RECENT DEVELOPMENTS IN THE ANALYSIS OF AN ITALIAN TREE-RING NETWORK WITH EMPHASIS ON EUROPEAN BEECH (FAGUS SYLVATICA L.)

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ABSTRACT. We have developed 22 chronologies from standing trees of nine species at 19 sites distributed throughout the Italian Peninsula. The most represented species is Fagus sylvatica L., with 11 chronologies distributed over the entire peninsula and well correlated to one another. Tree-ring chronologies were computed as an average of detrended and prewhitened ring-width series. First and second-order autoregressive models were selected for prewhitening. The order of autoregressive models fitted to Fagus sylvatica series was higher when age of sampled trees was greater. Based on principal component analysis, residual chronologies of Fagus sylvatica could be separated among a northern, a central and a southern group. This indicates broad phytoclimatic regions distributed along a latitudinal gradient, which most likely corresponds to large-scale climatic variation over the Italian Peninsula. The climatic response of beech trees was investigated at two sites in the central Apennines. Bootstrapped response functions showed that summer precipitation was the prominent climatic signal.

INTRODUCTION

Tree-ring networks have been established not only in semiarid zones but also in humid, temperate and cold regions all over the world (Hughes et al. 1982; Jacoby and Hornbeck 1987; Schweingruber, Briffa and Jones 1991). In Italy, tree-ring chronologies exist for alpine and northern regions (Brugnoli and Gandolfo 1991; Beber 1990; Nola 1988; Schweingruber 1985), but until recently very few chronologies had been published for non-alpine regions (Santini and Martinelli 1991; Bräker and Schweingruber 1989; Serre-Bachet 1985). Over the last seven years we have slowly expanded the number of tree-ring chronologies for the Italian Peninsula, to the point of developing our own tree-ring network. The present paper is a first attempt at summarizing the large-scale spatial information contained in the network, while at the same time uncovering climate-tree growth relations at selected sites. Emphasis is placed on European beech (Fagus sylvatica L.) in the Central Apennines.

METHODS

Sampling sites were selected throughout the Italian Peninsula, between 39.5° and 46.5°N and between 7° and 16.5°E (Fig. 1). Site and tree selection, as well as field and laboratory procedures, have already been described (Biondi 1988, 1992, 1993; Biondi and Visani 1993). Briefly, sites were selected to obtain a wide representation of latitudes, elevations, and forest types, while at the same time maximizing the likelihood of finding old trees and stands in areas with minimal anthropogenic manipulation and maximum climatic sensitivity. Tree selection focused on single or grouped trees that showed the best combination of old age and trunk health. Most samples were extracted from standing trees using Swedish increment borers 40 to 75-cm long. A few samples were taken from downed trees, logs and snags, either with an increment borer or with a chainsaw. At the laboratory, samples were machine-sanded and hand-polished, visually crossdated with the help of a binocular microscope and then measured using a sliding stage micrometer interfaced with a personal computer (Stokes and Smiley 1968; Phipps 1985).

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It should be noted that the development of a tree-ring network is a linear process only in retrospective. For instance, site selection was limited by the timely arrival of collection permits and, within a certain chosen area, it was marginally influenced by the preferences of local managers and/or repre-

Figure 1. Map of collection sites (■ = with European beech; ● = without European beech). Three-letter site codes are the same as in Table 1 and as in Figs. 2 and 3. The enlarged area shows the location of PNA and BSA sites with respect to meteorological stations (★: PE = Pescasseroli, PC = Pescocostanzo, CA = Civitella Alfedena, B = Barrea, S = Scanno, F = Frattura).
sentatives of the funding agencies. Furthermore, Italian forests have been managed for centuries, and no sampled stand could be considered free of human influence, even though every attempt was made to sample trees located in areas not easily accessible or set aside for conservation purposes as parks and natural reserves. Given the exploratory nature of the study, a certain amount of flexibility was given to the site and tree selection criteria. For example, when it became evident that European beech was very widespread and long-lived, with sound wood and crossdatable rings, it was added to the target list at sites originally selected because of other species, e.g., Parco del Pollino, where the original target was *Pinus leucoderms*.

Numerical processing was devised to maximize the cross-correlation between chronologies. Both long-term trends and short-range autocorrelation were removed from measured ring-width series, and the resulting indices were averaged by year to compute the final chronology,

\[ \bar{\omega}_t = \frac{1}{n_t} \sum_{i=1}^{n} \phi_p(B) \left[ \ln (w_{it} + c) - y_{it} \right], \]

with \( \bar{\omega}_t \) = residual chronology value at year \( t \), \( \phi_p(B) \) = autoregressive operator of order \( p \) (Box and Jenkins 1976), \( w_{it} \) = ring width at year \( t \) in specimen \( i \), \( c \) = positive constant added to avoid taking the logarithm of zero, \( y_{it} \) = intrinsic growth trend at year \( t \) in specimen \( i \), estimated by a cubic smoothing spline with 50\% variance reduction at a 50-year frequency (Cook and Peters 1981), and \( n_t \) = number of specimens that include year \( t \) — in this study, \( n_t \geq 2 \) to minimize the likelihood of dating errors. The order \( p \) of fitted autoregressive models was chosen according to a combination of objective and subjective criteria, as explained in detail by Biondi and Swetnam (1987).

Principal component analysis was used to delineate groups of tree-ring chronologies as determined by their correlation structure (Jolliffe 1986). We calculated the principal components based on the correlation matrix between *Fagus sylvatica* L. tree-ring chronologies. The correlation matrix was preferred to the covariance matrix in order to weight all chronologies equally, regardless of their overall variability (Jolliffe 1986: Chap. 4). The number of components retained for graphical analysis was determined according to the eigenvalue trace or scree plot. We used the component loadings, which represent the correlation between each original variable and the principal component, to provide reasonable interpretations of the retained components and to display the pattern of association between chronologies.

Climatic data published by the Italian *Servizio Idrografico di Stato* were converted into electronic files and then analyzed graphically and numerically. Meteorological stations chosen for further analysis were to cover at least a 30-yr period, to be located above 1000-m elevation, and to show data homogeneity (Fritts 1976). Six stations were selected, three of which had temperature records (Biondi 1993). Missing values at each station were estimated using data at nearby stations. Results reported here were obtained using the Pescasseroli and Pescoostanzo stations. The product-moment coefficient of linear correlation (\( r \), Sokal and Rohlf 1981) was employed to evaluate relations between precipitation and temperature variables recorded at the two stations.

The relationship between tree growth and climate was investigated by means of response-function analysis (Fritts *et al.* 1971; Guiot 1990). Since tree-ring chronologies were not autocorrelated, identifiable climatic signals referred to a single growing period. A 12-month dendroclimatic window, going backwards from August of the current growth year to the previous September, was chosen to define explanatory variables — monthly total precipitation and mean temperature. Confidence intervals (C.I.) of response functions were computed using the bootstrap method (Efron and Tibshirani
Bootstrapped response functions are more conservative than “traditional” response functions (e.g. those shown in Fritts 1976) because confidence intervals are wider and fewer predictors are deemed significant. Cropper (1985) demonstrated that 95% C.I. of “traditional” response functions are truly 66% C.I., hence bootstrapping makes response functions more accurate and easier to interpret.

RESULTS

The Tree-Ring Network

The tree-ring network for the Italian Peninsula consists of 22 chronologies for 9 species at 19 sites (Table 1, Figs. 1 and 2). Seven conifer species account for 10 chronologies and two angiosperm species account for the remaining 12 chronologies. The most represented species is *Fagus sylvatica* L., with 11 chronologies distributed over the entire peninsula (Table 1, Figs. 1 and 2). Pine species are the second largest group, with 6 chronologies, also scattered from northern to southern Italy. Tree-ring chronologies at Parco d’Abruzzo, Parco del Circeo, San Rossore, Campolino and Parco del Pollino have already been described (Biondi 1988, 1993; Biondi and Visani 1993). Additional information on the dendrochronological database was provided by Biondi (1992). Some results presented in earlier papers are reported here for comparison and clarity.

### Table 1. Summary Information on Tree-ring Chronologies Developed to Date

<table>
<thead>
<tr>
<th>Site Name</th>
<th>ID*</th>
<th>Species</th>
<th>First–Last</th>
<th>$L_c$†</th>
<th>T‡</th>
<th>C§</th>
<th>p#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cansiglio</td>
<td>CAN</td>
<td><em>Fagus sylvatica</em></td>
<td>1886–1988</td>
<td>103</td>
<td>3–5</td>
<td>5–11</td>
<td>1</td>
</tr>
<tr>
<td>Mottarone</td>
<td>MOT</td>
<td><em>Fagus sylvatica</em></td>
<td>1943–1989</td>
<td>47</td>
<td>5–12</td>
<td>8–23</td>
<td>0</td>
</tr>
<tr>
<td>Monte Barro</td>
<td>MBA</td>
<td><em>Fagus sylvatica</em></td>
<td>1867–1988</td>
<td>122</td>
<td>4–12</td>
<td>5–25</td>
<td>1</td>
</tr>
<tr>
<td>Mercurago</td>
<td>MERa</td>
<td><em>Pinus sylvestris</em></td>
<td>1913–1988</td>
<td>76</td>
<td>3–7</td>
<td>5–13</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MERb</td>
<td><em>Quercus robur</em></td>
<td>1925–1988</td>
<td>64</td>
<td>2–4</td>
<td>3–8</td>
<td>1</td>
</tr>
<tr>
<td>Monte Nero</td>
<td>MNE</td>
<td><em>Abies alba</em></td>
<td>1839–1989</td>
<td>151</td>
<td>5–12</td>
<td>5–17</td>
<td>2</td>
</tr>
<tr>
<td>Ca’ del Lupo</td>
<td>CDL</td>
<td><em>Pinus sylvestris</em></td>
<td>1912–1989</td>
<td>78</td>
<td>3–16</td>
<td>5–32</td>
<td>2</td>
</tr>
<tr>
<td>Monte della Scoperta</td>
<td>MSC</td>
<td><em>Fagus sylvatica</em></td>
<td>1903–1989</td>
<td>87</td>
<td>4–8</td>
<td>5–17</td>
<td>0</td>
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<tr>
<td>Campolino</td>
<td>CAP</td>
<td><em>Picea excelsa</em></td>
<td>1858–1988</td>
<td>131</td>
<td>3–12</td>
<td>5–24</td>
<td>0</td>
</tr>
<tr>
<td>Monte Gerbonte</td>
<td>GER</td>
<td><em>Larix decidua</em></td>
<td>1737–1988</td>
<td>252</td>
<td>3–10</td>
<td>3–19</td>
<td>1</td>
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<tr>
<td>Testa d’Alpe</td>
<td>TDA</td>
<td><em>Abies alba</em></td>
<td>1915–1988</td>
<td>74</td>
<td>2–14</td>
<td>3–28</td>
<td>1</td>
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<tr>
<td>Badia Prataglia</td>
<td>BAD</td>
<td><em>Fagus sylvatica</em></td>
<td>1773–1988</td>
<td>216</td>
<td>2–13</td>
<td>3–25</td>
<td>1</td>
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<tr>
<td>San Rossore</td>
<td>SRO</td>
<td><em>Pinus pinea</em></td>
<td>1897–1988</td>
<td>92</td>
<td>3–7</td>
<td>5–13</td>
<td>1</td>
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<tr>
<td>Maiella</td>
<td>MAI</td>
<td><em>Fagus sylvatica</em></td>
<td>1849–1988</td>
<td>140</td>
<td>1–4</td>
<td>2–7</td>
<td>2</td>
</tr>
<tr>
<td>Bosco di S. Antonio</td>
<td>BSA</td>
<td><em>Fagus sylvatica</em></td>
<td>1785–1988</td>
<td>204</td>
<td>1–9</td>
<td>2–17</td>
<td>2</td>
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<tr>
<td>Foresta Umbra</td>
<td>FOU</td>
<td><em>Fagus sylvatica</em></td>
<td>1852–1988</td>
<td>137</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Parco d’Abruzzo</td>
<td>PNAa</td>
<td><em>Fagus sylvatica</em></td>
<td>1670–1988</td>
<td>319</td>
<td>3–22</td>
<td>5–41</td>
<td>2</td>
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<tr>
<td></td>
<td>PNAb</td>
<td><em>Pinus nigra</em></td>
<td>1760–1987</td>
<td>228</td>
<td>3–8</td>
<td>5–16</td>
<td>1</td>
</tr>
<tr>
<td>Parco del Circeo</td>
<td>PDC</td>
<td><em>Pinus pinea</em></td>
<td>1885–1988</td>
<td>104</td>
<td>4–9</td>
<td>5–18</td>
<td>2</td>
</tr>
<tr>
<td>Parco del Pollino</td>
<td>MPOa</td>
<td><em>Pinus leucodermis</em></td>
<td>1036–1988</td>
<td>953</td>
<td>1–21</td>
<td>2–39</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>MPOb</td>
<td><em>Fagus sylvatica</em></td>
<td>1824–1988</td>
<td>165</td>
<td>3–4</td>
<td>5–7</td>
<td>2</td>
</tr>
</tbody>
</table>

*Chronology IDs are the same as in Figs. 1–3.
†Chronology length, from the FIRST to the LAST year.
‡Number of trees included in the chronology.
§Number of cores included in the chronology.
#Order of the autoregressive model used to obtain the residual chronology.
Fig. 2. Time-series graphs of residual tree-ring chronologies. Chronology IDs are the same as in Table 1. A. The *Pinus leucodermis* chronology at Parco del Pollino (MPOa) begins shortly after AD 1000. B. Several chronologies cover the last two centuries.

Besides annually-dated chronologies, tree-ring analysis provides accurate estimates of plant longevity, which relates to the multisided questions concerning senescence and death among plants (Molisch 1938; Loehle 1988). In our network, the oldest living tree was a 963-yr-old palebark pine (*Pinus leucodermis* Ant.), sampled in July 1989 at Parco del Pollino. Individuals more than two centuries old were identified at 11 sites for eight species (Biondi 1992). They included a 535-yr-old Abruzzo pine (*Pinus nigra* var. *italica* Hoch.), a 501-yr-old sycamore maple (*Acer pseudoplatanus* L.), a 475-yr-old yew (*Taxus baccata* L.), a 417-yr-old European beech (*Fagus sylvatica* L.), a 309-yr-old silver fir (*Abies alba* Mill.) and a 287-yr-old European larch (*Larix decidua* Mill.). Such max-
imum ages underestimate species longevity, because increment cores were taken at least 1.0 m above germination level and most cores did not include the stem pith.

First and second-order autoregressive models were used to remove autocorrelation from detrended ring-width series (Table 1). The order \( p \) of selected autoregressive models for beech tree-ring series decreased from two to one to zero with decreasing age of beech trees. When most specimens were taken from trees older than 150 yr, such as at Valzario (VAL), Parco d’Abruzzo (PNAa), Bosco di Sant’Antonio (BSA), Maiella (MAI), Foresta Umbra (FOU) and Parco del Pollino (MPOb), the best model was a second-order autoregressive process (Table 1). This model always included a positive relationship with the previous year, but a negative relationship between values two years apart (Biondi 1993). At Monte Barro (MBA), Cansiglio (CAN) and Badia Prataglia (BAD), where very few trees exceeded 100–150 yr of age, the best model was a first-order autoregressive process (Table 1) with a positive parameter estimate. At Mottarone (MOT) and Monte della Scoperta (MSC), where most tree ages were less than 100 yr, no significant autocorrelation remained after removing the growth trend, hence \( p \) was equal to zero (Table 1). Further research is needed to rigorously test if cambial age affects autocorrelation of wood growth in Fagus sylvatica and possibly in other tree species.

The Fagus sylvatica chronologies showed the best agreement with one another (Biondi 1992). For the common interval 1943–1988, the first three principal components of the 11 residual series explained a cumulative 65\% of the total variance, and the corresponding eigenvalues were all greater than 1. The first principal component (PC1) explained 40\% of the total variation, and it essentially measured overall annual growth patterns of European beech over the Italian peninsula, because all component loadings had the same sign and similar absolute values (Fig. 3). The Mottarone (MOT) chronology was the only exception, having a much smaller (0.18) first component loading than the other chronologies (0.44–0.84). As pointed out by Biondi (1992), the Mottarone site did not correlate to any other site, presumably because sampled trees were young, fast growing, and scarcely sensitive to year-to-year climatic variability.

The second principal component (PC2, 15\% of the total variance), represented a north-south contrast, because sites south of 43°N had negative loadings (−0.14 to −0.53) whereas sites north of 43°N have positive loadings (0.19 to 0.59), except for Valzario (VAL; −0.04; Fig. 3). This north-south contrast implies that, after the overall common climatic signal has been accounted for, the main source of large-scale spatial variability lies along a latitudinal direction. The third component (PC3) contributed about 10\% of total variation, and it was highly related to the Valzario site (0.70, Fig. 3). It might also represent a contrast between groups of sites within the major north-south subdivision: to the north, Valzario (VAL), Monte Barro (MBA) and Mottarone (MOT) had signs opposite to Monte della Scoperta (MSC), Badia Prataglia (BAD) and Cansiglio (CAN), and, to the south, Parco del Pollino (MPOb), Parco d’Abruzzo (PNAa) and Bosco di Sant’Antonio (BSA) had signs opposite to Foresta Umbra (FOU) and Maiella (MAI).

The large-scale geographic information provided by the beech chronologies was clarified when the first three component loadings were plotted together (Fig. 3). By comparing site locations (Fig. 1) with the patterns shown by the first three principal components (Fig. 3), it was possible to identify a northern, a central and a southern group of chronologies. The northern group included the Valzario (VAL), Cansiglio (CAN), and Monte Barro (MBA) chronologies. The Mottarone (MOT) chronology was closer to this group than to any other group, but it remained essentially an outlier with a large amount of site-specific variation. The central group was formed primarily by the Badia Prataglia (BAD) and Monte della Scoperta (MSC) chronologies. The southern group was the most numerous (even though it could be subdivided into two or three groups based on PC3), with Parco d’Abruzzo...
Fig. 3. Principal component analysis of *Fagus sylvatica* chronologies for the common interval 1943–1988. The first three principal components (PC1, PC2, and PC3) accounted for 65% of the total variance in the data set. Chronology IDs are the same as in Table 1. The southern group (●), the central group (■), and the northern group (■■) of chronologies can be easily recognized.

(PNAa), Bosco di Sant’Antonio (BSA), Maiella (MAI), Foresta Umbra (FOU), and Parco del Pollino (MPOb, Fig. 3).

**Climatic Response of European Beech in the Central Apennines**

Climatic response of beech trees was investigated at two sites in the central Apennines. Results obtained for the first site, Parco d’Abruzzo (PNAa), have already been published (Biondi 1993), so they are only summarized here for comparison with our findings at the second site, Bosco di Sant’Antonio (BSA). BSA is a typical example of an old-growth forest range, locally called difesa, used in the past for livestock grazing and wood cutting; it was set aside for conservation purposes in 1953 (Bortolotti 1985). Despite their proximity (Fig.1), the BSA and PNA sites were physiographically separated by high mountain ranges and characterized by widely different features. Beech samples at Parco d’Abruzzo were scattered throughout several mountains, and selected trees belonged to old-growth forest ranges, naturally-seeded high forests and coppices converted to high forests. At Bosco di Sant’Antonio, site boundaries were well defined and site conditions were homogenous in terms of elevation, slope, exposure, forest dynamics and vegetation structure. Elevation of cored trees ranged ten times more at Parco d’Abruzzo (1290–1895 m) than at Bosco di Sant’Antonio (1320–1375 m); slope ranged from 0 to 53% at the former site, and from 0 to 20% at the latter one (Biondi 1992). Furthermore, because of its productive function and its proximity to the mountain village of Pescocostanzo, past human intervention at Bosco di Sant’Antonio was greater than at many locations sampled within Parco d’Abruzzo.
We quantified the climatic regime experienced by beech trees at Bosco di Sant’Antonio by means of the nearby Pescocostanzo station (Table 2, Fig. 4). Based on data from 1922 to 1985, climate is characterized by cold snowy winters and summer drought. Annual precipitation averages 988 mm and mean annual temperature averages 7.9°C. August is the driest month, and December the wettest. January is the coldest month and July the warmest. Even though snow may fall as early as October, snowpack accumulates mostly from December through March, and it melts by the end of May (Fig. 4). Month-to-month variation in total precipitation is high, and no significant correlation exists between total precipitation in any two consecutive months. Monthly mean temperature follows a more regular, bell-shaped pattern over the year (Fig. 4), and pairs of consecutive months are more correlated in the summer than in the winter.

<table>
<thead>
<tr>
<th>Station*</th>
<th>Variable</th>
<th>N†</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min.</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pescocostanzo (41.88°N, 14.07°E; 1395 m)</td>
<td>Mean Temperature (°C)</td>
<td>47</td>
<td>7.9</td>
<td>0.8</td>
<td>5.5</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>Mean Maximum Temperature (°C)</td>
<td>47</td>
<td>12.1</td>
<td>1.0</td>
<td>9.8</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Mean Minimum Temperature (°C)</td>
<td>47</td>
<td>3.7</td>
<td>1.2</td>
<td>-1.2</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Total Precipitation (mm)</td>
<td>56</td>
<td>988</td>
<td>224</td>
<td>505</td>
<td>1601</td>
</tr>
<tr>
<td></td>
<td>Snow Cover (Total No. of days)</td>
<td>45</td>
<td>76</td>
<td>31</td>
<td>12</td>
<td>138</td>
</tr>
<tr>
<td>Pescasseroli (41.80°N, 13.78°E; 1150 m)</td>
<td>Mean Temperature (°C)</td>
<td>43</td>
<td>7.8</td>
<td>0.9</td>
<td>5.5</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>Mean Maximum Temperature (°C)</td>
<td>42</td>
<td>13.8</td>
<td>1.1</td>
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<tr>
<td></td>
<td>Mean Minimum Temperature (°C)</td>
<td>42</td>
<td>1.8</td>
<td>1.0</td>
<td>-0.2</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Total Precipitation (mm)</td>
<td>54</td>
<td>1571</td>
<td>350</td>
<td>960</td>
<td>2430</td>
</tr>
<tr>
<td></td>
<td>Snow Cover (Total No. of days)</td>
<td>43</td>
<td>68</td>
<td>29</td>
<td>10</td>
<td>116</td>
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</tbody>
</table>

*Three-dimensional coordinates of each station are given in parentheses (Fig. 1). Climatic diagrams are plotted in Fig. 4 (Pescocostanzo) and Fig. 5 (Pescasseroli).
†Number of years available.

Precipitation and temperature regimes at Pescocostanzo can be described as Mediterranean mountain climate, and they are similar to the ones described for the Pescasseroli station at Parco d’Abruzzo (Table 2 and Fig. 5; Biondi 1993). However, Pescocostanzo is located in a high plain surrounded by mountains, i.e. in a cold air drainage where “temperature inversion” and “rain shadow” effects are common. For instance, Pescocostanzo is at a higher elevation than Pescasseroli, but it is much drier (Table 2), especially during the winter (Figs. 4 and 5). Precipitation is lower at Pescocostanzo than at Pescasseroli in every month except July. Snowfall is less abundant, but snow cover lasts longer at Pescocostanzo than at Pescasseroli (Table 2, Figs. 4 and 5) because of different temperature regimes. Pescocostanzo is colder than Pescasseroli from October to April, and is warmer from May to September (Figs. 4 and 5), hence the annual range of mean temperature is greater at Pescocostanzo. However, the difference between day and nighttime temperatures is smaller at Pescocostanzo than at Pescasseroli, as shown by the higher mean minimum temperature and lower mean maximum temperature in every month, as well as on a yearly basis (Table 2).

Coefficients of linear correlation (r) between climatic variables at Pescocostanzo and Pescasseroli were usually highly significant (p-value < 0.001). On an annual basis, total precipitation at the two stations was more correlated (r = 0.55) than mean temperature (r = 0.48). On a monthly basis, the opposite was often true, with the notable exception of July. Total precipitation at the two stations had r = 0.65–0.76 in May and from July to December, r = 0.44–0.56 in the other months. Mean temperature at the two stations had r = 0.71–0.84 from December to June, and r = 0.50–0.67 from August to November, but was not significantly correlated in July, with r = 0.28, p-value = 0.066. The July
Fig. 4. Climatic diagram for Pescocostanzo, the meteorological station next to Bosco di Sant'Antonio (BSA; Table 1, Fig. 1). Precipitation data are from 1922 to 1985, temperature data are from 1932 to 1985, and snow cover data are from 1935 to 1985. No observations were recorded in 1943–1946. Monthly values are plotted first by month and then by year; the overall mean value for each month is used as a reference line and each yearly value is plotted above or below this line to show the spread around the mean.

Fig. 5. Climatic diagram for Pescasseroli, the meteorological station within Parco Nazionale d'Abruzzo (PNA; Table 1, Fig. 1). Periods of data coverage coincide with those for Pescocostanzo (Fig. 4), although missing values occur at different times at the two stations (Table 2).
correlation coefficient was the smallest one for mean maximum temperature and for mean minimum temperature as well.

Response functions were easier to interpret when significance of predictors was evaluated by means of bootstrapped confidence intervals (Fig. 6; Biondi 1993). At Parco d’Abruzzo, annual growth of beech trees is directly related to July and December precipitation, and it is inversely related to April temperature. Presumably, July precipitation is critical to alleviate summer drought, while December snowfall and April temperature control accumulation and melting, respectively, of winter snowpack, and hence they control a large proportion of moisture supply during the growing season (Biondi 1993). At Bosco di Sant’Antonio summer rainfall is still critical to alleviate moisture stress during the warmest season, but June is much more important than July (Fig. 7) and the role of winter snowpack is not significant. As explained in previous paragraphs, these two neighboring sites are ecologically and climatologically different. In particular, July climate is uniquely dissimilar from the other months between the stations of Pescasseroli and Pescolostanzo, and snowpack accumulation and melting rates differ considerably at the two sites. However, additional studies are needed to formulate viable hypotheses on the underlying mechanisms that determine these differences in climate-tree growth relationships.

Fig. 6. Response functions between the Fagus sylvatica chronology at Parco d’Abruzzo (PNA) and monthly climatic variables at Pescasseroli for the 1950–1985 period. Climatic predictors are monthly total precipitation and mean temperature from the previous September (S) to the current August (A). A. Bootstrapped confidence intervals (B.C.I.) with true 95% probability highlight July (J) and possibly December (D) precipitation and April (A) temperature as prominent climatic signals; $R^2 = 0.58$. B. “Traditional” confidence intervals (C.I.) with nominal 95% probability, but true 66% probability; $R^2 = 0.65$. Several climatic predictors seem significant, and their interpretation is problematic.
CONCLUSION

The tree-ring network we have developed for the Italian Peninsula consists of 22 tree-ring chronologies at 19 sites. Despite the millennia-long human influence on Italian ecosystems, a total of 11 sites yielded individuals more than two centuries old for eight tree species. Information provided here and elsewhere (Biondi 1992; Biondi and Visani 1993) is most valuable to highlight species and pinpoint sites with the highest potential for future dendrochronological work in non-alpine Italian regions. At present, the variability among sites in terms of elevation, topography, substrate, soil, and vegetation types hinders detailed dendroecological interpretations.

*Fagus sylvatica* is the most promising species in terms of plant longevity, widespread distribution, crossdating quality and climatic sensitivity. Principal component analysis of beech tree-ring chronologies delineated a northern, a central and a southern group. These groups identify broad phytoclimatic regions distributed along a latitudinal gradient, which likely corresponds to large-scale climatic patterns across the Italian Peninsula. Bootstrapped response functions showed that summer precipitation was the prominent climatic signal at two sites in the central Apennines. Ongoing research efforts are aimed at disentangling the multivariate information embedded in annual rings of beech trees, and also at the exploitation of existing tree-ring chronologies for dendroclimatic reconstructions.

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**Fig. 7. A.** Response function between the *Fagus sylvatica* chronology at Bosco di Sant'Antonio (BSA) and monthly climatic variables at Pescolostanzo for the 1950–1985 period. Climatic predictors are monthly total precipitation and mean temperature from the previous September (S) to the current August (A). Bootstrapped confidence intervals (B.C.I.) highlight June (J) and possibly July (I) precipitation as the prevalent climatic signal; $R^2 = 0.56$.

**B.** Time-series graphs of the *Fagus sylvatica* chronology at Bosco di Sant’Antonio (—) and of the response function estimates (····) for the 1950–1985 period.
Proxy records of past environmental changes are not abundant in Southern Europe and the Mediterranean Basin, where dendrochronological studies may provide much needed scientific information (Meko 1985; Dutilleul and Till 1992; Serre-Bachet 1992). The new Italian network presented here is another mosaic stone needed to complete existing tree-ring databases, such as those developed by Schweingruber (1985) and Serre-Bachet (1992). Once combined with ongoing research efforts in other Mediterranean countries (e.g. Kuniholm and Striker 1987; Gutiérrez 1989; Creus et al. 1992; Guibal 1992; Biger and Liphschitz 1992), dendrochronology of Italian species will contribute significantly to our understanding of climate-tree growth relations in temperate environments.

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