Annals of Silvicultural Research
39 (2), 2015: 100-110

http://ojs-cra.cilea.it/index.php/asr

Research paper

Stand structure and influence of climate on growth trends of a Marginal forest population of *Pinus nigra* spp. *nigra*

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Received 20/03/2015 - Accepted 11/11/2015 - Published online 15/12/2015

Abstract - The Black pine of Villetta Barrea (*Pinus nigra* ssp. *nigra* var *italica*) is a variety of the *nigra* subspecies. It is naturally distributed only in the Abruzzo Region, near the village of Villetta Barrea, with a rear-edge Marginal Population. A dendrochronological sampling of the population was implemented with the aim of studying its stand structure and the most probable interactions between growth trends and climate. Mensurational data were used to characterize the stand and, furthermore, the general correlation function (CF) and the moving correlation function (MCF), with a 30 years window, were used to assess the interrelation between the growth of the tree rings and the climate.The results indicated that the past forest management, mainly carried out with thinnings from below and selective cuttings, influenced the current structure of the forest (mean diameter) but no differences in growth trends were detected within the population. The survey on Villetta Barrea Black pine showed a positive and statistically significant correlation between the ring-width and the average temperatures of the months of December (before the ring formation - t-1), February and March; but it also showed a negative correlation with the temperatures of July, September and October of the current year (t). Moreover, the analysis with moving correlation functions suggested that, in the last decades, the population has negatively reacted to very few climate factors and, in particular, to the changes in temperatures (both minimum and maximum temperatures). This is especially true for the shifts occurred in September, the year of the ring formation.

Keywords - *Pinus nigra* ssp. *nigra* var. *italica,* Villetta Barrea, Marginal Forest Population, Abruzzo, tree-rings.

Introduction

Tree-rings analysis is becoming a common technique used for analysing forest resources, with particular regard to the marginal forest populations (Hampe and Petit 2005). It can help in: (i) investigating past endogenous and exogenous dynamics; (ii) detecting correlations between species and climate and finding pointer years (Spiecker 2002, Gallucci and Urbinati 2009); and, finally, (iii) forecasting species adaptation potential to the Global Change effects (Linares and Tiscar 2010, Amodei et al. 2012, Mazza et al. 2013). Furthermore, it is also a useful tool for the management of forest resources, because climate change may have different impacts on different forest ecosystems.

The expected changes in tree-growth might influence the competitive relationships between species, genetic pools and the geographic distribution of forest species (Lindner 2000). Following climate change effects, it is likely that forest species will migrate or will have to adapt to new environmental conditions (Parmesan 1996, Parmesan 2006).

In such a framework, and to make a better use of existing potentials and/or minimize the negative impacts of climate change on forests, conservation strategies should be developed principally in the southern Mediterranean area. A large number of “rear-edge Marginal populations” (Hampe and Petit 2005) is actually located here because the area was a glacial refugium (Petit et al. 2003, Afzal-Rafii and Dodd 2007).

In particular, the European Black pine (*Pinus nigra* J.F. Arnold 1785) can be considered a collective and Tertiary-relict species which was already present during the Pliocene, in sites where it occurs at present (Vidakovic 1974). It continued to spread during the Quaternary age (Gellini and Grossoni 2003) and, due to its wide and very discontinuous distribution, genetic and phenotypic variability is very high among populations (Isajev et al. 2004). Botanists have described at least fifteen subspecies in the course of time (Fenaroli and Gambi 1976), but today there is a general agreement on the division into six subspecies (Quézel and Médail 2003), ranging from Spain to Turkey. In spite of this, many isolated populations have been recognized, due to the fragmented range of the Black pine across Europe.

The Black pine of Villetta Barrea (*Pinus nigra* ssp. *nigra* var. *italica*) belongs to the nigra subspe-

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http://dx.doi.org/10.12899/ASR-1066

cies and is native of the Abruzzo Region (Central Italy), near the small town of Villetta Barrea (41.7768 N, 13.9374 E). The species is currently distributed on the two opposite sides of the Sangro valley, on approximately 400 hectares, and is partly included in an integral reserve in the Camosciara area (Abruzzo National Park).

In order to study the relationships between growth, climate and forest management of the Villetta Barrea Black pine, we investigated the only official seed stand for the *italica* variety of *nigra* subspecies existing in Italy and in Europe (code number "ABR04" of the Regional Register of the Basic Material of Abruzzo), which is also the only managed part of this Marginal Forest Population (MaP). Mensurational data were used to determine the stand structure in relation to the site attributes and the past management, while the tree ring series were analysed to determine the influence of climate on growth trends.

Materials and methods

Study area and silvicultural history

The seed stand covers an area of about 105 hectares which is characterized by a typical Mediterranean climate (Fig. 1). It is mainly a pure-pine stand, variously mixed with beech stools, mostly in the more humid zones and at the higher elevations. The last management plan of the Municipality of Villetta Barrea (valid for the period 2002-2011), divided the seed stand into five compartments (see Tab. 1).

Many documents were found in the repository of the forest administration of Villetta Barrea and reported in the last management plan (Chapter 5 of the approved document). Even if very few documents described the past silvicultural treatment, the main practice of the past was a sort of selective felling. It is mentioned that the oldest cutting dates back to the early 1600, when the Black pine was used principally for buildings and infrastructures. A sort of selective logging was often conducted across the whole area, until the first decades of the twentieth century.

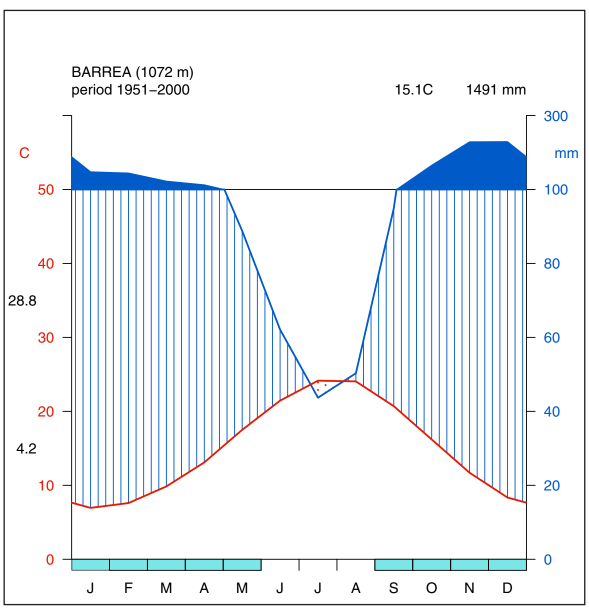

Figure 1 - Walter & Lieth diagram for the location of Barrea, the nearest meteorological station to Villetta Barrea.

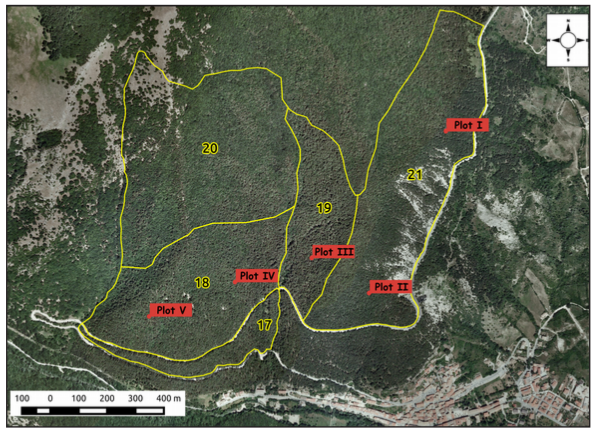

Figure 2 - Spatial distribution of survey plots (red points and labels) and forest compartments (yellow lines and numbers) across the investigated area.

Many economic transactions were registered by the forest administration, reporting the amount of the sold trees, the purchaser and the price. A few trees were also felled for the internal use of the community of Villetta Barrea.

Since 1924, the National Forest Service (office of Villetta Barrea) promoted a change, from this type of selective felling, towards an even-aged silvicultural approach which was aimed at giving more light to the soil; this condition being believed to better maintain the black pine in pure stands. Nevertheless, this practice was never really applied and pine stands have been slowly abandoned.

Survey of mensurational parameters

Five circular plots with 20 metres radius were placed in the study area to describe stand variability (Fig. 2). Plot position was initially chosen following a random but stratified criterion (one plot per compartment). However, after a first field survey, two compartments were excluded from the analysis: (a) the unit 17, because too small and without any substantial structural difference from unit 18 (Tab. 1); (b) the unit 20, mainly dominated by beech coppice black pine, being present only with isolated trees or small groups.

Consequently, 2 of the 5 plots were re-assigned to the two larger compartments (18 and 21). The position of each plot was recorded using GPS and all the sampled trees were numbered, making the plots permanent for any further analysis or survey.

In each plot, we measured the diameter at breast height (DBH) of all trees and the total height on a

Table 1 - Main characteristics of the analysed compartments and survey plots.

Compartment	Area	Elevation	Slope	Aspect	Plot
17	5.13 ha	1080 m	40%	S	-
18	22.63 ha	1175 m	50%	SE	IV ; V
19	11.64 ha	1200 m	50%	W	III
20	33.74 ha	1470 m	60%	SE	-
21	31.86 ha	1200 m	65%	SE	I ; II

representative sample of 10-15 trees (25% of total number). Also the trees volume of each species was calculated with the ForIT package (Puletti et al. 2014) of R Cran software (R Core team 2014), i.e. the implementation of the biomass and volume models worked out by Gasparini and Tabacchi (2011) and Tabacchi et al. (2011) for the 2nd Italian National Forest Inventory (INFC 2005).

A non-parametric ANOVA on DBH was performed to assess the differences between plots. Each plot was considered as a different treatment, while differences among the plots in slope and aspect were included into the error variance.

Dendrochronological sampling

The dendrochronological samples were collected following the "Principle of aggregate tree-rings" (Cook 1987) this being the more largely used in dendrochronology. The principle states that any individual tree-growth series can be "decomposed" into an aggregate of environmental factors, both "endogenous" and "exogenous", affecting the pattern of tree-growth over time. The terms "endogenous" and "exogenous" are used to differentiate forest disturbances developed by the trees themselves (endogenous), from disturbances arising from processes independent from the forest (exogenous). For instance, the gap-phase is an endogenous stand dynamics process, whilst an insect attack or a thinning implementation are exogenous processes.

The aggregate series in a fixed moment " t " can be expressed with the formula [1]:

$$R_t = A_t + C_t + D1_t + D2_t + E_t$$

where:

- R_t is the observed ring-width series;
- A_t is the age-size related trend in ring-width;
- C_t is the climatically-related environmental signal;
- $D1_t$ is the disturbance pulse caused by a local endogenous disturbance;
- $D2_t$ is the disturbance pulse caused by a stand-wide exogenous disturbance;
- E_t is the largely unexplained year-to-year variability not related to the other signals.

A_t, C_t, and E_t are assumed to be continuously present in R_t, while $D1_t$ and $D2_t$ may or may not be present depending on a disturbance occurred at a considered time or not. When the aim is to study the relationships between growth (R_t) and climate (C_t), the other factors should be minimized and, consequently, a correct sampling of the trees is very important.

Following the structure of the formula, a data collection and a subsequent pre-analysis on the seed stand of Villetta Barrea were made to minimize the effects of A, D1 and D2 and maximise C. After the forest mensuration survey, 5-7 cores at each plot (depending on the abundance of suited trees) were extracted with a 5-mm diameter increment borer, at breast height, from healthy, dominant and straight trees, to maximize the effect of "C". Each series was then prepared in the lab on a wooden support, measured with LINTAB6® and cross-dated to minimize or eliminate any probable error due to missing rings or reading mistakes. Afterwards, each tree-ring series was standardized separately with a double detrending procedure. The negative exponential curve was used to remove the trend due to the tree circumference increasing with age (A), whereas low-frequency variance and other disturbances (D1 and D2) were removed using a spline function (Cook 1981) with a 50% frequency response (cut-off) of 10 years to emphasize higher inter-annual frequency climatic variance (Cook 1981, Biondi and Visani 1993, Amodei et al. 2012).

Before any classical climatic correlation analysis, and in order to complete the information derived from ANOVA on DBH, both not-standardized and standardized tree ring series were also used, in a second ANOVA, to asses differences between plots (for the common growing period only). The analysis was performed to check dissimilarities and to verify if the plots were grouped in the same way as DBHs .

The influence of climate on tree-ring growth was investigated using the mean correlation function (CF) and the moving correlation functions (MCF) based on Pearson's correlation coefficients (Fritts 1976). CF and MCF are based on the same assumptions but they use different principles and time-periods. While CF takes into account the whole growing period of trees, MCF uses a smaller interval of time repeated for the whole period (generally 20-30-40-50 years, depending on the available data, species sensitivity and case-study). In this case, a 30-year window was used to avoid biases which could be induced by extreme events and to retain the influence of mid-frequency climate variations. Each moving window analyzes a cycle of 30 years, going forward from year to year. In both cases (CF and MCF) monthly climate variables (maximum, minimum temperatures and monthly precipitation) were sequenced from October of the previous year

Table 2 - Mean mensurational values of survey plots.

PLOT (Comp.)	M_dbh (cm)	CV_dbh	M_ht (m)	Tr/ha (m^2)	G/ha_P (m^3)	Vol/ha_P (m^2)	G/ha_B	Age
I (21)	24.5	42%	13.9	1138	46.6	321.0	1.3	124-179
II (21)	26.4	56%	14.3	923	50.6	372.5	0.2	104-145
III (19)	22.8	64%	11.8	1082	39.6	259.7	0.7	143-184
IV (18)	28.0	35%	19.5	1178	60.2	574.5	0.8	80-99
V (18)	28.3	41%	16.52	724	45.7	266.0	2.0	104-118

M_dbh = mean diameter at breast height; CV_dbh = coefficient of DBH variation; M_ht = mean height; Tr/ha = number of trees ha^{-1}; G/ha_P = Basal area of Pinus ha^{-1}; Vol/ha_P = Volume of Pinus ha^{-1}; G/ha_B= Basal area of Broadleaves ha^{-1}

(t-1) to September of the year of growth (t) and the results of the correlation functions were tested for significance using the 95% percentile range method after a bootstrap process with 1,000 replications.

The *dplR* package (Bunn et al. 2014) and the *bootRes* package (Zang and Biondi 2012) of R cran software were used for the tree ring series management and the computation of the climatic correlation.

Climatic data

Data from a weather station located in the Barrea village (41,7570 N; 13,9919 E approx. 1,000 metres a.s.l.) were initially made available. Data series were anyway discontinuous, especially regarding rainfall. To get through the problem, a complete dataset was derived from ClimateEU database (http://www.ualberta.ca/~ahamann/data/climateeu.html), an unpublished software for the interpolation of climate data from PRISM database (Daly et al. 2008). It was applied for monthly precipitations and temperatures from 1901 to 2009. ClimateEU data were compared with local data calculating the fitness of ClimateEU tested with a regression method. In addition, Mann-Kendall non-parametric test was applied to assess the presence of climatic trends, possibly influencing the analysis (Brunetti et al. 2006).

Results

Mensurational data were collected during the growing season 2012 and are summarized in Tab. 2, Fig. 3 and 4. Mean DBH ranged between 22.8 cm (plot III) and 28.3 cm (plot V) whilst maximum tree height varied from 23 m (plot IV) to 16.1 m (plot III). The highest values of tree mean height (19.5 m), number of trees (1,178 ha^{-1}), basal area per hectare (60.2 m^2 ha^{-1}) and volume (574.5 m^3 ha^{-1}) were measured in plot IV. Plot III had the lowest mean tree height (11.8 m), basal area (39.6 m^2 ha^{-1}) and volume (259.7 m^3 ha^{-1}) and the highest variation of DBHs (64%). In addition, plots III and IV were characterized by the oldest and the youngest dominant trees, respectively. Height curves are compared in Fig. 3. Plots I, II and III were shaped similarly as for slope but with different values. In general, the stand structure revealed to be very variable chiefly for mean tree height and standing volumes.

The ANOVA on DBH confirmed the high variability and, as expected, grouped plots exactly according to compartments (Tab. 3 and Fig. 4).

The dendrochronological sampling was implemented in the following year (2013) before the start of the growing season. The main statistics on tree rings series, plot chronologies and mean stand chronology are reported In Tab. 4. The age of dominant trees ranges between 80 and 184 years with a mean annual increment between 0.627 mm (Plot IV Tree 1 - P4T1) and 1,967 mm (Plot V Tree 1 - P5T1). Sensitivity was generally low whereas the first order autocorrelation was quite high, it emphasizing the high inter-annual correlation between tree-ring widths. Calculating first-order autocorrelation coefficients on standardized indices, the absolute values ranged between 0.11 and 0.22. That means that only a small amount of the low-frequency year-to-year variation was not corrected with the standardization procedure.

Similarly to DBH ANOVA, the analysis on raw tree rings series on the common growth period (1933-2012) too, showed statistically significant differences among plots. Plots were however grouped differently following the age of sampled trees (Tab. 5 and Fig. 5). As expected, ANOVA on detrended (i.e. standardized) chronologies did not show the same differences (Fig. 6).

Before the searching of climatic correlations, ClimateEU data were carefully checked and compared to local data for the common time-period available (1955-2010). Regressions were always highly significant with a very high adj-R2 for temperature, but not for precipitation due to many missing values (mainly for storage errors) in the Barrea's database. At all

Table 3 - Results of Kruskal-Wallis Rank Sum Test and relative post-hoc test (Wilcoxon Rank Sum and Signed Rank Tests).

Statistical Mean DBH	Plot (compartment)	Group
26.43	IV (18)	A
26.28	V (18)	A
23.03	II (21)	B
22.63	I (21)	B
19.19	III (19)	C

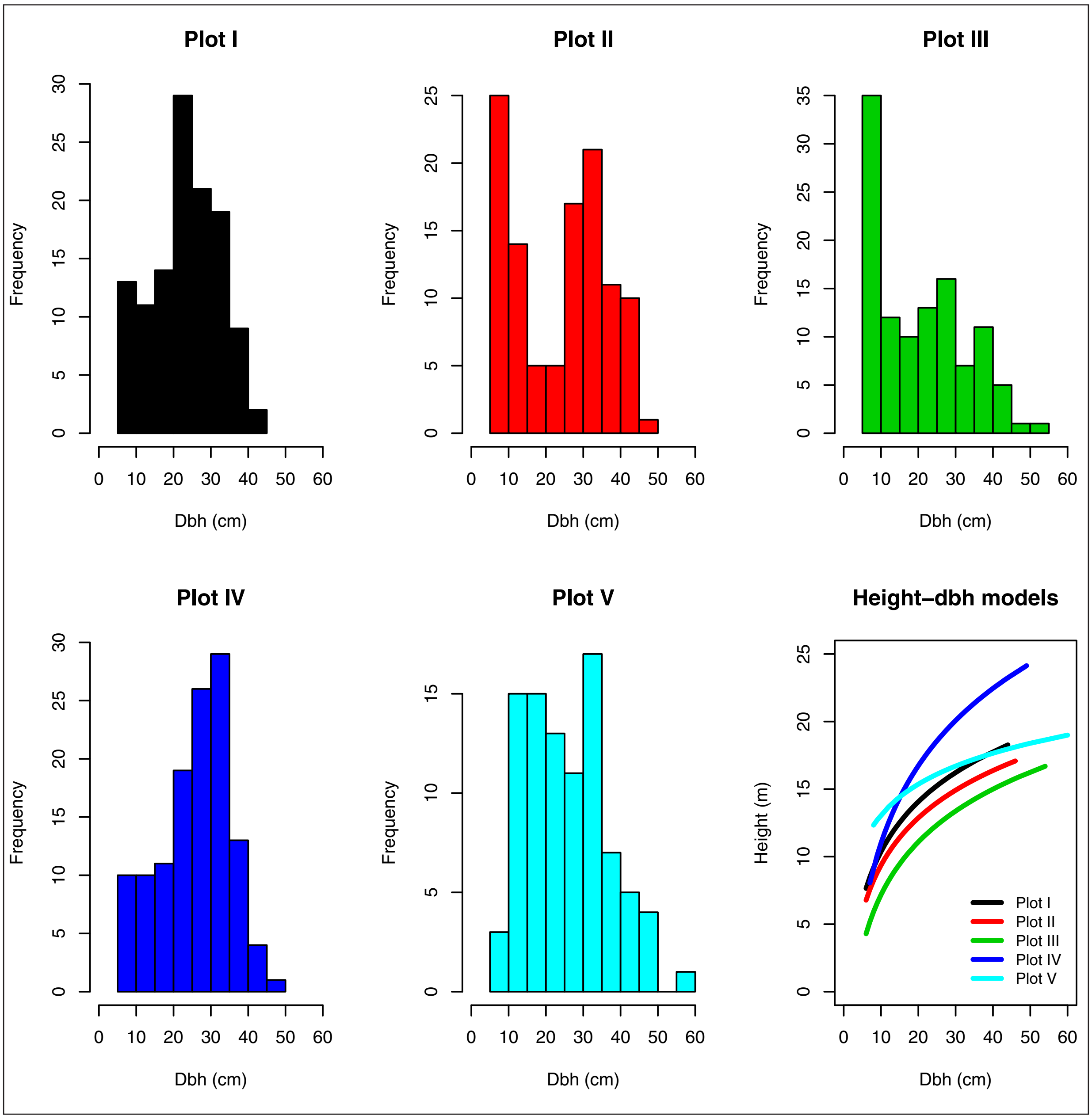

Figure 3 - Histograms of dbh values in each plot and comparison between the height-dbh models.

cases, however, the slope of functions showed a very high p-level, that means both the ClimateEU's and the Barrea's trends were statistically comparable (Tab. 6).

The Mann-Kendall test assessed the absence of climate trends, even if a growing linear trend in annual maximum and minimum temperatures was observed (Fig. 7) with +0.009°C/year for minimum and +0.004°C/year for maximum temperatures. Particular trends were detected only over the periods 1900-1940, 1941-1975 and 1976-2010. Over the first period, minimum temperatures, compared with maximum temperatures, were detected as growing more rapidly (+0.015°C/year vs. +0.006°C/year). Within the central period, minimum t. remained quite stable whilst maximum t. had a sensible decrease until 1960, reaching the same values of the early 1900. Over the third period, temperature continued to rise with close mean values (+0.029°C/year for minimum temperatures and +0.026°C/year for maximum t.). The same periods and trends were analysed for the precipitation amount. Very low adjusted-R2 (0.07-0.04) were detected, demonstrating lack of statistical relationships. Nevertheless, a general decrease between 1901 and 2010, even if relatively low (approx. -1.02 mm/year), was quite clear (Fig. 8, third plot with green line).

Correlations between species' growth and climate were then detected with CF and MCF, these showing different trends and results. With CF a significant and positive correlation was found with the minimum temperatures (Fig. 8) of the previous month of December, and the months of February and March of the same year, whilst a negative cor-

Table 4 - Main statistics of tree rings series.

Series	First	Last	Years	M	SD	SK	S1	S2	G	AR	ARS
M-P1	1834	2012	179	1.080	0.847	2.287	0.123	0.127	0.287	0.926	0.142
M-P2	1868	2012	145	1.137	1.493	1.163	0.156	0.157	0.359	0.899	0.100
M-P3	1829	2012	184	1.036	0.679	2.692	0.147	0.151	0.279	0.925	0.067
M-P4	1914	2012	99	1.745	0.785	0.698	0.165	0.162	0.249	0.872	0.060
M-P5	1895	2012	118	1.984	1.62	1.916	0.156	0.157	0.402	0.852	0.078
chrono	**1829**	**2012**	**184**	**1.578**	**0.823**	**1.165**	**0.141**	**0.146**	**0.278**	**0.873**	**0.081**

M = mean increment (mm); SD = standar deviation; SK = Skewness; S1 & S2 = sensitivity of first and second order; G = Gini coefficient; AR = Autocorrelation; ARS = Autocorrelation after standardization.

relation was found with the minimum temperatures of July and September of the current year. The maximum temperatures (Fig. 9) of the same winter months were correlated in the same way (positive), whilst a negative correlation was detected only for May within the same growing season. Concerning precipitation, the growth was significantly and negatively correlated only with the events of the previous December (Fig. 10). The analysis with MCF (Fig. 11) highlighted many periods in which we had a significant relationship between radial growth and climate. Whilst some of them were roughly stable with time, others appeared unstable throughout the period. The main correlations with temperatures were generally confirmed, even if not continuously, across the whole time-series. The minimum temperatures of August and September were negatively correlated over different decades. More evident and continuous correlations were detected with the minimum temperatures of February and March but only until 1950. Furthermore, only the minimum temperatures of March were significant, but only between 1975 and 1982. Other positive correlations were present and more continuous in the considered period and concerned maximum temperatures of the same months. As for the last decades of the concerned period, significant correlations were found only during October (minimum), December and September (maximum). In relation to the rainfall amount, very low and fragmented events were detected, especially in the last period (1973-2010) and regarding May and June of the growing season (t).

Discussion

The seed stand of the MaP is a pure Black pine forest where broadleaves are quite sporadic and relatively more present where local conditions (such as ditches or cooler exposures) allowed them to be more competitive. In general, the vertical structure of stands showed two well-recognizable levels with Black pine as dominant species. Beech and ash were particularly present as stools following the selective cutting operated in the past and the animal browsing. In many areas, above all where beech was unable to compete, such as where we

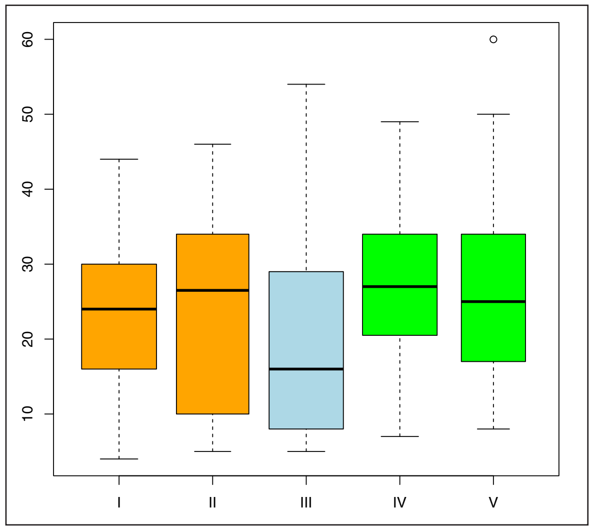

Figure 4 - Boxplot of DBH values.

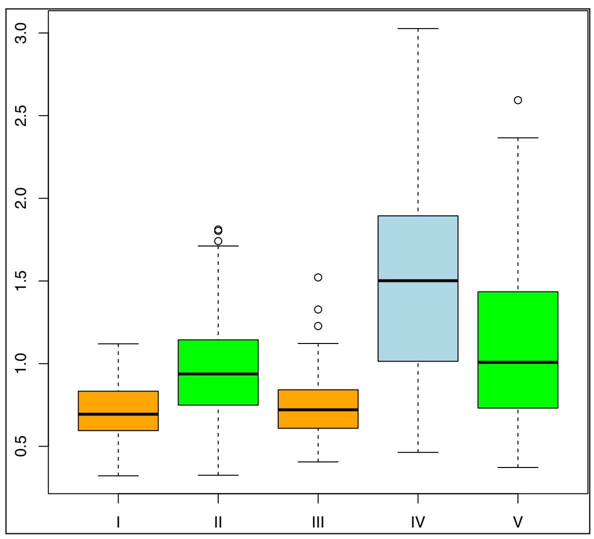

Figure 5 - Boxplot of ringwidths of raw chronologies.

Table 5 - Results of Kruskal-Wallis Rank Sum Test and relative post-hoc test (Wilcoxon Rank Sum and Signed Rank Tests) on raw chronologies on the common growth period.

Statistical Mean ringwidth	Plot (compartment)	Group
1.515 mm	IV (18)	A
1.137 mm	V (18)	B
0.973 mm	II (21)	B
0.744 mm	III (19)	C
0.710 mm	I (21)	C

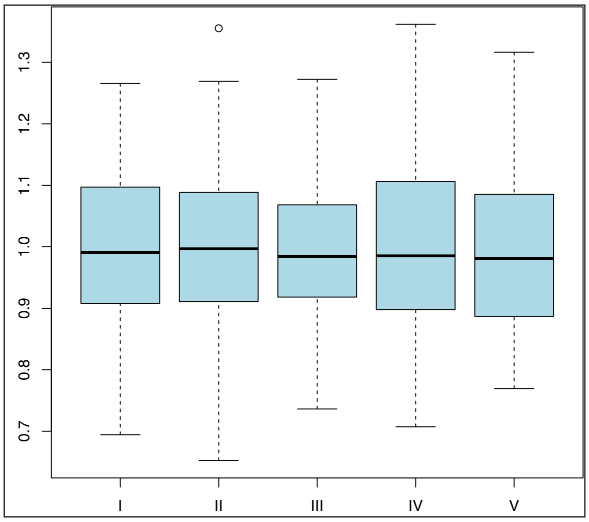

Figure 6 - Boxplot of ringwidths of detrended chronologies.

Table 6 - Results of regressions analysis based on the linear formula y = mx + q. Significance of parameters are reported with the following legend: p<0.1 (.), p<0.05 (*), p<0.01 (**), p<0.001 (***).

Variable	Adj R^2	Intercept (q)	Slope (m)
Minimum annual temperature	0.927	-0.655***	0.918***
Maximum annual temperature	0.977	2.617***	0.955***
Total annual precipitation	0.369	15.705**	1.143***

have southern exposures or shallow soils, Black pine occupied both levels.

Stand data collected in 2012 did not show any significant difference between the present time and the situation before the approval of the last management plan. In fact, any practices' implementation was reported by the management administration during the years 2001-2011 and no traces of tree felling were detected on the ground. ANOVA on DBH showed that forest structure was influenced by forest management, but also that mean radial increment was mainly influenced by stand age, site quality and ecological dynamics. According to our results, three different stand structures could be identified as follows:

• Even-aged adult stands (compartment 18 - plots IV and V): pine stands in these plots can be considered as even-aged with trees from medium to large size- and small DBH variation. The standing volume was chiefly related to the high number of medium-sized trees, and ranged from 259 m3 ha-1 to 574 m3 ha-1. The maximum age of dominant trees varied between 80 and 120 years, small-sized trees were sporadic and mainly young broadleaves. Maximum tree height was 21 m.

• Even-aged stands with old trees (compartment 21 - plots I and II): These plots can be considered as even-aged; the plot II had a high number of small-sized trees with DBH lower than 15 cm, probably due to a natural regeneration process. Standing volumes were quite similar, around 350 m3 ha-1 but the age of the bigger trees was very variable, ranging from 104 to 179 years.

• Uneven-aged stands with very old trees (compartment 19 - plot III): mean DBH and tree height

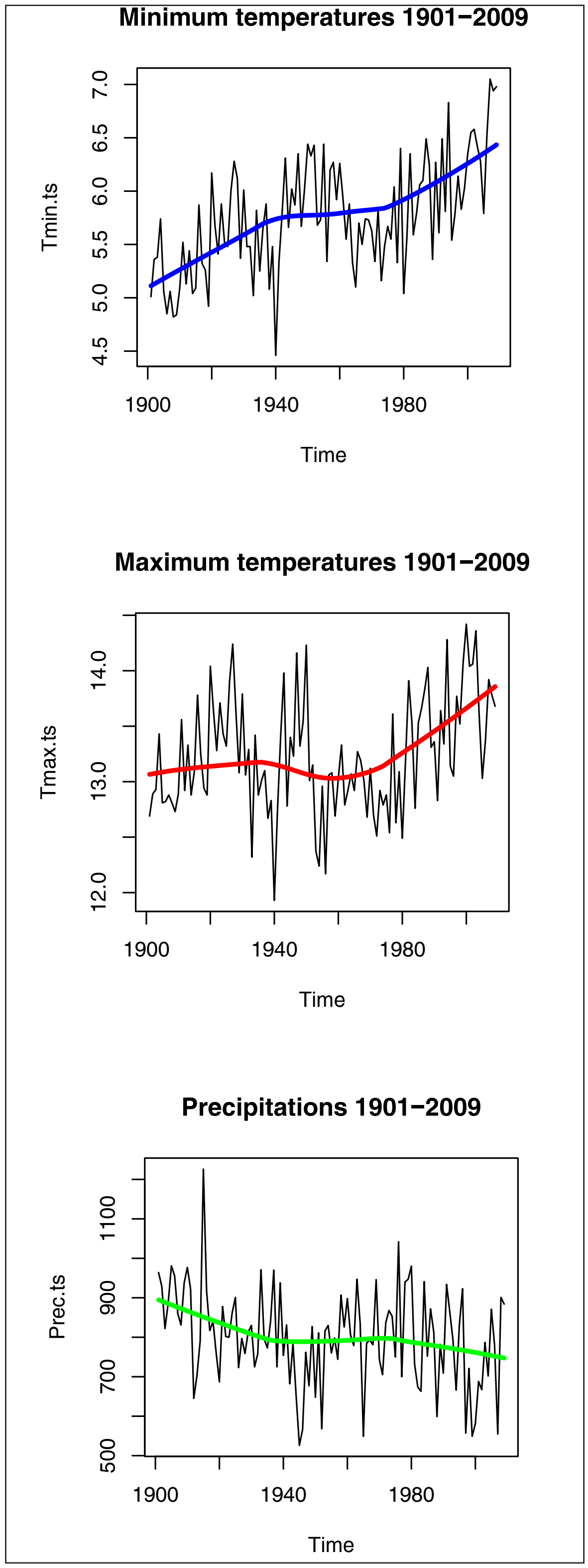

Figure 7 - Trends of minimum (blue line) and maximum (red line) annual temperatures and annual precipitations (green line) from 1901 to 2009 in Villetta Barrea (ClimateEU data).

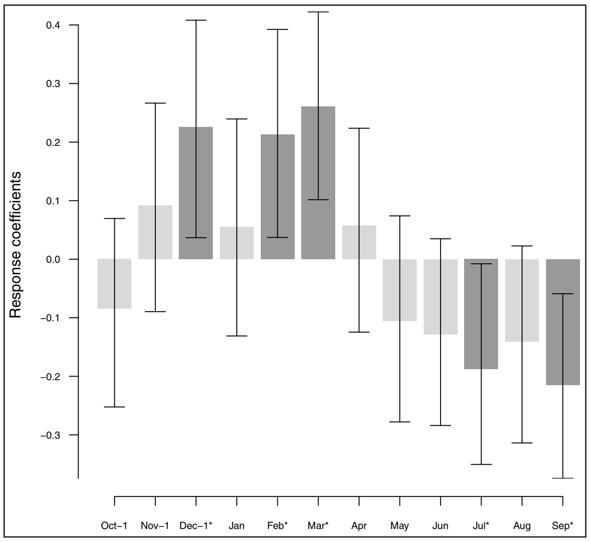

Figure 8 - Correlation function for Minimum temperatures.

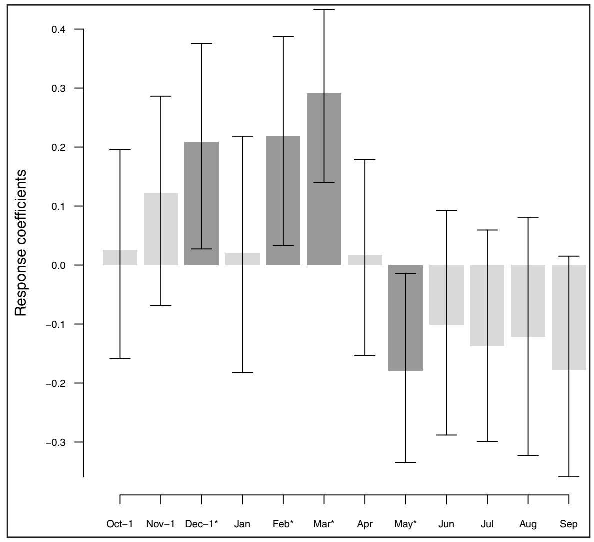

Figure 9 - Correlation function for Maximum temperatures.

were the smallest surveyed over the whole area. Tree density was very high, surely due to the high number of small-sized trees, and the coefficient of variation of DBH was high too, this indicating a very variable vertical structure. Standing volumes were the lowest measured, around 250 m3 ha-1. This stand could be considered as uneven-aged, where Black pine has established a natural regeneration dynamics. In this area the oldest (dominant) trees are aged from 143 to 184 years.

Climate influenced in the same way the growing trends, despite differences in age and size of trees. Dendrochronological analyses demonstrated that, despite a different mean increment in each of the sampled areas, mainly related to tree age, trees reacted in a similar way.

As reported in many other studies on Black pine spp., sensitivity to high summer temperatures was confirmed (Génova and Fernández 1999, Martin-Benito et al. 2010, Amodei et al. 2012). On the other hand, no continuous and recent correlation with the precipitation amount effect was detected, this probably depending on two main factors: the autecology of the Black pine of Villetta Barrea and the local soil structure. Black pine of Villetta Barrea is a bit more tolerant to drought stresses than other *Pinus nigra* subspecies (Gellini and Grossoni 2003). In addition, soil and local ecological conditions can increase or reduce water availability during different seasons as well as the amount of snow in winter.

It has been demonstrated that growth response and climate must be analysed in accordance to soil substrate characteristics and that pines on quartzite bedrock are much more sensitive to the precipitation amount than similar populations on dolomite and calcareous bedrocks (Génova and Martinez-Morillas 2002). In calcareous soils, the effect of the chemical alteration of the bedrock may offer to

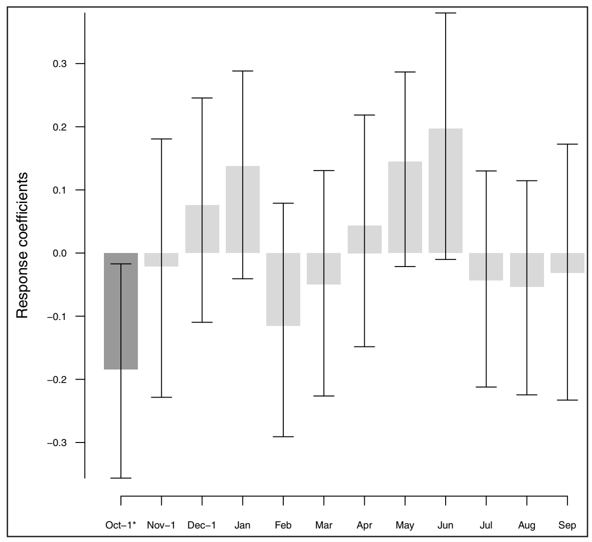

Figure 10 - Correlation function for Precipitations.

pine roots the opportunity to explore deeper levels (Amodei et al. 2012).

A positive correlation between radial growth and late-winter temperatures (February and March) in CF results was also reported by Linares and Tiscar (2010) on Salzmann pine in southern Spain. In this situation, trees may open buds earlier and, consequently, increase the length of the growing season. This is very likely to occur in Villetta Barrea, where water availability does not appear to be a problem. Results from MCF analysis pointed out few months with very unstable correlation and the lack of statistical significance over the last decades. The months detected as main driving forces with CF, proved to be relevant only for past events such as the temperatures of February and March. The endemic population of Villetta Barrea seemed to be less sensitive than a few planted stands analysed by Piermattei et al. (2014).

Some factors, not relevant with CF, turned out to be important with the MCF analysis and especially

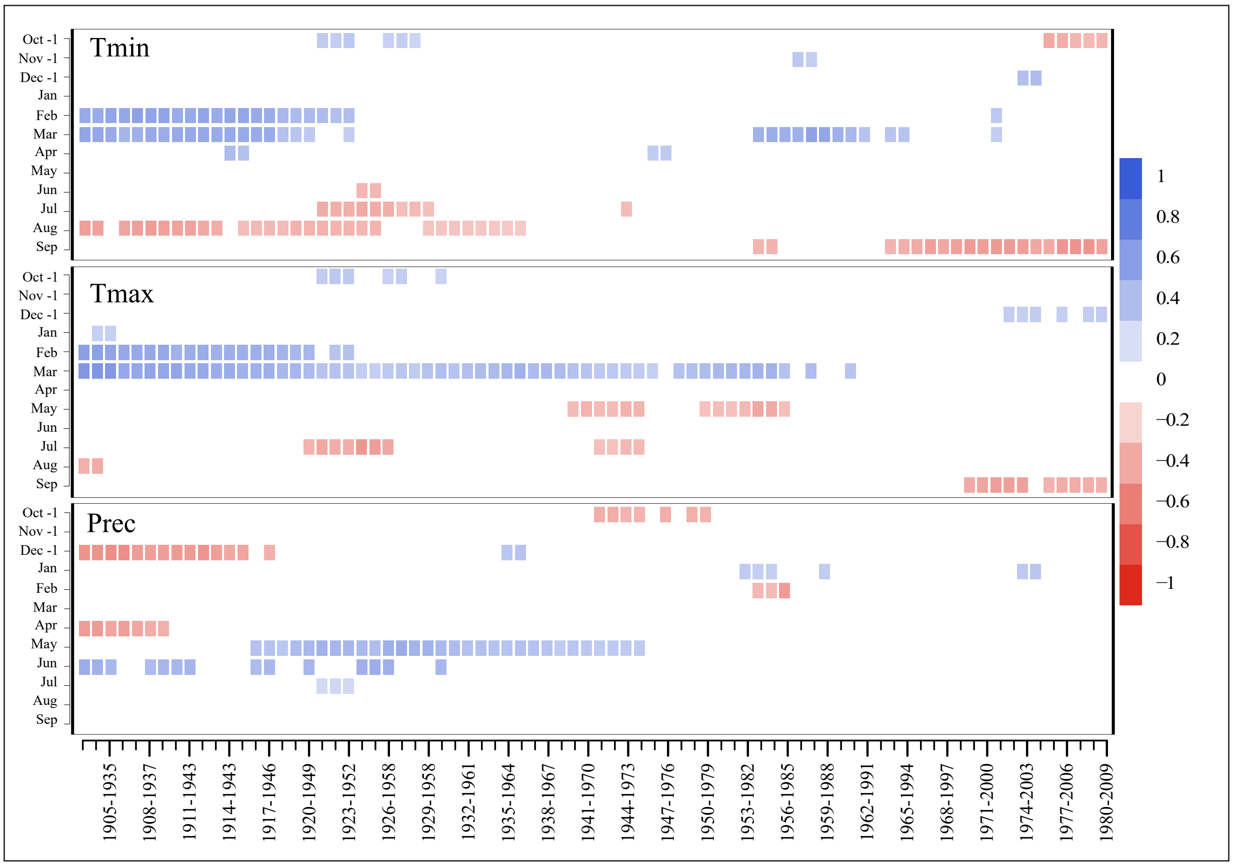

Figure11 - Result of the analysis with moving correlation function from period 1901-1930 (the first on on the left side) to 1980-2009 (the last on on the right side). Only significant correlations (p-value > 0.05) are reported.

concerning the last decades, such as the minimum temperatures of the previous October. In addition, also the shifted response from August to September was detected. In fact, the minimum temperature of August was statistically significant only in the past decades as long as the late '60s, whilst the same variable in September becomes relevant over the last decades. In this case the connection is probably linked to the cold stress that is likely to occur in late September at high elevation. High temperatures in late summer months can induce a longer growing season which can suddenly stop when an extreme event occurs. In this case, the moving windows approach of MCF appeared as a very good tool to address the study of forest species adaptability to climate change.

Definitively, the temperatures of September demonstrated to be the main driving force for the growth of Black pine of Villetta Barrea in the MaP and, in any case, the genetic provenance must also be accounted as a possible driver for variability.

Conclusions

Tree-ring analysis showed that the relationship between radial growth and climate was not affected by different stand structures and tree ages. The influence of climate factors is currently no longer active and the species is probably adapting to a new-established, changing environment. This will probably play a key role in the future and it is an issue to be duly taken into account in the management planning.

Many other questions and issues must be developed to cover all the possible analyses connected to marginal forest populations and to the management of forest genetic resources in view of the expected Global Change. For instance, the available information about tree species genetics and local adaptation progress must be carefully accounted.

The comparison between the population of Villetta Barrea and other populations and subspecies (mainly *nigra* and *laricio*) was useful to assess whether the one examined here is a case of genetic adaptation or an example of phenotypic plasticity and further similar surveys should be encouraged.

Acknowledgements

This study has been carried out as part of the ABRFORGEN project "*Implementation of forest nursery chain and organization of a modern management of forest genetic resources in Abruzzo*" a partnership between CREA-SEL and Abruzzo

Region and the COST Action FP 1202 "*Strengthening conservation: a key issue for adaptation of marginal/peripheral populations of forest trees to climate change in Europe (MaP-FGR)*". We thank also the Regional Agro-meteorological Center of Scerni for providing climatic data and scientific support.

The authors also thank the reviewers for helpful comments on an early draft.

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