IL NUOVO CIMENTO VOL. 23 C, N. 2 Marzo-Aprile 2000

Climate and site dependence of the annual growth of silver fir (*Abies alba* Mill.) in the Northern Apennines, Italy

D. GAMBETTI (1), G. LO VECCHIO (1), T. NANNI (1) and F. H. SCHWEINGRUBER (2)

(1) *Istituto FISBAT-CNR - via Gobetti 101, I-40129 Bologna, Italy*

(2) *Federal Institute for Forest, Snow and Landscape Research Birmensdorf - Switzerland*

(ricevuto il 22 Febbraio 1999; revisionato il 25 Ottobre 1999; approvato il 3 Febbraio 2000)

Summary. — We focused our study on the relationship between ring width formation of silver fir and the climatic factors. Therefore, we collected material on two sites of the Northern Apennines at different altitudes, slope and soil characteristics and compared tree ring width with meteorological data from a neighbouring station. The results are that the ring growth depends mainly on the winter mean temperature of the current year, the summer precipitation and the mean summer temperature of the preceding year. The influence of winter mean temperature is more pronounced at high altitudes. The mean summer temperature and summer precipitation had a stronger effect on the growth year at lower altitudes and on the following year at higher altitudes.

PACS 92.60.Ry – Climatology.

1. – Introduction

The existence of a relationship between climate and tree rings growth is widely known [1] and a lot of studies have been performed to define it all over the world for several kinds of trees. As concerns silver fir, a great deal of dendroclimatic calibration studies have been carried out in Europe [2-6] and in particular in Italy [7] over the last fifty years.

With regard to the Italian Apennines, studies on silver fir were performed from North to South.

In the North (Camaldoli and Vallombrosa), Ciampi [8] observed a strict relationship between temperature and cambial growth rhythms, Gindel [9] found that radial growth is related to June-August precipitation when trees are grown on steep slopes and shallow soil at southern exposure, Calistri [10] gave evidence of a positive relationship between radial growth and May-October precipitation when trees are grown on deep soil and flat ground, Corona [11] concluded that the fir radial growth is influenced by the rainfall in spring and by the maximum temperature in summer and the temperature of October has some influence as well as the rainfall of the preceding year, Lo Vecchio and Nanni [12] did not find clear results.

In the central Apennines (Bosco Abeti Soprani-Pescopennataro—IS) Romagnoli and Schirone [13] found a positive correlation between the ring width and June-August precipitation and a negative correlation between winter precipitation and summer maximum temperature.

In the Southern Apennines (Calabria-Serra San Bruno), Freni [14] and Santini and Martinelli [15] observed an inverse relationship between the tree-ring series and the mean maximal temperatures of May, June and July and a direct relationship with the rainfall of May, June and September.

Because no clear relationships have been found, we tried a new sampling strategy aimed at understanding: how silver fir responds to climate, if the climate-growth relationship is the same in different ecological conditions and if it is possible to interpret some extremely large or small tree rings.

2. – Material

2·1. *Site individuation and description.* – We cored dominant trees from natural stands, in Abetone (Sestaione valley, Pistoia) and Campigna (Bidente delle Celle valley, Forlì). The sampling sites are shown in fig. 1 and the specification are given in table I.

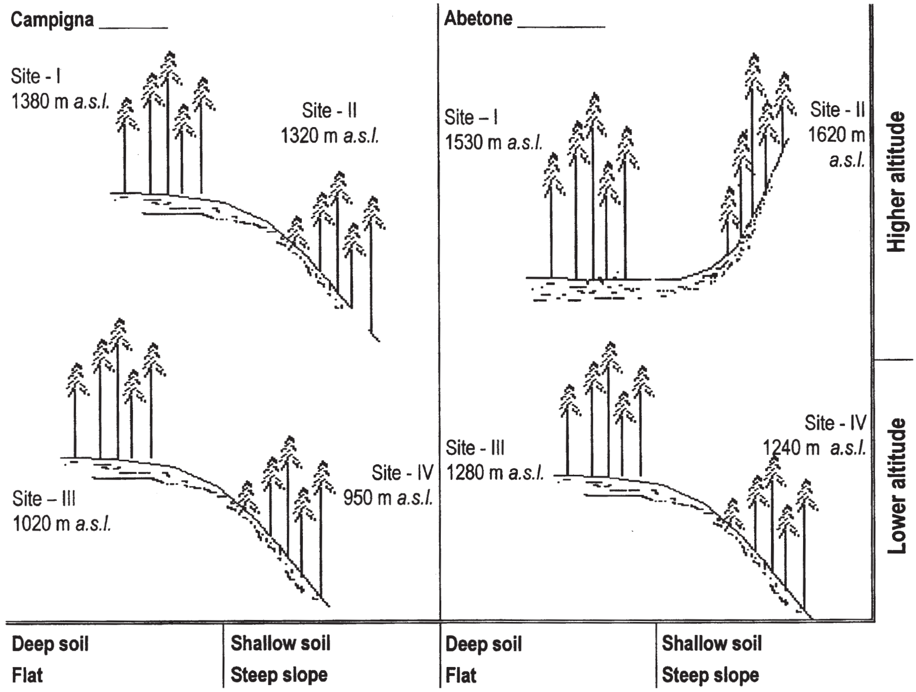


Fig. 1. – Ecological characterization of the sampling sites. Campigna I: a group of firs is embedded in a beech stand, on deep soil and flat ground; Campigna II: scattered firs form with beeches a widely spaced forest, on steep slope and shallow soil; Campigna III: like Campigna I; Campigna IV: like Campigna III but on steep slope and shallow soil. Abetone I: scattered firs are embedded in a beech stand, on deep soil—remarkable water keeping—and flat ground; Abetone II: firs in small groups form with beeches a thick forest, on steep slope and shallow soil; Abetone III: scattered firs in a beech forest and a group of great old firs in a beech coppice, on deep soil and flat ground ; Abetone IV: like Abetone II.

TABLE I. – *Sampling sites and meteo-stations.* (*Fosso*: ditch, small valley, couril; *Costa*: hillside, ridge).

Place	Stand	Toponym	Compartment	Altitude (m.s.l.)	Exp.	Slope
Abetone	Meteorological station: altit. 1340 m; lat. 44° 07′ N; long. 10° 09′ E (Green.)					
	I	Sestaione V. Fortezza	380-372	1530	E	0-5°
Geogr. Co-ord.	II	» »	380	1620	E-SE	40°
44° 07° 00″ N	III	» Fosso del Pianaccio	421-422	1280	E	15°
10° 09′ 00″ E	IV	» Fosso della Rena	416	1240	E	45°
Campigna	Meteorological station: altit. 1068 m; lat. 43° 53′ N; long. 11° 42′ E (Green.)					
	I	Bidente delle Celle V. Poggio Martino	9	1380	E-NE	18°
Geogr. Co-ord	II	» Costa Poggio Aggio Grosso	6	1320	SE	43°
43° 53′ 17″ N	III	» Fosso delle Capanne Vecchie	22	1020	NE	0-5°
11° 42′ 00″ E	IV	» » » »	21	950	W-NW	44°
Vallombrosa	Meteorological station: altit. 955 m; lat. 43° 43′ N; long. 11° 35′ E (Green.)					

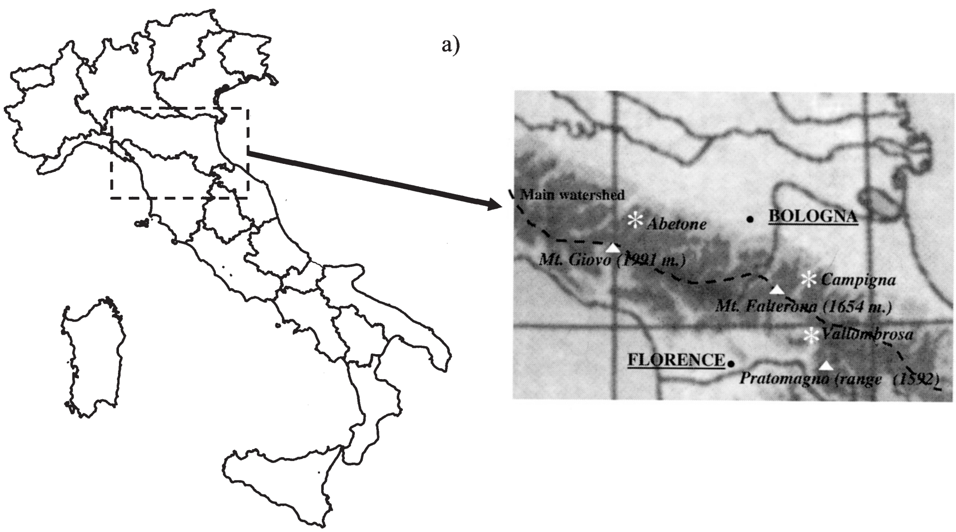
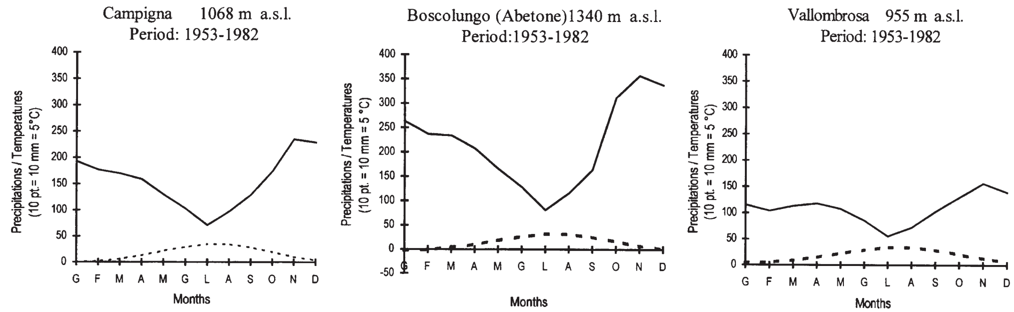


Fig. 2. – a) Geographical localization of the sampling areas.

b)

c)

Fig. 2. (*Continued*) – b) View from Campigna woodlands (sites I and II). c) View from Abetone woodlands (site II).



Walter-Lieth diagram for Campigna, Abetone and Vallombrosa

Characteristcs mean values

Period: 1953-1982	Campigna	Abetone	Vallombrosa
Mean annual temperature	8.4 °C	6.9 °C	9.2°C
Yearly precipitations:	1870 mm	2597 mm	1300 mm
Absolute maximum temperature - and date	34.0 °C (08.17.1956)	31.5°C (08.15.1966)	-
Mean of the maximum temperatures of the hotest month	28.4 °C	27.7°C	-
Annual termic excursion	17.3 °C	17.3°C	14.9°C
Mean of the minimum temperatures of the coldest month	-11.2°C	-13.6°C	-
Absolute minimum temperature - and date	-20.0°C (01.03.1979)	-21.0°C (01.14.1968)	-

Fig. 3. – Cimatic diagrams. Only Vallombrosa have been used for dendroclimatic calibrations.

We cored two sites at the upper (I and II) and two sites at the lower (III and IV) line in a growing area of silver fir. The two regions are characterized as follow:

Campigna

The sampling area is located on the northern slope of the Apennines, near the watershed (fig. 2a). The higher mountains are Mt. Falco (1658 m), Mt. Falterona (1654 m). The geological bedrock is a sandstone bank (Oligocene) intercalated to marl banks (Miocene). The region is characterized by a steep slope with several parallel streams. Soils are principally acid-brown and podzol-brown types (*Dystric cambisols/Umbric leptosols*—FAO classification). Vegetation is represented by mixed woods (fig. 2b) with silver fir (*Abies Alba* Mill.), beech (*Fagus sylvatica* L.) and other tree species (*Acer pseudoplatanus* L., *Ulmus glabra* Hudson, *Fraxinus excelsior* L., etc.). Other typical species are *Carpinus betulus* L., *Dryopterix filix-mas* (L.) Schott., *Sanicula europea* L., *Prenanthes purpurea* L. In the widely spaced areas, where the soil is shallow there are *Vaccinium myrtillus* L., *Luzula nivea* (L.) DC., *Deschampsia flexuosa* (L.) Trin., *Festuca heterophylla* (Lam.) etc.

The climate is temperate-axeric-cold, with a small thermal annual range, cold winters and fresh summers; more details are given in fig. 3.

Abetone

The Abetone area is located about 90 km (North-West direction) from Campigna and similar in morphology, geology, pedology and hydrography. Samples were collected from Southern slope of the Apennines, near to the watershed (fig. 2c). The higher mountains are: Alpe delle Tre Potenze (1890 m) Libro Aperto (1936 m) Mt. Cimone (2165 m). Vegetation is similar to Campigna. At Abetone the mean temperatures are lower and the annual rain are more abundant than at Campigna, and local thermal-inversion phenomena are frequent. But, the climatic character is similar in both regions (fig. 3).

2·2. *Samples.* – 130 firs (two cores per tree), for a total of 260 cores were taken: 36 from Campigna I, 36 from Campigna II, 28 from Campigna III, 32 from Campigna IV, 32 from Abetone I, 34 from Abetone II, 34 from Abetone III, 28 from Abetone IV.

We described every stand floristically and characterized the trees by the circumference Kraft classification and located them in the stand.

2·3. *Climatic data.* – We have mean monthly temperature and monthly precipitations data available from Campigna (period 1953-1984) and Abetone (period 1927-1987) stations of the National Hydrographic Service, and from Vallombrosa (these series were reconstructed for the period 1872-1989 and tested by Gandolfo and Sulli [16].

The series of Campigna are too short and the Abetone series have missing data that can produce false effects in estimating the shifted correlation. Therefore, we correlated the climatic series of these stations with those of Vallombrosa. For both monthly temperature and precipitation the correlation coefficient between Vallombrosa and Campigna are always greater than 0.7 (significance > 99.9%) and between Vallombrosa and Abetone are always greater than 0.5 (significance > 97.7%).

Therefore, for the dendroclimatological study, we used data from Vallombrosa station located approximately 30 km and 100 km far in a straight line, respectively, from the Campigna and Abetone sampling sites. The Vallombrosa series are reliable, without missing data and about as long as our dendrochronologies.

For dendroclimatological analysis we used the annual and seasonal mean temperatures and yearly and seasonal precipitation. Yearly temperature (YT) and precipitation (YP) were conventionally made to correspond to the period from December 1st to November 30th, while the date of the solar year in which January occurred was assigned to it; winter (WT for temperature and WP for precipitation) to the months of December-January-February, spring (SpT for temperature and SpP for precipitation to March-April-May, summer (ST for temperature and SP for precipitation) to June-July-August, and Autumn (AT for temperature and AP for precipitation) to September-October-November.

3. – Methods

Cores were glued onto holders, marked with a code and sanded with fine-grained sandpaper.

Ring widths were measured with a tree ring measuring system composed of the CCTRMD device (Computer Controlled Tree Ring Measurement Device [17]), combined to a binocular WILD M3B (1/100 mm resolution) and connected to a PC with the CATRAS programme (Computer Aided Tree Ring Analysis System [17]).

Altogether we analyzed 130 curves obtained from the average of the ring width measurements of the two cores taken from each tree.

Single curve tests, synchronization and crossdating were performed and eight mean chronologies (one for each site) were carried out. In addition, for each chronol-

TABLE II. – *Table of pointer values and pointer intervals for Abetone and Campigna tree ring width chronologies.* The symbols represent: positive pointer value ⊕, negative pointer value ⊖, no pointer value ○, positive pointer interval ⊞, negative pointer interval ⊟, no pointer interval □.

Year	Abetone				Campigna			
	I	II	III	IV	I	II	III	IV
1873	○□	○□	⊕□	⊕□	○□	○□	○□	○□
1875	○□	○□	⊖□	○□	⊖□	○□	⊖□	○□
1876	○□	○□	○□	○□	○□	⊕□	⊕□	○□
1878	○□	○□	⊕□	⊕□	⊕□	○□	○□	○□
1879	○□	⊖□	⊖⊟	⊖□	○□	○□	○□	○□
1880	○□	○□	○□	○□	○□	○□	⊖□	○□
1881	⊕□	⊕⊞	○□	○□	○□	○□	○□	○□
1882	○□	⊖□	○□	○□	○□	○□	○□	○□
1883	⊖□	⊖□	○□	○□	○□	○□	⊖□	○□
1884	⊕□	⊕⊞	⊕□	⊕□	○□	⊕□	○□	○□
1887	○□	○□	○□	○□	○□	○□	○□	⊕□
1888	⊖□	⊖□	⊖□	⊖□	⊖□	⊖□	○□	○□
1889	⊕□	○□	○□	○□	○□	○□	○□	○□
1890	○□	○□	○□	○□	○□	⊕□	○□	○□
1891	○□	⊖□	○□	⊖□	○□	○□	○□	○□
1892	○□	○□	○□	○□	○□	⊖□	⊖□	○□
1893	⊕□	○□	○□	○□	○□	○□	⊕□	○□
1894	○□	○□	○□	○□	○□	○□	⊕□	○□
1895	○□	○□	○⊟	⊖□	⊖□	⊖□	⊖□	⊖□
1896	⊖□	⊖□	⊖□	⊖□	○□	○□	○□	⊖□
1897	○□	○□	○⊞	⊕□	⊕⊞	○⊞	⊕□	○□
1898	⊕□	⊕□	○□	○□	○□	○□	○□	○□
1899	○□	⊕□	○□	○□	○□	○⊞	○□	○□
1900	○□	○□	○□	○□	⊖□	○⊟	⊖□	○□
1901	○□	○□	○□	○□	○□	○□	○□	⊕□
1902	○□	○□	○□	○□	○□	⊕□	○□	○□
1904	⊕□	○□	○□	○□	○□	○□	○□	⊖□
1906	○□	⊕□	○□	○□	○□	○□	○□	○□
1907	○□	○⊟	⊖⊟	⊖□	○□	○□	⊖□	⊖⊟
1908	⊖□	⊖□	⊖□	○□	○□	○□	○□	○□
1910	⊕□	⊕□	⊕□	○□	○□	⊕⊞	⊕□	⊕□
1911	○□	○□	○□	○□	○□	○□	○□	⊖⊟
1953	○□	○□	○□	○□	⊖□	○□	⊖□	○□
1954	⊖□	○□	○□	○□	○⊞	○⊞	○□	⊕□
1955	○□	⊕□	⊕⊞	⊕⊞	⊕□	⊕⊞	○□	○□
1957	○□	○□	⊖□	⊖□	○□	○⊟	○□	○□
1959	○□	○□	○□	○□	○□	⊖□	○□	○□
1960	○□	○□	○□	○□	○□	⊕□	○□	○□
1960	⊕□	⊕□	⊕□	○□	○□	⊕□	○□	○□
1962	○□	○□	○□	○□	○□	○□	○□	⊖□
1963	⊖⊟	⊖⊟	⊖⊟	⊖□	⊖⊟	⊖⊟	○□	○□
1964	⊕⊞	⊕⊞	○⊞	○□	⊕⊞	⊕⊞	⊕□	⊕□
1965	○□	○□	○□	○□	○□	○⊟	⊖□	⊖⊟
1966	○□	○□	⊕□	○□	○□	○□	○⊞	○□
1968	⊖□	○□	○□	○□	⊖□	○□	⊖□	○□
1969	○□	○□	○□	○□	○□	⊕⊞	⊕⊞	⊕□
1970	○□	○□	⊕□	⊕□	○□	○□	○□	○□
1972	○□	○□	○□	○□	○□	⊖⊟	○□	○□
1912	○□	○□	⊖□	○□	○□	⊖□	○□	○□
1913	⊖□	⊖□	○□	○□	○□	⊕⊞	⊕□	⊕□
1914	⊕□	⊕□	⊕⊞	○□	○□	○□	○□	○⊟
1917	○□	○□	○⊞	○□	○□	○□	⊖⊟	⊖□
1918	○□	○□	○□	○□	○□	○□	○□	⊕□
1921	○□	⊕□	○□	⊕□	○□	○□	○□	⊕□
1922	○⊟	⊕⊟	⊖⊟	⊖⊟	○□	○⊟	⊖□	○⊟
1923	⊖□	○□	○⊞	○□	○□	⊖□	○□	⊖□
1924	○□	○□	○□	○□	⊖□	○□	○□	○□
1925	○□	○□	○⊞	⊕⊞	⊖⊞	○⊞	○□	○□
1926	○□	○□	⊕□	⊕□	⊕□	⊕⊞	⊕□	⊕□
1928	○□	○□	⊖□	○□	○□	⊖⊟	⊖□	⊖□
1929	⊖□	○□	○□	⊖□	○□	○□	○□	○□
1930	○□	○□	⊕□	○⊞	○⊞	⊕⊞	⊕□	⊕⊞
1931	○□	⊖□	⊖⊟	○□	○□	○□	⊖□	⊖⊟
1932	⊕□	○□	○⊞	⊕□	○□	○□	○⊞	○□
1933	○□	○□	⊕□	○□	○□	○□	○□	○□
1935	○□	⊖□	⊖⊟	⊖□	○□	○□	○□	○□
1936	○□	⊕⊞	○□	⊕□	○□	○□	○□	○□
1937	○□	⊕□	⊕□	○□	○□	○□	⊕□	⊕□
1938	○□	⊕⊟	⊖⊟	○□	○□	⊕□	○□	○□
1939	⊖⊟	⊖□	⊖□	⊖□	⊕□	○⊟	○□	○□
1940	○□	○⊞	⊕⊞	⊕□	○⊟	○□	○□	⊕□
1941	⊕□	○□	⊕□	○□	○□	○□	○□	○□
1942	○□	○□	○⊟	○□	○□	○□	⊖⊟	⊖⊟
1943	○□	○□	○□	○□	⊕⊞	○□	○□	○□
1944	⊖□	○□	⊖□	○□	⊕⊟	⊖⊟	○□	○□
1947	○□	⊖□	○□	○□	⊖⊟	⊖⊟	⊖□	⊖□
1949	⊕⊞	⊕⊞	⊕⊞	⊕□	⊕⊟	⊕⊟	⊕⊞	○□
1950	○□	○⊟	○⊟	○□	○□	○⊟	⊖□	⊖□
1951	○□	○□	○□	○□	○□	○□	○□	⊕□
1952	○□	○□	○□	○□	○□	○⊞	⊕□	○□
1974	○□	○□	○⊟	○□	○□	○□	⊖□	○□
1975	○□	○□	○□	○□	⊖⊟	⊖⊟	○□	○□
1976	○□	○□	○□	⊕□	○⊞	○□	○□	○□
1977	⊖□	○□	○□	⊖□	○□	⊕□	⊕□	⊕□
1979	⊕□	⊕□	○□	○□	○□	○□	○□	○□
1981	⊖□	⊖□	○□	○□	⊖⊟	⊖□	○□	○□
1982	⊕⊞	○□	○□	○□	○⊞	○□	○□	○□
1985	⊕□	⊕⊞	⊕⊞	⊕□	⊕⊞	⊕□	○□	○□
1986	○□	⊖⊟	○⊟	○□	○□	⊖⊟	⊖□	⊖□
1987	○□	○□	○□	⊖□	○□	○⊞	○□	○□
1989	⊕□	⊕□	○□	○□	○□	○□	○□	○□
1990	○□	○□	○□	○□	○□	○□	⊕□	⊕□
1991	○□	○□	○□	○□	○□	○□	⊖□	⊖□
1992	○□	⊖□	○□	⊕□	○□	○□	○□	○□
1993	⊕⊞	○□	○□	○□	○□	○□	○□	○□

ogy, skeleton plots were elaborated for the Cropper mean and Interval trend to obtain, respectively, information about *Pointer values* and *Pointer interval* (table II).

According to [18] we define:

Pointer value: event value in one and the same year in many individuals of a group of trees;

Pointer interval: cross-dated intervals of tree rings series showing the same upward or downward trend in a group of trees;

Event value: an extreme value in a tree-ring series of measurements of any kind of parameter;

Event year: year with a conspicuous, easy detectable feature within an individual ring sequence (*e.g.* a narrow or wide, an injury, etc.);

Pointer year: concentration of cross-dated event year within a group of trees.

For each of the eight chronologies the 13y-running mean was calculated and the standardization was performed dividing the actual value (X_i) by the smoothed value (X_i^0) to obtain the index chronology $I_t = X_i/X_i^0$ [19]. The index chronologies from Campigna (C-I, C-II, C-III, C-IV) and Abetone (A-I, A-II, A-III, A-IV) are shown in fig. 4. They all reach 1993 from: 1875 (C-I), 1865 (C-II), 1874 (C-III), 1886 (C-IV), 1837 (A-I), 1845 (A-II), 1834 (A-III), 1843 (A-IV).

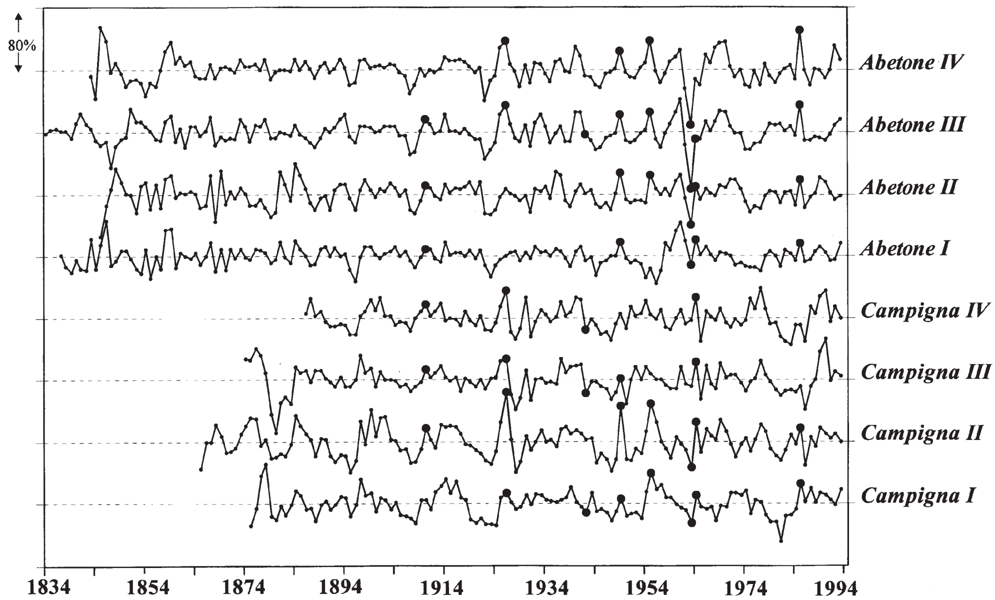


Fig. 4. – Tree ring width index chronologies of Campigna and Abetone (n = number of samples). Campigna I: 1380 m, deep soil $n = 36$; Campigna II: 1320 m, shallow soil $n = 36$; Campigna III: 1020 m, deep soil $n = 28$; Campigna IV: 950 m, shallow soil $n = 32$; Abetone I: 1530 m, deep soil $n = 32$; Abetone II: 1620 m, shallow soil $n = 34$; Abetone III: 1280 m, deep soil $n = 34$; Abetone IV: 1240 m, shallow soil $n = 28$. Dots indicate the years examined in the ecograms.

We performed:

a) correlation analysis between each index chronology from Campigna and Abetone and seasonal Vallombrosa temperature and precipitation series (tables III and IV), for the period 1890-1989;

b) the same analysis with monthly Vallombrosa temperature and precipitation data (fig. 5), for the periods 1890-1989, 1890-1939, 1940-1989;

c) single year analysis on the basis of skeleton plots. Some results are shown in echograms (figs. 6-13);

d) correlation analysis between all chronologies, two by two for the period 1890-1993, obtaining both correlation values and sign test (table V), to interpret the influence of environmental factors on ring growth.

4. – Results and discussion

4·1. *Climate-chronologies correlations.* – The results of correlation tests between chronologies and seasonal meteorological parameters are shown in table III and IV. As concerns temperatures, the correlation coefficients are:

– positive (significance > 99%) with WT for all sites, the best at highest altitudes (C-I, A-II);

– negative (significance > 95%) with ST of the preceding year for all sites—no significant correlation for A-I;

– negative (significance > 95%) with ST of the current year only for Campigna and greater at lower sites on shallow soil on steep slopes.

As concerns precipitation, the correlation coefficients are:

– positive (significance > 99%) with SP of the preceding year, better for lower sites and deep soil;

– positive (significance > 99%) with SP of the current year for sites II, III, IV of Campigna and IV of Abetone.

Fresh and moist summers of the preceding year appear the most important stimulating factor of the ring growth. This is more evident at higher altitudes in shallow soil on steep slopes and at lower altitudes in deep soil (AII, AIII, CII, CIII). Fresh and moist summers of the current year are a stimulating factor only at lower altitudes. Very cool winters are an important limiting factor, more at higher altitudes.

TABLE III. – *Correlation coefficients between Campigna chronologies and Vallombrosa seasonal meteorological parameters.* t = growth year, $t-1$ = preceding year, WT = mean winter temperature, ST = mean summer temperature, SP = summer precipitations. The confidence limit is > 99% for boldface data, between 99% and 95% otherwise.

Campigna	WT	ST	SP
I 1380 m s.l.m. Deeper soil	**Year t: $r = 0.34$**	Year t: — Year $t-1$: $r = -0.21$	Year t: — **Year $t-1$: $r = 0.36$** Year $t-2$: $r = 0.21$
II 1320 m s.l.m. Shallow soil on steep slope	**Year t: $r = 0.28$**	Year t: $r = -0.18$ **Year $t-1$: $r = -0.29$**	**Year t: $r = 0.34$** **Year $t-1$: $r = 0.49$**
III 1020 m s.l.m. Deeper soil	**Year t: $r = 0.29$**	Year t: $r = -0.23$ **Year $t-1$: $r = -0.23$**	**Year t: $r = 0.38$** **Year $t-1$: $r = 0.50$**
IV 950 m s.l.m. Shallow soil on steep slope	**Year t: $r = 0.30$**	**Year t: $r = -0.32$** Year $t-1$: $r = -0.20$	**Year t: $r = 0.36$** **Year $t-1$: $r = 0.31$**

TABLE IV. – *Correlation coefficients between Abetone chronologies and Vallombrosa seasonal meteorological parameters.* t = growth year, $t-1$ = preceding year, WT = mean winter temperature, ST = mean summer temperature, SP = summer precipitations. The confidence limit is > 99% for boldface data, between 99% and 95% otherwise.

Abetone	WT	ST	SP
I 1530 m s.l.m. Deeper soil	**Year t: $r = 0.25$**	Year t: $r =$ —	Year t: $r =$ — **Year $t-1$: $r = 0.20$**
II 1620 m s.l.m. Shallow soil on steep slope	**Year t: $r = 0.36$**	Year t: $r =$ — **Year $t-1$: $r = -0.22$**	Year t: $r =$ — **Year $t-1$: $r = 0.23$**
III 1280 m s.l.m. Deeper soil	***Year* t: $r = 0.21$**	Year t: $r =$ — **Year $t-1$: $r = -0.27$**	Year t: $r =$ — ***Year* $t-1$: $r = 0.3$**
IV 1240 m s.l.m. Shallow soil on steep slope	**Year t: $r = 0.27$**	Year t: $r =$ — Year $t-1$: $r = -0.2$	***Year* t: $r = 0.24$** **Year $t-1$: $r = 0.28$**

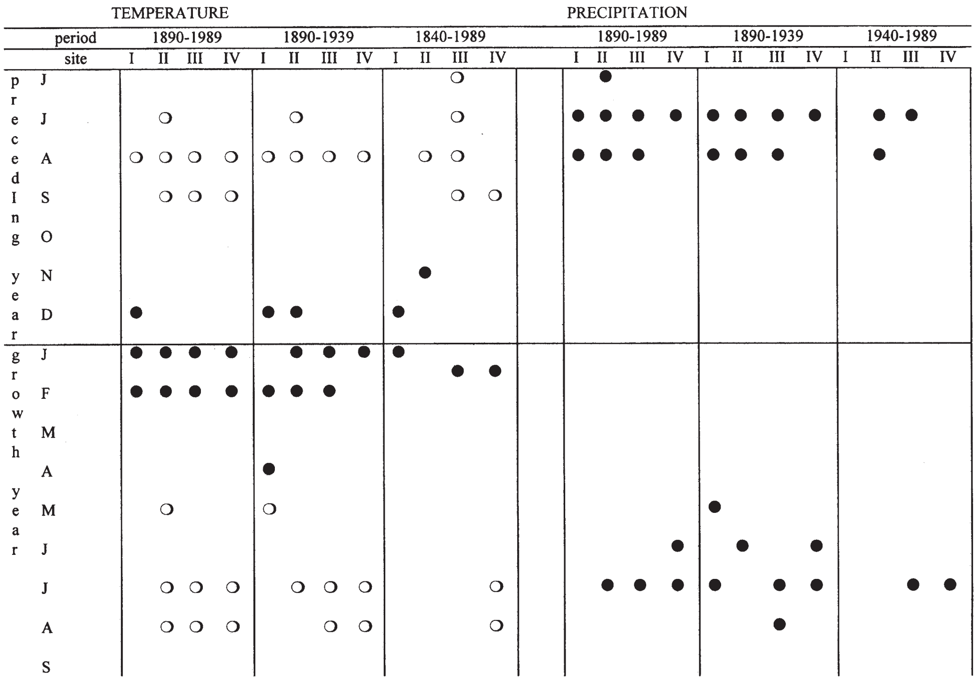


Fig. 5. – Results of the correlation analysis between annual tree ring widths of Campigna and monthly meteorological parameters from Vallombrosa. Dots represent correlation coefficients positive (●) and negative (❍) with confidence limit greater than 95%.

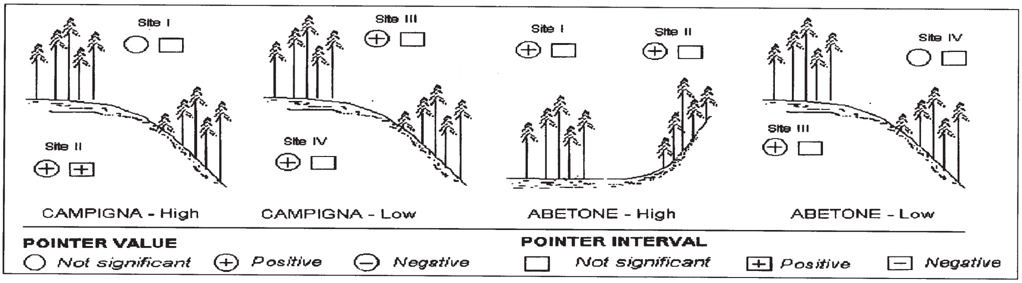
All the correlation values are low because the meteorological records from Vallombrosa do not reflect the real situation at the stands.

To highlight the connection between the ring growth and climate in more detail, we performed a correlation test between chronologies and monthly meteorological parameters. This enabled us to find a relationship that, if too weak for a single month or opposite for two months, can be hidden in a three months mean. The results for Campigna are shown in fig. 5. For the period 1890-1989, monthly analysis confirms the seasonal results and gives evidence that the September temperature of the preceding year (for lower sites or high sites and shallow soil) and May temperature of the current year affect ring width. The results relative to the periods 1890-1939 and 1940-1989 are well consistent and match the ones of the whole period.

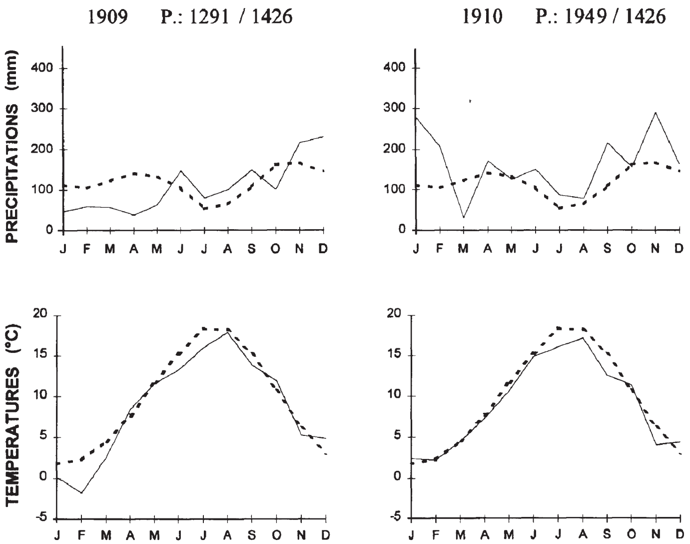
4·2. *Single years analysis.* – To test the above results and to better evaluate how other local factors, as altitude and soil characteristics, influence the ring growth we analyzed some single years in detail (figs. 6-13).

If we indicate the current year with (t) and the preceding year with $(t-1)$, and compare WT, ST and SP of the current year with their mean values for the period 1890-1989, we observe that:

– almost all stands give a positive response (*positive Pointer interval* and *Interval trend*) when WT(t) and SP$(t-1)$ are above their mean values and ST$(t-1)$ is below its mean value (*e.g.*: 1910, 1926, 1949, 1955, 1964);



Preceding Year (t-1)	Current Year



CLIMATIC DIAGRAMS

Data from Vallombrosa
Period: 1890-1989
Reference year : 1910
Plotted years: t, t-1
________ year trend
- - - - - - - - - mean
P: total year precipitations
/ mean annual precipit.

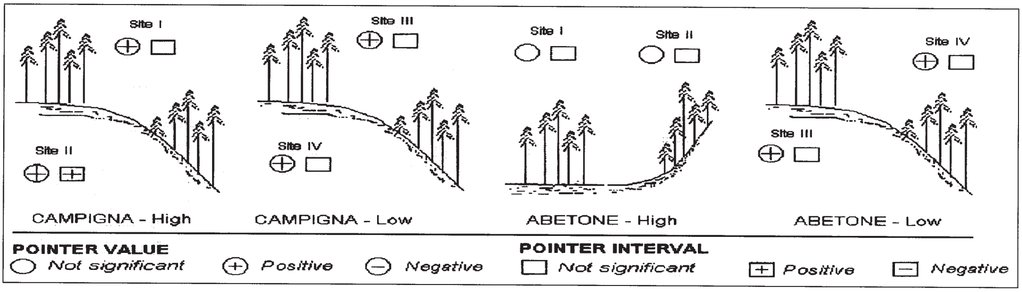
Year: 1910

Current year: cool-moist (J-S) summer, warm-moist winter
Preceding year: cool (J,J) -moist (J-S) summer

Probable dendroecological interpretation:
General pattern: positive pointer values at most sites.
Cool-moist (J-S) of the current and preceding year stimulate growth.

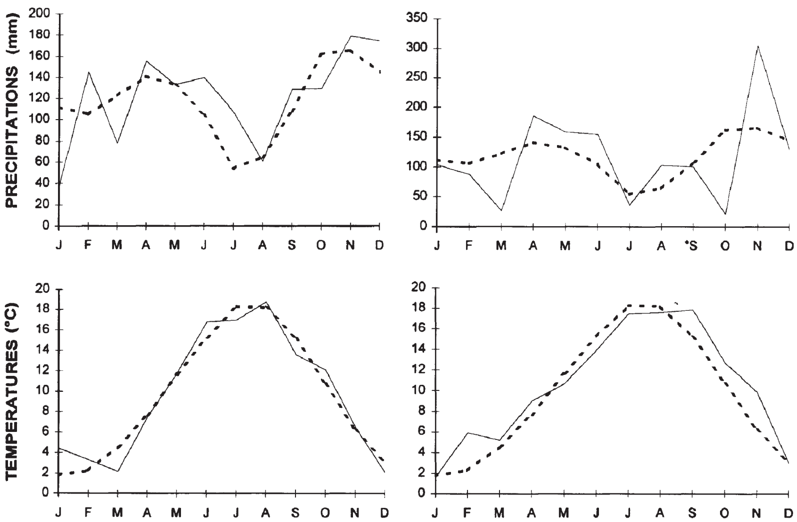
See 1926

Fig. 6. – Ecogram, year 1910.



1925 P.: 1471 / 1426

1926 P.:1415 / 1426



Year: 1926

Current year: cool (M-A) moist (A,M,J,A) summer, temperate winter
Preceding year: moist (J,J) summer

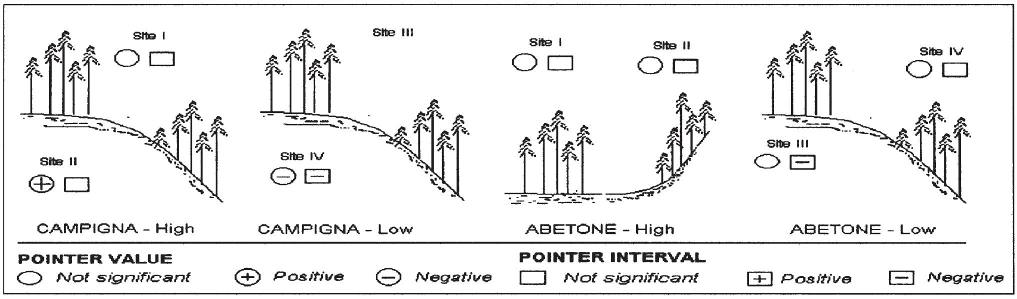
Probable dendroecological interpretation:

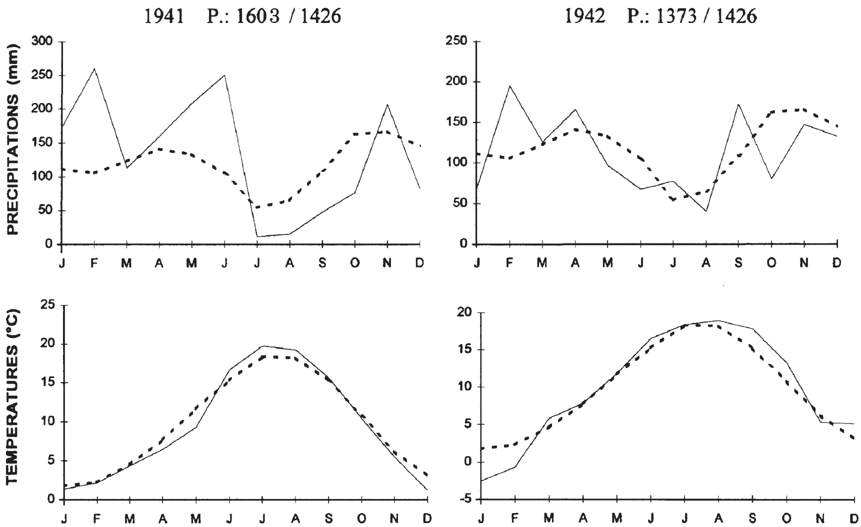
General pattern: positive pointer values and pointer intervals.

Moist (J,J) of the preceding year and cool (M-A) and moist (A, M, J) of the current year stimulate growth mainly at all sites.

See 1910

Fig. 7. – Ecogram, year 1926.



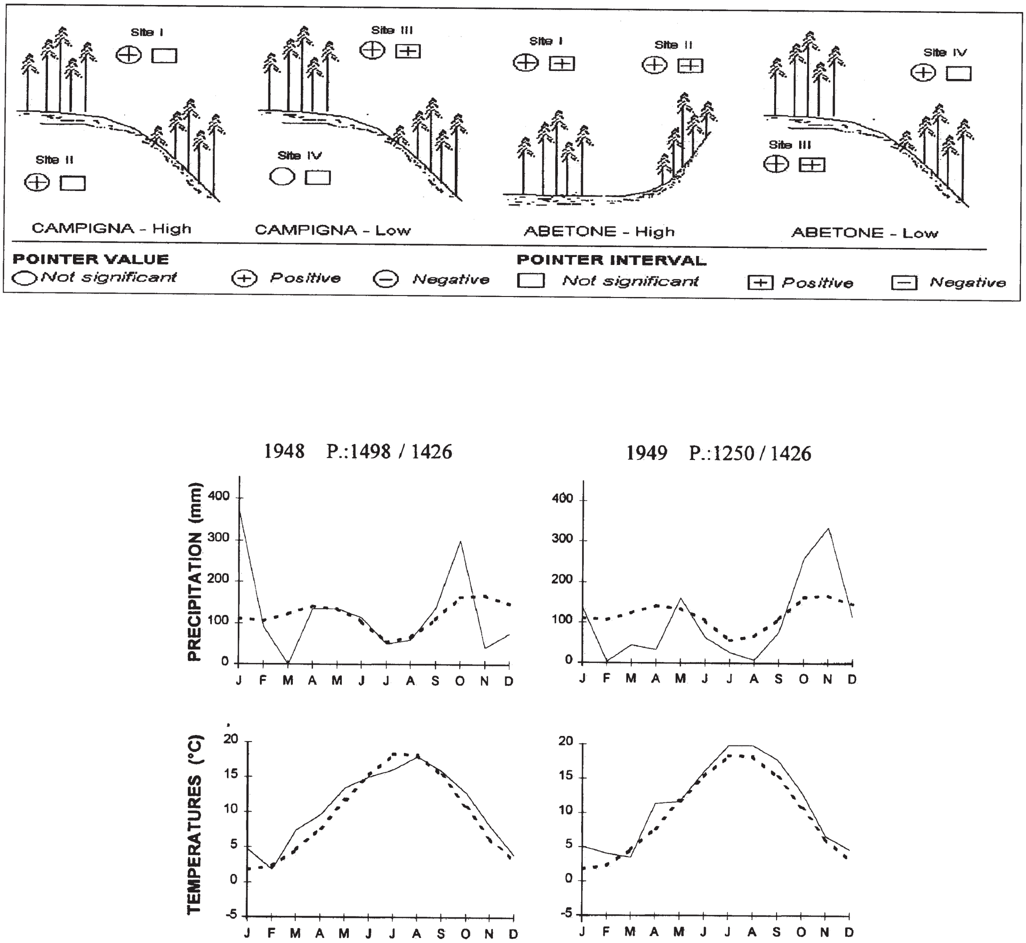


Year: 1942

Current year: dry (M,J) and warm (J,A,S) summer, cool (D-F) winter
Preceding year: warm (J,J,A) -dry summer

Probable dendroecological interpretation:
General pattern: negative or insignificant pointer values or pointer intervals. Warm (J,J,A) of the preceding year, cool (D-F) winter, dry (M, J,A) and warm (J,A,S) of the current year reduced growth mainly at lower sites.

Fig. 8. – Ecogram, year 1942.

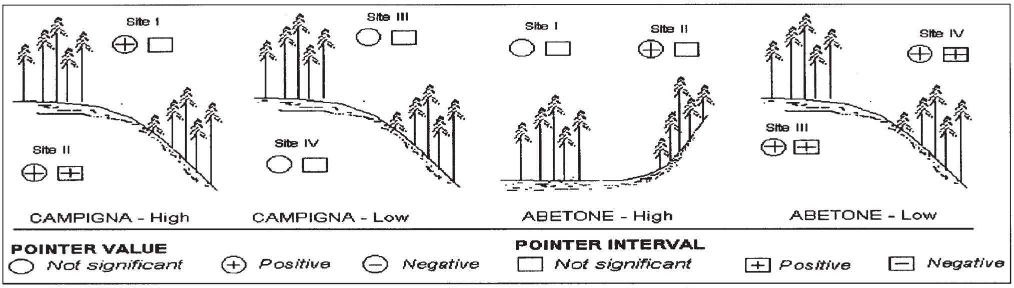


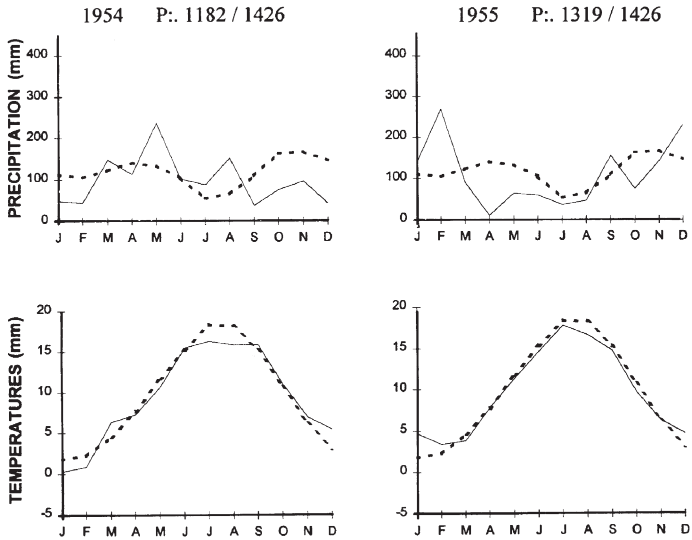
Year: 1949

Current year: dry (J,J,A,S) warm (J,J,A,S) summer, warm (JF) dry (D,F) winter
Preceding year: cool (J) summer

Probable dendroecological interpretation:
General pattern: positive pointer values and pointer intervals at most sites.
Fresh (J,J) of the preceding year stimulate growth. Warm- dry (J-S) of the current year does not affect the ring growth if the site is at the high altitude and/or the soil is deep.

Fig. 9. – Ecogram, year 1949.





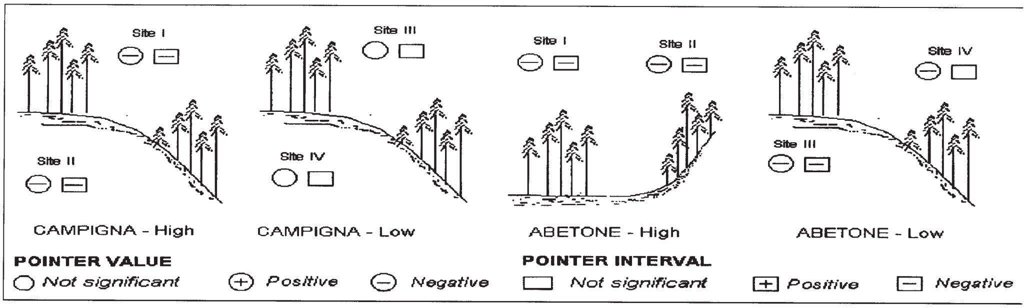
Year: 1955

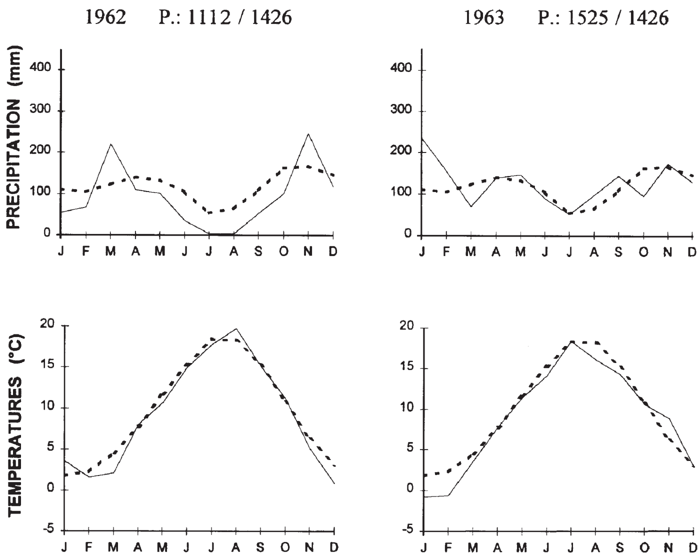
Current year: dry (M-A) and cool (J-S) summer, warm (D-F) moist (J,F) winter
Preceding summer: cool (J,A) and moist (J,A) summer.

Probable dendroecological interpretation:
General pattern: positive or insignificant pointer values and pointer intervals.
The cool (J,S) and moist (A,M,J,A) of the preceding year and the fresh (J-S) of the current year stimulate growth. The drought in A-A does not limit growth.

See 1985

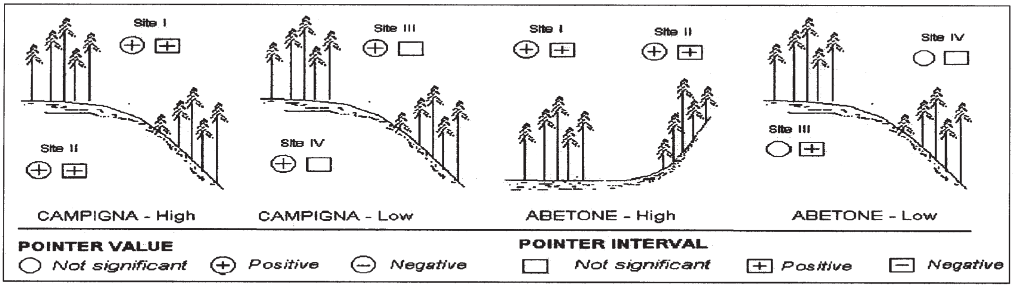
Fig. 10. – Ecogram, year 1955.

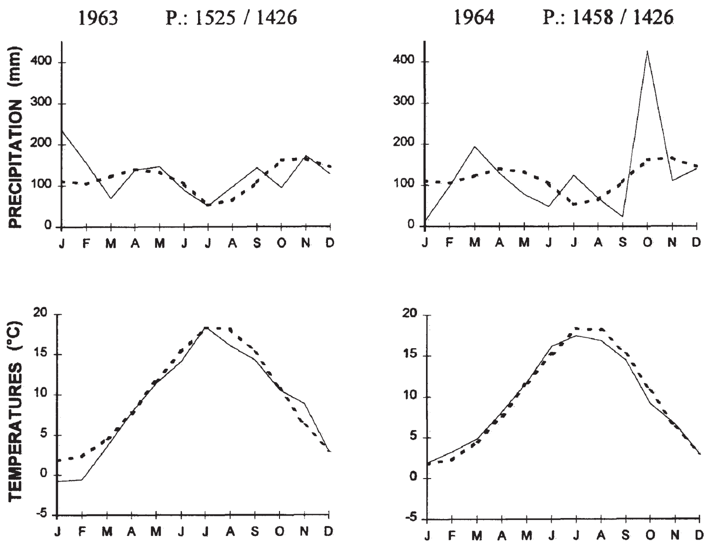




Year: 1963
Current year: cold-moist (J,F) winter, fresh (A,S) summer *Preceding year*: very dry (A-O) summer
Probable dendroecological interpretation: General pattern: negative pointer values and pointer. intervals at most sites. Dry (A-O) of the precending yeartogether with cool (J,F) affect growth negatively at higher sites. Some frost-rings were observed in the wood.

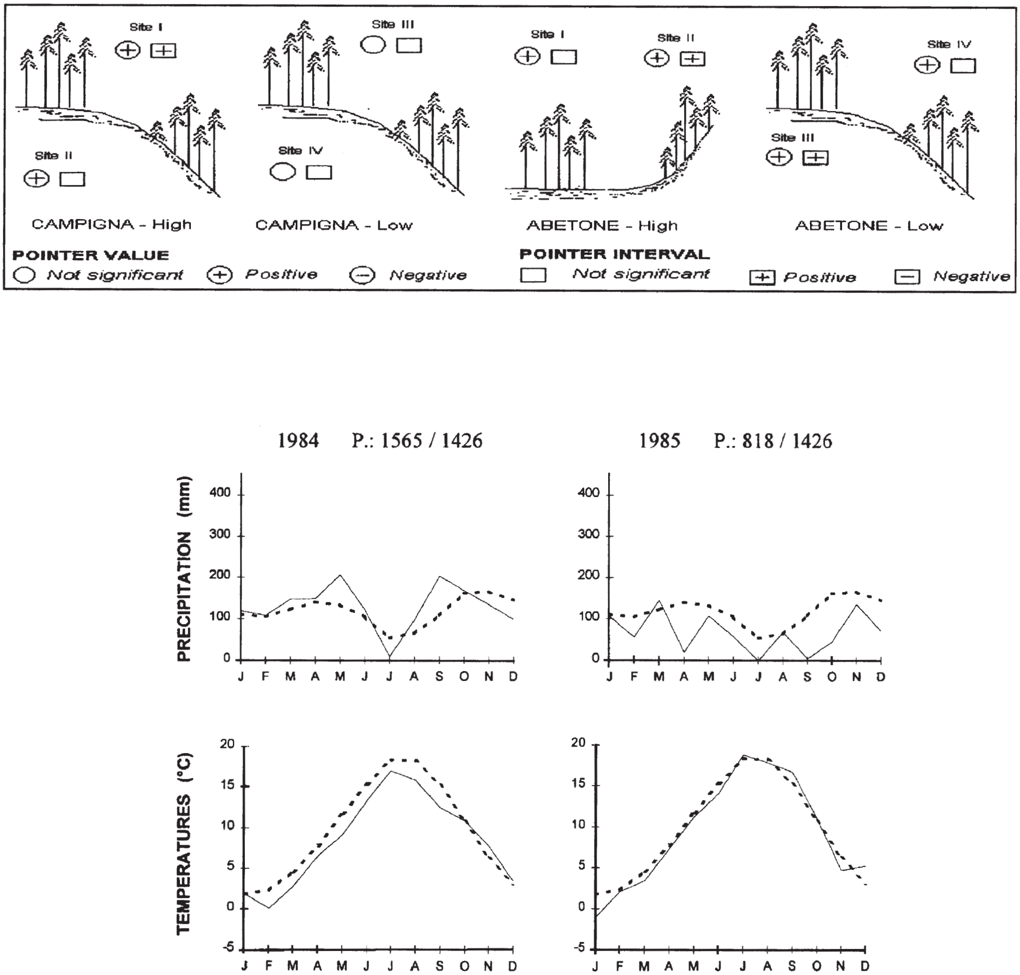
Fig. 11. – Ecogram, year 1963.





Year: 1964
Current year: cool (J,A, S) summer, temperate winter *Preceding year*: fresh (A) summer
Probable dendroecological interpretation: General pattern: positive pointer values and pointer intervals at most sites. The best condition: fresh summer, both of preceding and current year, and temperate winter.

Fig. 12. – Ecogram, year 1964.



Year: 1985

Current year: dry (A-S) summer , cool (J) winter
Preceding year: cool (F-S) summer

Probable dendroecological interpretation:

General pattern: positive pointer values and pointer intervals at most sites.

Cool (F-S) and moist (M,J,A,S) of the preceding years stimulate growth. The drought in A-A of the current tear does not limit growth at higher sites.

See 1955

Fig. 13. – Ecogram, year 1985.

TABLE V. – *Matrix of similarity of eight tree ring width chronologies for the period* 1890-1989: *sign test* (*low*) *and correlation* (*high*). The confidence limit is: 99% for boldface data, between 99% and 95% underlined data, < 95% lightface data.

	C-I	C-II	C-III	C-IV	A-I	A-II	A-III	A-IV
C-I		**0.60**	**0.41**	**0.37**	0.12	**0.42**	**0.33**	**0.38**
C-II	**0.71**		**0.61**	**0.62**	0.22	**0.48**	**0.50**	**0.57**
C-III	**0.70**	**0.78**		**0.80**	0.12	**0.35**	**0.27**	**0.30**
C-IV	**0.65**	**0.70**	**0.75**		0.22	0.25	0.22	0.25
A-I	0.55	0.60	0.56	0.50		**0.60**	**0.53**	**0.42**
A-II	**0.64**	**0.65**	**0.69**	0.58	**0.83**		**0.70**	**0.66**
A-III	0.54	**0.65**	**0.64**	0.57	**0.69**	**0.72**		**0.88**
A-IV	0.56	**0.63**	**0.60**	0.57	**0.64**	**0.69**	**0.79**	

Correlation index

Sign test

– stands give a negative response (*negative Pointer interval* and *Interval trend*) when WT (t) and SP ($t-1$) are below their mean values and ST ($t-1$) is above its mean value (*e.g.*: 1942, 1963);

– in 1985 WT (t) is not enough below its mean value to overcome the positive influence of the SP ($t-1$) and ST ($t-1$).

4·3. *Site correlations.* – In table V the sign test values and the correlation coefficients between the eight chronologies are shown for the period 1890-1989. Best correlation are found between chronologies at the same location and at similar altitudes. Comparing different stations, higher correlation are found between chronologies at roughly the same heights and soil conditions (see C-II and A-IV).

How the meteorological parameters can differently affect the tree-ring growth as a function of the soil characteristics and heights can be deduced from table V. The correlation values between C-IV and all stands from Abetone and the correlation values between A-I and all stands from Campigna are the lowest (significance < 95%). This can be explained by means of the environmental characteristics of these two sites:

– A-I stand grows in deep soil at 1580 m, that is probably the best growing condition for silver fir in that area, so ring width is weakly affected by unfavourable climatic conditions (table IV);

– all Campigna stands grow at altitudes lower (from 950 m to 1380 m) than A-I and are more affected by climatic parameters as table III shows.

In a similar way we can explain the poor correlation between C-IV and all Abetone sites:

– C-IV is the stand of Campigna at lowest altitude and growing in shallow soil, this is probably the worst condition for silver fir. So ring width is strongly affected by climatic parameters (see table III).

The ring growth appears to depend mainly on environmental conditions (altitude and soil depth) and then on climatic parameters. We reached very similar conclusions considering separately the periods 1890-1939 and 1940-1989.

5. – Conclusions

We concluded that:

a) a cool and moist summer of the current and preceding year is the best condition for tree ring growth at every stand and site (fig. 6, 7, 12),

b) a dry and warm summer of the preceding year together with a cool winter of the current year is the worst condition for tree ring growth (fig. 8, 11),

c) a cool winter of the current year is a limiting factor at higher altitudes (fig. 11),

d) a dry current summer can limit ring growth only at low altitudes and/or in shallow soil (figs. 9, 10, 13),

e) stands growing at high altitudes in deep soil are less affected by climatic variation.

The results obtained in this work encourage additional research, where the objectives are to ascertain and quantify the effect of the environmental factors on the growth of silver fir with a better knowledge of the climatic parameters in the examined area. A good starting point for this new research could be micro climatic measurements of temperature and precipitation, obtained by sensors located in the woodland, to improve the quality of the meteorological data and, consequently, the reliability of correlation tests.

REFERENCES

[1] FRITTS H. C., *Tree rings and climate* (Academic Press, New York) 1976.
[2] BECKER M., *Can. J. For. Res.*, **19** (1989) 1110.
[3] BERGMANN F. and KOWNATZKI D., *The genetic variation pattern of silver fir* (*Abies alba*) *monitored from enzyme gene loci*, in *Proceedings of the 5th IUFRO-Tannensymposium, Zvolen, 1988* p. 21.
[4] BERGMANN F., *Genetica*, **82** (1990) 1.
[5] LARSEN J. B. and MEKIC F., *Silvae Genetica*, **40** (1991) 188.
[6] SERRE-BACHET F., *Dendrochronologia*, **3** (1986) 45.
[7] BRÄKER O. U. and SCHWEINGRUBER F. H., *Standorst-Chronologien Teil 2: Apenninen-Halbinsel*, FDK: 561.24 : 101 : (450) : (44), 1989.
[8] CIAMPI C., *It. For. Mont.*, **6** (1954) 303.
[9] GINDEL J., *Monti e Boschi*, **6** (1959) 157.
[10] CALISTRI I., *It. For. Mont.*, **4** (1962) 148.
[11] CORONA E., *Ann. Acc. Ital. Sci. For.*, **32** (1983) 149.
[12] LO VECCHIO G. and NANNI T., *Dendrochronologia*, **11** (1993) 165.
[13] ROMAGNOLI M. and SCHIRONE B., *Ann. Acc. Ital. Sci. For.*, **41** (1992) 3.
[14] FRENI C., *Ann. Acc. Ital. Sci. For.*, **4** (1955) 135.
[15] SANTINI A. and MARTINELLI N., *Giorn. Bot. Ital.*, **125** (1991) 895.
[16] GANDOLFO C. and SULLI M., *Ann. Ist. Sper. Selv., Arezzo*, **XXI** (1990) 141.
[17] ANIOL R. W., *Dendrochronologia*, **5** (1987) 135.
[18] SCHWEINGRUBER F. H., ECKSTEIN D., SERRE-BACHET F. and BRAKER O. U., *Dendrochronologia*, 8 (1990) 9.
[19] SCHWEINGRUBER F. H., *Tree Rings: Basic and Applications of dendrochronology* (Kluwer Academic Publishers, Dordrecht) 1987.