas.



## Introduction

Silver fir (*Abies alba* Mill.) is an indigenous tree species growing in many southern and central European mountain forests. In Italy Silver fir is widespread across the Alps and more scattered along the Apennines, due to post-glacial climate dynamics and anthropogenic pressure (Longauer et al., 2003).

Clustering techniques applied to an Italian tree-ring network displayed a geographical similarity between the northern Apennines and the eastern Alps silver fir populations (Carrer et al., 2010). This could be related to the similarity of both macroclimate features (Brunetti et al., 2006) and genetic structures between these two geographic areas compared to the central and southern Apennines ones (Parducci et al., 1996). Pollen and genetic analyses have sustained the existence of a post-glacial migration route from the northern and central Apennines northwards and a progressive isolation of the southern Calabrian populations in their glacial refuge, the southernmost post of its natural range (Longauer et al., 2003).

The species reduced adaptability due to insufficient genetic variation is assumed as the main predisposing factor making silver fir populations of central Apennines more sensitive to increasing drought. Populations at the margins of their species distribution area often feature a greater sensitivity of radial growth to climate variability (Fritts, 1976; Macias et al., 2006; Linares, 2011), and may respond better to environmental changes.

The climatic trends in the Mediterranean Basin during the last 50 years show an increase of mean temperature (2–4 °C), and of both frequency and intensity of severe droughts (IPCC, 2001; Xoplaki

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et al., 2006; García-Ruiz et al., 2011). A progressive trend analysis performed by Brunetti et al. (2006) showed that the most relevant trend differences at temporal scale are in summer, with 0.8 K per century in the last 50 years and 1.8 K per century in the last 30 years.

Increasing forest resilience to climate change and sustainable forest management are major challenges that forestry must face in order to preserve sensitive ecosystems such as tree species marginal populations in mountain areas. The recent abandonment of these areas, together with an exponential increase of conservation constraints and the aggressive behaviour of competitive species (e.g. *Fagus sylvatica* L.) have considerably reduced the high value of silver fir timber in the Apennines. On the other hand due to its high commercial relevance many silver fir stands, probably of the same provenance, were previously planted since the VI century even in not very suitable sites (Urbinati and Romano, 2012). The increased number of dieback events, probably caused by insufficient genetic diversity, could be interpreted as a lower adaptability of marginal populations to environmental stress.

Several studies have demonstrated the relevant climate sensitivity of silver fir especially with late spring and summer climate variables (Rolland et al., 1999; Manetti and Cutini, 2006; Büntgen et al., 2007; Carrer et al., 2010). Climate–growth responses of *A. alba* along altitudinal gradients have mainly identified water availability as a major tree growth limiting factor especially at low-elevation forests (Macias et al., 2006; Camarero et al., 2011; Pasho et al., 2012; van der Maaten-Theunissen et al., 2013).

A dendroecological approach seems appropriate to assess tree growth responses to contrasted environmental factors within the tree–climate–site complex at regional scales (Cook et al., 2001), highlighting the local interactions between site and climate conditions.

Climatic signals retained in tree-ring widths are typically related to the high frequencies variability (Strumia and Cherubini, 1997; Carrer and Urbinati, 2001; Pfeifer et al., 2005). Additional information correlated to low frequency variability may reveal a wider range of growth responses to climate and, in more detail, similarities or contrasting signals in growth patterns among different sites and forest stands.

Silver fir, especially in the Apennines, requires developed soils (loam–sandy) and form naturally mixed stands with *F. sylvatica* and other deciduous species (*Acer* spp.); pure stands are also present but they are usually plantations. Silver fir Apennines populations, when classified as "priority habitat" of the Natura 2000 Network of the European Union (9210* Apennine beech forests with *Taxus* and *Ilex* and 9220* Apennine beech forests with *A. alba*) require conservation and deeper knowledge especially on species adaptation to non-stationary environmental conditions. This study is part of the ongoing "Resilfor" Life+ Nature project (08NAT/IT/000371) set up for the conservation and restoration of native *A. alba* populations in beech forests of Central Italy. The aims of this study are: (i) to identify the main spatial patterns in the frequency domain of both silver fir growth and climate variables in five different sites and (ii) to detect the overall climate sensitivity of the target species through time.

## Materials and methods

### *Study sites and climate data*

We selected five mixed beech-fir mountain forests in Central Italy located at different altitudes between 770 and 1350 m a.s.l., all classified as a priority habitat in Sites of Community Interest (SCI) within the Natura 2000 Network. Three are in Tuscany: Verna (VRN, 1160 m a.s.l.), Camaldoli (CAM, 1120 m a.s.l.) and Pigelleto (PGL, 770 m a.s.l.) and two in the Marches: Fonte Abeti (FAB, 1000 m a.s.l.) and Colle Abete (CAB, 1350 m a.s.l.) (Fig. 1). CAM, FAB are mainly pure regular even-aged high forests, VRN is a stratified beech-maple-fir forest, PGL is an irregular mixed hardwood forest and CAB is a stored beech coppice in conversion to high forest, with silver fir in the intermediate or co-dominant layer (Table 1).

Due to the lack of representative meteorological stations in mountain areas or long-term dataset for several sites, we used records from the Climate Research Unit (CRU, University of East Anglia, UK) for maximum monthly temperature (Tmax) and total precipitation ($P$) in the period 1901–2009, gridded on a $0.5 \times 0.5$ degree network. The selected climate series, corresponding to the closest grid point to the five areas in which the silver fir stands are located, were subjected to homogeneity tests and adjustments and taken from the Royal Netherlands Meteorological Institute (http://climexp.knmi.nl/) (van Oldenborgh and Burgers, 2005). Since VRN and CAM sites are very close one to another were included in the same climate grid point (Casentino – CAS). To assess the presence of climatic trends, we applied the Mann–Kendall non-parametric test (Brunetti et al., 2006).

### *Dendrochronological analysis*

At each site, two cores per tree were extracted with a 5-mm diameter increment borer at breast height on the cross-sides of the trunk; only healthy dominant or co-dominant straight trees with a symmetric crown were selected. The increment cores were mounted on wooden supports, air dried, and sanded with progressively finer sandpaper (from 200P to 600P) to obtain a smooth cross-section, and ring width was measured from bark to pith with a precision of 0.01 mm. The raw tree-ring widths series were visually and statistically checked for measurement errors and cross-dated using both the dendrochronology program library in R (Bunn, 2010) and COFECHA computer program (Holmes, 1983). Five mean site chronologies were built from a total of 325 tree-ring series and 193 trees, then truncated at a minimum sample size of <5 series. To remove low-frequency variance, each tree-ring series was standardised with a double detrending procedure with software ARSTAN: a negative exponential curve to remove trends due to the increasing tree circumference and a spline function with a 50% frequency response (cut-off) of 10 years to emphasise higher inter-annual frequency variance (Cook and Peters, 1981). The first order serial autocorrelation (AC1) was used to detect the persistence retained after the standardisation. The indices were calculated as ratios between the actual and fitted values. The signal strength in the tree ring-series was tested using the expressed population signal (EPS), which is commonly adopted as a criterion for assessing the reliability of chronologies (Wigley et al., 1984).

### *Spatial variability in growth patterns*

Common growth patterns were explored with a principal components analysis (PCA) to assess the shared variance for the time period covered by all the series. The PCA transformed the tree-ring indices into a new set of variables (PCs; principal components), calculated from the covariance matrix of the original data. Loadings plots of the weighting coefficients for the first two PCs were used to display the clustering of chronologies with similar growth patterns.

Spatial variability in tree-ring widths was also investigated using a wavelet transform to perform a decomposition of tree-ring chronologies into a cascade of band-pass data series from 2 to $2^4$ years by means of a multi-resolution analysis for one-dimensional signals (Torrence and Compo, 1998; Bunn, 2008). The Bonferroni method was used to correct the significance levels for multiple