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Climatic and Environmental Influences on Mountain Pine (*Pinus montana* Miller) Growth in the Central Italian Alps

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Abstract

In this paper we analyze upright mountain pine (*Pinus montana* Miller) radial growth responses to climatic and environmental factors in a valley of the Central Italian Alps. This valley is characterized by intense geomorphological dynamics that can mostly be traced back to instability processes and particularly to debris flows. Here, there are also less active areas that allow undisturbed tree growth and permit dendroclimatic research to be performed. The relationship between climatic factors and radial growth in mountain pine was established by Pearson's correlation and response functions using four chronologies. Two were built using trees located on opposite valley slopes; the other two from the valley bottom. One of these last two is constructed with trees growing in areas occasionally affected by sheetfloods. We found that the climate of the summer months has the strongest influence on tree-ring growth: especially May and July mean temperatures and June precipitation. In contrast, the chronology built with trees located in the valley bottom in an area affected by sheetfloods, shows different climate-growth relationships especially concerning summer precipitation. The burial made by silt layers and the more impermeable conditions of the substrate seem to be the main factors regulating tree growth in this area. Comparing this chronology with the reference chronologies, we found that some years with growth anomalies in the disturbed site correspond to debris flow events dated by previous studies in nearby fans. This paper points out the potential use of mountain pine for dendroclimatic reconstruction and the influence of soft slope processes on tree growth.

Introduction

High mountain environments are very sensitive to climatic variations and human impact. These influences are some of the main factors responsible for continuous and rapid environmental change. Climatic variations affect geomorphological process dynamics, changing their strength and frequency, especially for climate-dependent or climate-correlated events such as avalanches and debris flows. Moreover, because of current climate warming, the vegetation system is also changing and treelines are increasing in elevation (Ozenda and Borel, 1995). These climatic and environmental variations are recorded in tree rings. Analysis of climatic signal in natural archives and in tree vegetation is the first step to correlation with other proxy data, such as previously dated geomorphologic events.

As demonstrated by ecological and dendroclimatic research carried out in the European Alps, the most climatically sensitive tree species at the timberline, especially with regard to temperature, are *Larix decidua* Miller and *Pinus cembra* L. (Serre, 1978; Tessier, 1986; Huesken and Schirmer, 1993; Nola, 1994; Nola and Motta, 1996; Motta and Nola, 1997; Strumia and Cherubini, 1997; Urbinati and Carrer, 1997). Our research was conducted in the Central Italian Alps, and it is unique because the tree population that we analyze probably represents a hybrid between *Pinus mugo* Turra and *Pinus uncinata* DC. here referred to as *Pinus montana* Miller (Santilli et al., 2002, also defined as *Pinus mugo* aggr. according to Minghetti, 1997, and the *Pinus mugo* group according to Pignatti, 1982). Only a limited number of studies have been done concerning upright mountain pine (Brang, 1988; Cherubini et al., 2002, for dendroecological elements; Schueller and Rolland, 1995; Rolland et al., 1998, for dendroclimatic elements).

In this paper we use several mountain pine chronologies constructed by sampling trees growing in undisturbed areas. These chronologies had been used as reference chronologies to date debris flow events and to study erosive processes in previous studies (Santilli and Pelfini, 2002; Santilli et al., 2002; Pelfini and Santilli, 2003; Pelfini et al., 2005). We used the same chronologies to perform dendroclimatic analysis with the goal of highlighting relationships between tree growth and climate. Moreover, we investigate possible effects of local disturbance factors due to edaphic conditions or geomorphological processes on tree growth: we therefore used another chronology, built with samples collected from trees growing in an area occasionally affected by sheetfloods. Sheetfloods are low-energy geomorphological processes that are unable to wound trees. Our purpose is to test if the trees affected by sheetfloods are different in their growth and in their climate-growth relationships in comparison to the chronologies from sites not affected by sheetfloods.

Study Area

Valle del Gallo is located between upper Valtellina (Lombardy, Northern Italy) and upper Valle dello Spöl at an altitude of between 1900 and 2200 m a.s.l. (Fig. 1a). This is a high mountain environment where instability processes are very common. In this valley the very frequent and heavy rainfall, common in summer,

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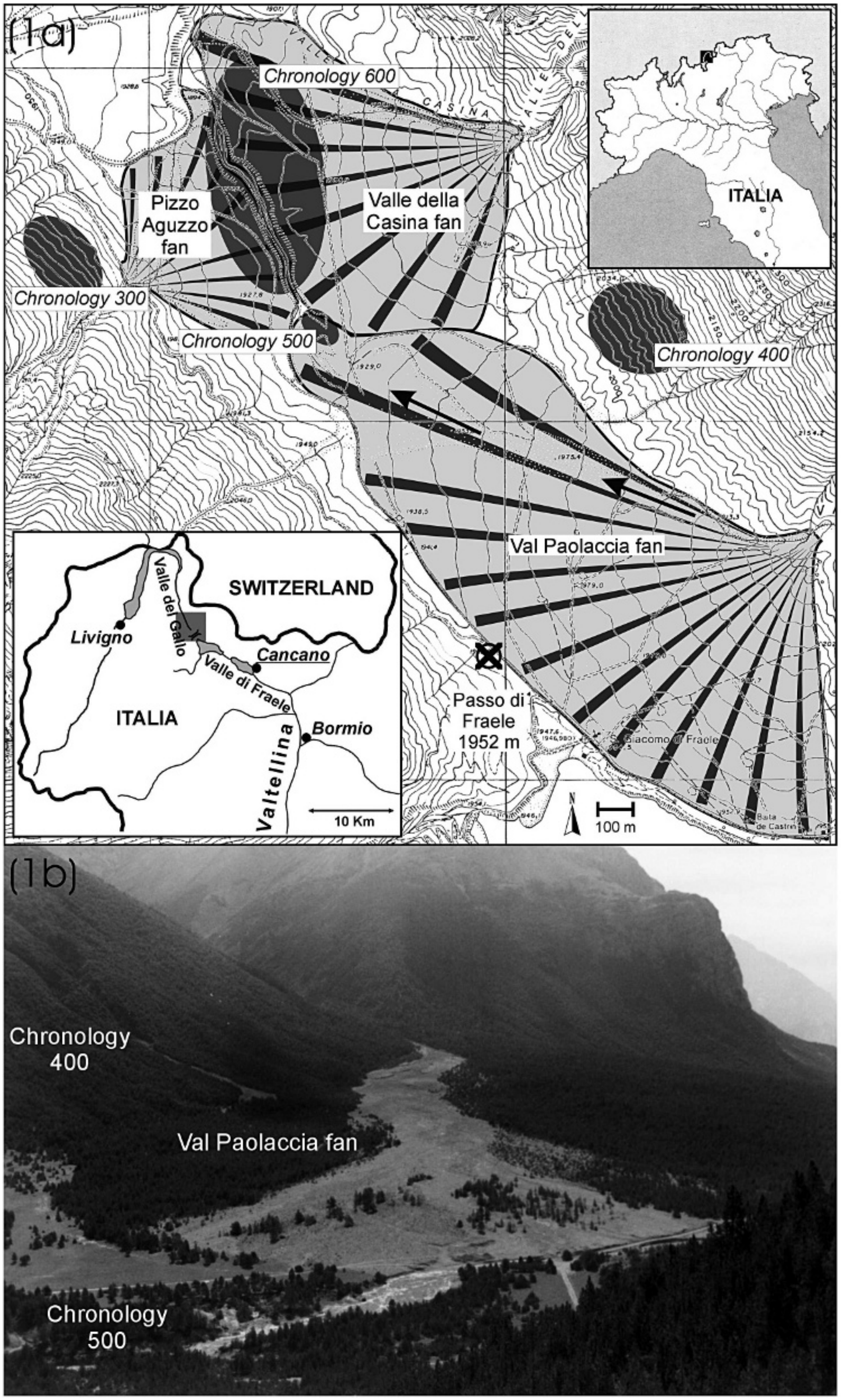

FIGURE 1. (a) Study area map: the figure shows the position of the sampled populations and the fans of the upper Valle del Gallo (from the Regional Technical Map 1:10.000 sections No D1b3 "Lago di Livigno Sud" and No D1c3 "S. Giacomo di Fraele"). (b) View of the Valle Paolaccia fan and position of populations 400 and 500.

trigger debris flows and sheetfloods. As a result, many debris flow fans dominate the landscape (Fig. 1b).

The climate is continental with maximum temperatures and precipitation in July and August. The mean temperature for 1978–2003 is 2.7°C, and the temperature range from January to July is 16.8°C (Santilli, 2005). Frost can occur from November to April, while from May to October frost is rare. Precipitation is concentrated in summer, with more than one-third falling from June to August during the vegetative period. Average annual precipitation is 828 mm (1936–2003 period; data from the A.E.M., Cancano meteorological station) (Fig. 2).

Mountain pine is the dominant tree species, evenly covering the valley bottom and slopes up to the treeline. Trees are very often affected by debris flows in nearly all locations of the study area. Very often these processes bury tree boles, open stem wounds, tilt trunks, or uproot trees. In other areas rare sheetfloods

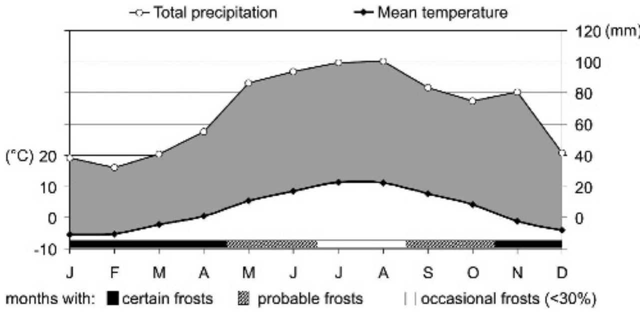

FIGURE 2. Climate diagram for the Cancano meteorological station. Temperature covers the period 1936–2003; precipitation covers the period 1978–2001.

descend from the Val Paolaccia fan, below a small tributary valley, and deposit fine material at trunk bases without mechanical damage. Finally, isolated areas on the slopes and in the valley bottom allow undisturbed tree growth (Santilli et al., 2002; Pelfini and Santilli, 2003; Santilli and Pelfini, 2002, 2006).

Materials and Methods

SAMPLING STRATEGY AND CHRONOLOGY CONSTRUCTION

Four tree-ring chronologies were built by sampling four mountain pine populations: two populations situated on the two facing Valle del Gallo slopes (code 300 on the east-facing slope, and code 400 on the west-facing slope), at an altitude of between 2000 and 2100 m; another population (code 500) located in the valley bottom, close to the margin of the Val Paolaccia fan, at an altitude of about 1930 m; the last population (code 600) located in a stable area, also in the valley bottom (in the distal part of the Valle della Casina and Pizzo Aguzzo fans), at an altitude of about 1930 m (Fig. 1a, 1b). All these populations grow on gravel substrate, except the 500 population that grows on sheetflood-deposited silt. Particular attention was therefore paid to this last group of trees.

Thirty dominant trees with regular growth and crown were sampled for each population, taking two cores at breast-height from each stem. The cores were then fitted to wooden supports and prepared according to standard methods (Schweingruber, 1988). Ring-width measurements were taken, accurate to 0.01 mm, using a digital positioning table (LINTAB). Date accuracy and the measurement quality of the tree-ring series were statistically and visually verified using two programs: COFECHA (Holmes, 1983; Grissino-Mayer, 2001) and TSAP-Win, thus eliminating possible dating errors. For each population we performed a validation of the ring-width series by selecting only the series with high correlation with their mean chronology ($r > 0.5$) (Hofgaard et al., 1999) for further analyses.

Raw growth-series were then standardized to remove long-term growth trends (Fritts, 1976; Cook and Briffa, 1990). Based on the *67%n criterion* (Cook and Briffa, 1990) applied to the mean length of all growth series, all the series were standardized dividing the observed values by those predicted by a cubic smoothing spline with 50% cut-off at a 60-yr wavelength. Next, autocorrelation was removed from each series using an autoregressive model (Cook and Briffa, 1990), and finally, a residual chronology was calculated for each population by applying a biweight robust mean. All four residual chronologies were built employing the ARSTAN program (Grissino-Mayer et al., 1996).

CHRONOLOGY COMPARISONS

The four residual chronologies were compared in the common period 1939–2001, where all of them have a good stability of the signal, defined by Subsample Signal Strength (Wigley et al., 1984; Cook and Briffa, 1990) at 90%. Statistical comparison of the chronologies was based on Gleichläufigkeit, Cross Correlation, T-Value, and Cross Date Index similarity indices.

Interannual growth variations were checked using visual analysis and were also identified by calculating growth index differences between pairs of chronologies and between each chronology and the mean chronology (named "Mean"); the latter was built using the 300, 400, and 600 chronologies (these chronologies show very similar patterns and were then used as reference chronologies). Years in which differences between the chronologies were higher than one standard deviation were considered as meaningful; for all comparisons, the standard deviation of the differences between the chronology with higher variability (500) and the Mean was considered as the threshold value for identifying years with growth anomalies.

Dates obtained with this method were then compared with dates of known debris flow events of the two adjacent fans of Valle Paolaccia and Valle della Casina (Fig. 1a) (Santilli and Pelfini, 2002, 2006) in order to identify possible similarities.

CLIMATE AND RADIAL GROWTH RELATIONS

Relations between radial growth and climate were assessed via Pearson's correlation and response function linear models (Fritts, 1976; Fritts and Guiot, 1990). The four residual chronologies were compared with 24 climatic predictors using monthly mean temperatures and monthly total precipitation from October of the preceding year to September of the growth year for both models. This 12-mo interval is considered a typical biological year for southern Europe (Tessier, 1984; Nola, 1996; Motta and Nola, 1997; Carrer and Urbinati, 2001). Pearson's correlations and response functions were computed using the DENDROCLIM2002 program (Biondi and Waikul, 2004), with 1000 bootstrap iterations both for correlation and response functions.

The Cancano meteorological station is located near the Cancano lake, at an altitude of 1948 m; due to the short temperature data record (the series starts in 1978) and the lack of some monthly precipitation values (3.6% of missing values), we built regional temperature and precipitation records incorporating data from two other meteorological stations (Livigno and Bormio) located within a 15-km radius of the study area (Table 1). The Livigno station is located at a slightly lower level than the study area (1810 m a.s.l.) on a very broad valley bottom with a south-north orientation, whereas the Bormio station is located in a basin, open to the south, at the opening of Valfurva in Valtellina, at an altitude of 1225 m a.s.l. The climatic series of the three meteorological stations show high intercorrelation for monthly temperatures and monthly total precipitation.

The two complete regional monthly temperature and precipitation series were built by estimating the missing values in one station from the other stations; the MET program (Grissino-Mayer et al., 1996) was used to build the regional climatic series. Since the presence of climatic trends could bias the results of correlation and response functions, we tested the two climatic series on the period of the dendroclimatic analysis (1939–2001): mean annual temperatures do not show a significant trend, while annual precipitations show a small positive trend of 131 mm over the 63-yr period of analysis (Fig. 3). This increase in precipitation was quantitatively measured at several stations in western Trentino (Bisci et al., 2004).

TABLE 1

Characteristics and correlations of the climatic series for the three meteorological stations considered.

	Characteristics of the series			Intercorrelation of the series		
Meteorological station	Bormio	Cancano	Livigno			
Latitude, longitude (N, E)	46°28′ 10°22′	46°31′ 10°18′	46°32′ 10°08′			
Elevation (m a.s.l.)	1225	1948	1810			
		Temperature				
First year	1924	1978	1962		Bormio	Cancano
Last year	2001	2003	2001	Cancano	0.96	1
Length of the series (years)	78	26	40	Livigno	0.97	0.97
Missing data (%)	6.1	0.0	0.0			
Mean annual temperature (°C)	7.8	2.7	1.7			
		Precipitation				
First year	1921	1936	1979		Bormio	Cancano
Last year	2001	2003	1995	Cancano	0.91	1
Length of the series (yr)	81	68	17	Livigno	0.87	0.91
Missing data (%)	0.5	3.6	2.5			
Mean annual precipitation (mm)	739	828	637			

Results

CHRONOLOGY STATISTICS

Chronology characteristics vary among the four sampled sites (Table 2). The 300 and 400 chronologies from the slopes, show generally similar characteristics: same mean sensitivity, very similar standard deviation values and Signal to Noise Ratio (SNR, Briffa and Jones, 1990). With respect to the two slope chronologies, the 500 chronology shows slightly higher ring-width, mean sensitivity (index linked to interannual variations) and standard deviation values. There are much higher values of autocorrelation, of variance due to autoregression and of variance in the PC1. The SNR and the Expressed Population Signal (EPS, Briffa and Jones, 1990) are lower. Nevertheless the 500 chronology shows the highest correlation values among all the radii, among trees, and within trees. The 600 chronology shows values similar to those of the two slope chronologies for mean sensitivity and standard deviation. But, like the 500, it shows high values of autocorrelation, of variance due to autoregression and of series correlation. Of all the chronologies, it has the lowest SNR and EPS values.

CHRONOLOGY COMPARISON

The residual, 300, 400 and 600 chronologies, show nearly the same growth patterns especially from about 1930, and almost never have opposite growth variations (Fig. 4). Calculation of various similarity indices confirms the very similar nature of the three chronologies (Table 3): the "Gleichläufigkeit" values are particularly high, indicating strong pattern agreement in the three chronologies. The 500 chronology instead, shows higher growth variability and in some years even opposite trends with respect to the three reference chronologies. Even if this chronology is constructed from trees about 20 yr younger than the ones used for the other chronologies, its growth variability is higher than the one shown by the other chronologies in their younger portions. The calculation of the differences in growth variation among the three chronologies and between the 500 and the Mean, shows how there are just small differences in the growth patterns among the three reference chronologies (Fig. 5a, 5b, 5c). In contrast, the 500 chronology shows strong differences with respect to each of the reference chronologies (not shown) and to the Mean (Fig. 5d): this led to a standard deviation of the differences with the Mean that is double with respect to those of any of the pairs of reference chronologies (Table 3).

Considering the first pair (300 vs 400, Fig. 5a), 1997 alone slightly exceeds the threshold value of one standard deviation; in all other years the differences in growth variations between 300 and 400 are below this limit. For the second pair (600 vs 300, Fig. 5b), just 1953, 1978, and 1988 exceed the limit. The last pair (600 vs 400, Fig. 5c) has only 1951 slightly over the threshold value. The differences between the 500 chronology and the Mean frequently and strongly exceed the set limit (Fig. 5d). Chronology 500 clearly shows more favored growth than the reference chronologies in years 1944, 1946, 1962, 1976, 1984, 1986, and 1994, and inhibited growth in years 1948, 1953 (600 series excluded), and 1987. All these dates (except 1946, 1948, 1953 just for the 600 series, and 1984), are years where the 500 shows opposite growth variation with respect to the reference chronologies.

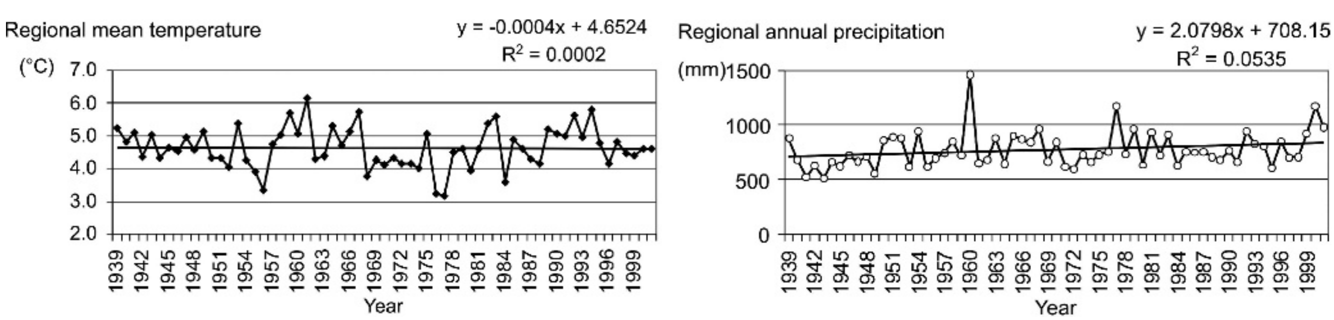

FIGURE 3. The regional annual series of temperatures and precipitation derived from the regional monthly series used for the dendroclimatic analysis. Linear regression lines and respective equations are shown.

TABLE 2

Characteristics of the residual chronologies.

Chronology code	300	400	500	600
First year of chronology	1900	1882	1915	1888
Last year of chronology	2001	2001	2001	2001
Chronology length (years)	102	120	87	114
First year with SSS at 90%	1928	1913	1939	1937
Number of trees	21	22	16	15
Number of radii	33	32	22	20
Mean ring width (mm)	0.9	0.75	1.11	0.93
Mean sensitivity	0.14	0.14	0.19	0.15
Standard deviation	0.11	0.12	0.18	0.13
Autocorrelation order 1[a]	0.25	0.26	0.63	0.44
Variance due to autoregression[a] (%)	5.7	7.9	31.2	19.7
ARMA model (AR)	1	1	1	1
Common interval analysis:				
First year of common interval analysis	1939	1939	1939	1939
Signal to noise ratio	10.56	12.26	8.5	4.61
Variance in the first principal component (%)	37.72	38.82	51.72	46.79
Expressed population signal	0.91	0.92	0.89	0.82
Intercore correlation	0.35	0.36	0.47	0.42
Intertree correlation	0.35	0.36	0.46	0.40
Intratree correlation	0.55	0.56	0.7	0.66

[a] These values relate to the standard chronology

CLIMATIC RELATIONS

Dendroclimatic analysis for 1939–2001 shows that the three reference chronologies, 300, 400, and 600, have similar relations to the temperature and precipitation variables for almost all months. The 500 chronology shows a different patterns in the correlation coefficients (Fig. 6a, 6b).

TABLE 3

Similarity indices and standard deviation of the differences calculated between pairs of residual chronologies and between the 500 and the Mean chronology (mean of reference chronologies 300, 400, and 600). Analysis performed on the common period 1939–2001. GSL, statistical significance of the *Gleichläufigkeit*: ***99.9%.

	300 vs 400	600 vs 300	600 vs 400	500 vs 300	500 vs 400	500 vs 600	500 vs Mean
Gleichläufigkeit	90	80	89	77	75	72	80
GSL	***	***	***	***	***	***	***
Cross Correlation (%)	75	80	82	25	39	48	40
T-Value	8.9	10.5	11.1	2.0	3.3	4.3	3.5
Cross Date Index	126	108	123	25	27	44	36
Standard deviation	0.078	0.075	0.071	0.171	0.155	0.147	0.152

Temperatures: Generally for all three reference chronologies the months of the growing season are more important than all the preceding months considered. In particular:

- for the months from October to April there is no evident correlation with climatic variables;
- May and July have an important role in tree growth: correlation is positive and the significance level is exceeded in May (all reference series) and July (series 400 and 600; and nearly the 300 series); for all the reference chronology July is significant also for the response functions;
- June has a negative (but not significant) correlation with the three reference chronologies;
- September seems to have a certain positive influence on radial growth, especially for chronology 300.

The chronology 500 correlation coefficients show different patterns to those of the other chronologies: especially for the

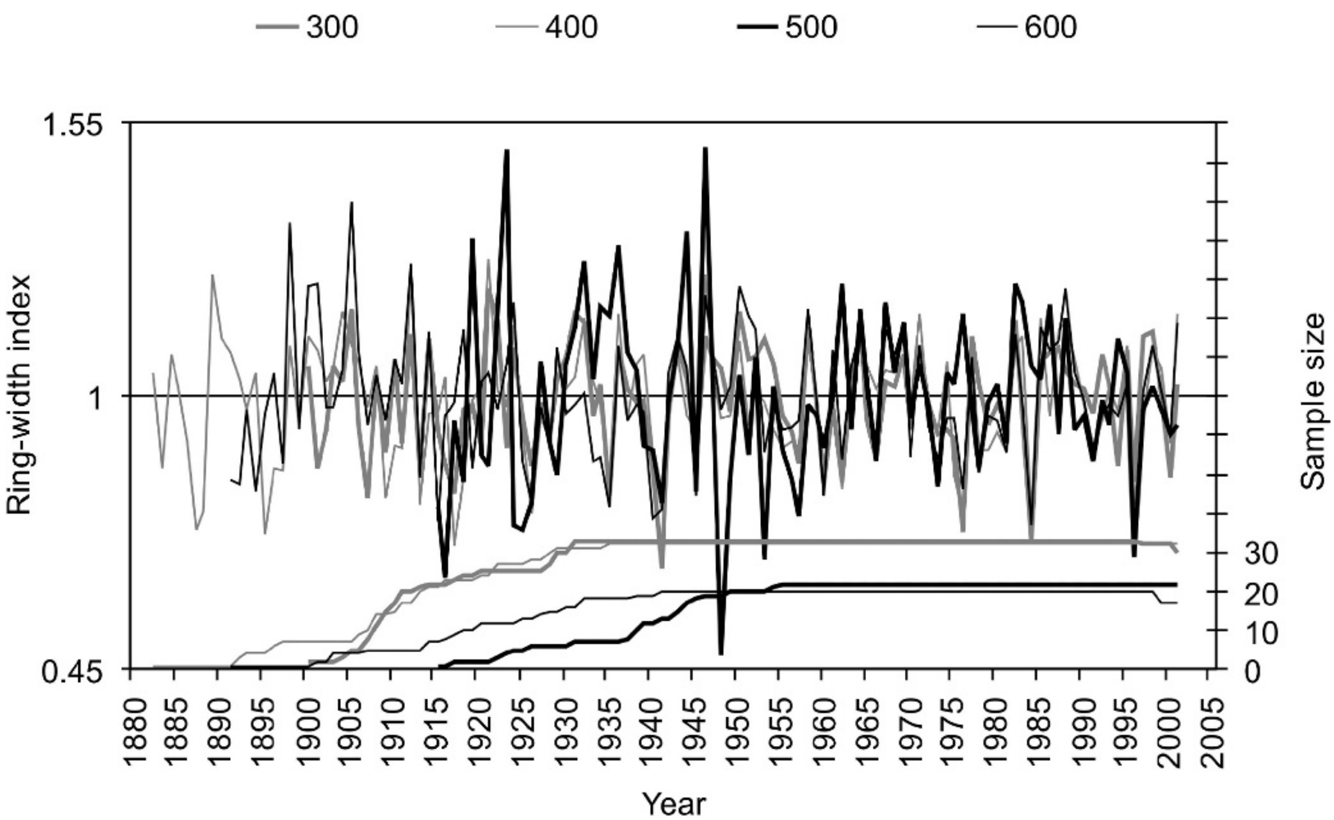

FIGURE 4. The four residual chronologies of mountain pine. The sample size of each chronology is also shown.

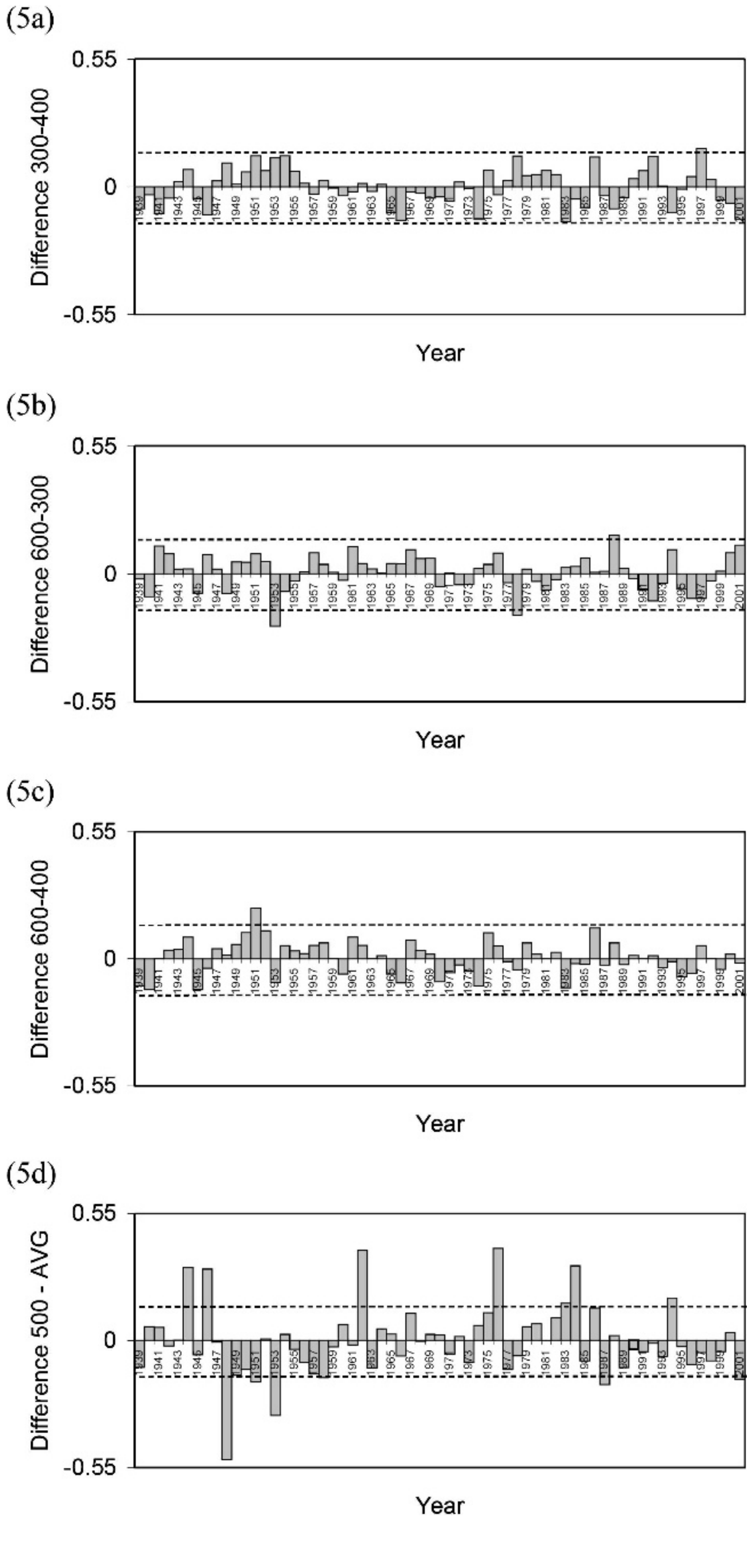

FIGURE 5. (a, b, c, and d) The graphs depict the differences between couples of residual chronologies. The dotted lines show the upper and lower limits of one standard deviation from the mean: the standard deviation of the differences between the 500 chronology and the Mean was used in all graphs.

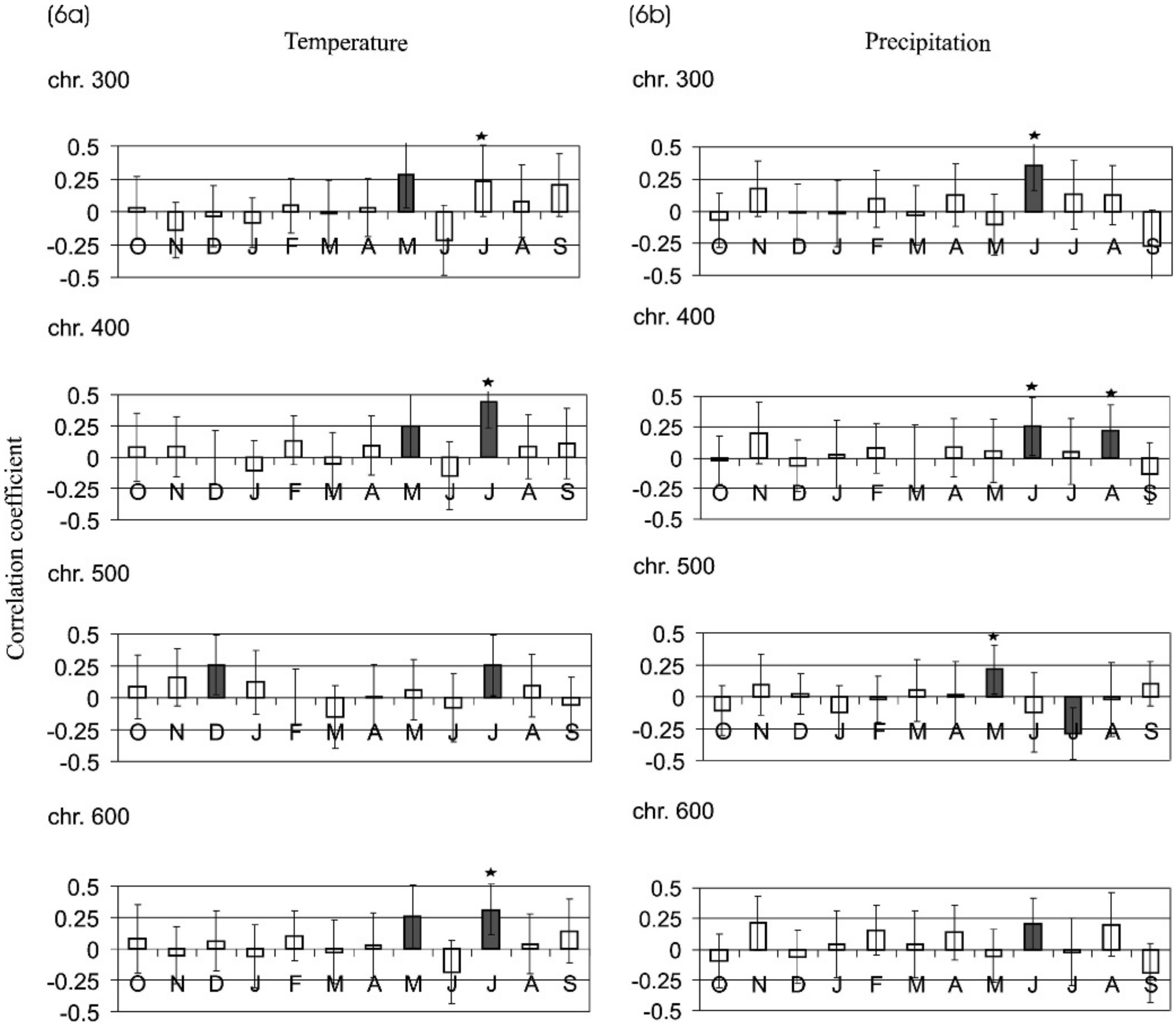

FIGURE 6. (a and b) Correlation coefficients based on the four residual chronologies, showing the effect of temperature (a) and precipitation (b) on the tree ring-width indices. The graphs show median correlation coefficients for monthly mean temperatures and monthly total precipitation, from October to September, during 1939–2001, for the meteorological stations used. Significant months at the 0.05 level for correlation function are colored in gray; the vertical lines show the significance limits, fixed using the 95% Percentile Range method (Biondi and Waikul, 2004). Asterisks indicate significant factors from the response function analysis.

months preceding the growing season they show a different relation to climate. In particular:

- months from November to January, show a positive correlation, with correlation values higher than those of the reference chronologies; December exceeds the significance level;
- March, instead, is negatively correlated;
- the May, June, and August correlation coefficient patterns agree with those of the reference chronologies, but the first two months show much lower absolute values;
- July has an important role also for the growth of these trees, with positive correlation exceeding significance.

Precipitation: The most important months for radial growth are those of the growing season. For the 300, 400, and 600 chronologies, the correlations with precipitation show similar patterns:

- for the months preceding the growing year, November is positively correlated with the three reference chronologies and nearly exceeds the significance for the 600 chronology;
- months from June to August show a positive correlation (except July for the 600 series);
- June is particularly important: all the reference chronologies are directly and significantly correlated to precipitation of this month; June is significant also for the response function (not for the 600 chronology);
- August positively influences growth, especially for chronology 400, where this month is significant both for correlation and response function;
- September is negatively correlated with all of the three reference chronologies.

In general, for the growing season the correlation coefficients of chronology 500 have an opposite trend with respect to the correlation coefficients of the three reference chronologies, and there are no important months concerning the period prior to the growing season:

- May is positively correlated, exceeding the significance level both for correlation and response functions;
- an important role is evident for July, strongly negatively correlated.

Discussion

Chronologies 300, 400, and 600 show high similarity both in their growth trends and in relation to climatic variables: since they were built with trees growing in similar environmental conditions, even if from two opposite slopes and the valley bottom (at about 100 m of difference in altitude), they have similar responses to climate variability, confirming that climate at these altitudes is one of the most important limiting factors on tree growth. In contrast, the 500 chronology shows higher growth variability and also different growth patterns with respect to the reference chronologies: this suggests that, besides climate, some environmental factors could have affected their growth.

The climatic conditions of the growing season have an evident influence on mountain pine radial growth in this area. In particular, strong positive correlations were found in May and July for temperature and in June for precipitation. On the contrary, even if less marked, there is a negative correlation for June temperatures and for September precipitation. Good thermal conditions from late spring positively influence tree-ring width. However, as summer begins, water availability is more important, allowing plants to build new earlywood tissues and to more easily distribute nutrients. High temperatures during the summer period, particularly in July, enhance successive growth phases until late summer. September precipitation seems to inhibit growth at the end of the growing season. Winter temperatures have little influence on tree growth.

Chronology 500, even if constructed with trees located few hundreds of meters from those of the other chronologies, shows remarkable differences both in growth trends and in relations with climatic factors. The results obtained from dendroclimatic analysis show that during the growing season, the greater differences between chronologies 300, 400, and 600 and chronology 500 are determined mainly by the different influence that precipitation has on growth. The correlation coefficients of chronology 500, in fact, show an opposite relationship with precipitation compared to those of the other chronologies, with the particular negative influence of July precipitation on ring width. This inverse relation with precipitation could be attributed to the different water availability that can affect trees of the 500 population in the event of heavy precipitation. Indeed, the topography of this part of the valley bottom is quite flat and the soil particularly rich in silt; it can therefore easily retain water, as directly observed on 2 July 2003 and 16 July 2004 (Santilli and Pelfini, 2005). Summer months show the highest frequency of rainy days and the highest amount of total precipitation: large quantities of water fall in a short amount of time and in restricted areas, become a critical factor in triggering debris flows and sheetfloods (Santilli, 2005). Finally, winter temperatures are positively correlated with the growth of the 500 population trees in the successive vegetative period.

The differences between chronology 500 and the Mean (Fig. 5d) are more marked compared to the differences among the single reference chronologies: chronology 500 has higher growth than the Mean in seven years out of the ten that exceed the established limit.

TABLE 4

Comparison between dates obtained from the differences between the 500 chronology and the Mean, and the dates of debris flow events that occurred along the Val Paolaccia and Valle della Casina fans main channels (Santilli and Pelfini, 2002; Santilli, 2005). Years with matching dates are written in bold. Years where the difference between the 500 chronology and the Mean slightly exceed the value of one standard deviation are in parentheses.

Years with enhanced growth for chr. 500 (500 vs Mean)	Years with suppressed growth for chr. 500 (500 vs Mean)	Years with debris flow events in the Val Paolaccia fan	Years with debris flow events in the Valle della Casina fan
		1941	1941
1944			
1946			
	1948	**1948**	
		1951	1951
	1953		**1953**
		1955	
			1959
		1960	
1962		**1962**	**1962**
			1964
		1970	
			1972
		1975	1975
1976			
		1977	1977
			1978
			1979
		1980	1980
1984			
(1986)		**1986**	**1986**
	(1987)		
		1990	
		1991	
		1992	1992
			1993
(1994)			
			1995
		1997	
		2000	
		2001	2001

Some of the dates obtained correspond to those of known debris flow events dated on the surrounding fans (Table 4). In particular, there is date matching in years 1948, 1962, and 1986 with the debris flows on the Val Paolaccia fan, and in years 1953 and 1986 for the adjacent fan (Valle della Casina fan; Santilli and Pelfini, 2002; Santilli, 2005). In fact, population 500 grows at the bottom of the Val Paolaccia fan, and is on the direction of the main channel, from which finer particles of transported material occasionally arrive in sheetfloods. In other years when growth differences are meaningful (1944, 1946, 1976, 1984, 1987, and 1994), there is no correspondence with dated debris flow events.

This could be due to the facts that:

- debris flows dated along the Val Paolaccia fan channel have not necessarily reached this area;
- the soil covering may not produce immediate effects on tree growth during the same year; tree responses also depend on the moment of the vegetative season in which burial occurs. This fact can sometimes induce dating errors (Braam et al., 1987);

- trees can react in different ways depending on light or deep material layer deposition. Thick deposits burying the stems can strongly inhibit radial growth because of high pressure placed on roots and because trees must develop adventitious roots (Strunk, 1995, 1997; Astrade et al., 1998); moreover, soil-water balance alteration can also occur. Other studies (Alestalo, 1971) report that light burial can cause reduced radial growth. In other cases, instead, it was found that light soil burial can induce increased radial growth consequent on nutrient and organic matter contribution from decomposed, buried, herbaceous vegetation (Heikkinen, 1994).

Conclusions

This study allows us to outline some important elements concerning upright mountain pine growth in relation to climate and also to outline the influence of nondestructive geomorphological processes on growth. This study stresses the role of climatic conditions on mountain pine growth, as deduced from significant correlations of summer temperature and precipitation. The presence of a strong climatic signal within the reference chronologies emphasizes mountain pine's potential in reconstructing summer temperatures and precipitation, especially considering its longevity (some trees found in the valley are around 300 yr old).

Concerning the growth anomalies of the 500 chronology, we can conclude that the influence of sheetfloods is probably both direct (since the new layers covering the substrate can stress the roots), and indirect because sheetfloods give a silty texture to the substrate making it more impermeable and thus altering relations with climate variables (especially with precipitation). It is important to note that the 600 chronology, even if built with trees growing on gravel in an area close to the 500 chronology, does not show different relations to climate (as with the other reference chronologies) or growth anomalies. This study also restates the importance of site selection in dendrochronology, as tree growth can be easily disturbed even by minor and not easily detectable geomorphological processes.

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