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STRUCTURAL AND DENDROCHRONOLOGICAL CHARACTERIZATION OF MOUNTAIN PINE PERSISTENT WOODLANDS ON THE MONTI DEL SOLE - DOLOMITI BELLUNESI NATIONAL PARK

High-mountain ecosystems, located at the geographical distribution limit of the species, may provide valuable information about tree-growth responses to changes in climate conditions and land uses. In order to provide a first description of a mountain pine ecotone, at the alpine treeline, three plots were sampled along an altitudinal gradient in the Monti del Sole (Dolomiti Bellunesi National Park, Veneto, Italy) on a northwestern slope from 1850 to 2000 m a.s.l. In order to reconstruct recent dynamics of Pinus mugo *Turra ssp.* mugo *(mountain pine) at this altitudinal range dendroecological methods were used, which allowed reconstructing the age structures of tree populations. Raw mean chronologies showed the long-term variability, related to non-climatic signals due to age, size and stand dynamics. The raw mean chronology of Plot 1 followed the typical exponential negative trend, while raw mean chronologies of Plot 2 and Plot 3 depicted an increasing growth trend, starting from early fifties of 20*th *century. There was a greater ring width in Plot 2, than the other two plots. These mountain pine scrublands belong the* Sorbo chamaemespili - Pinetum mugi *association and form persistent woodlands.*

Key words: mountain pine; dendrochronology; alpine treeline; Dolomiti Bellunesi National Park.
Parole chiave: pino mugo; dendrocronologia; treeline alpina; Parco Nazionale Dolomiti Bellunesi.

1. Introduction

In high-elevation forests, tree growth is mainly constrained by physical components of the environment (Körner, 1999). High mountains ecosystems are therefore considered particularly vulnerable to climate change

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(BENISTON, 1994; GRABHERR *et al.,* 1995; BENISTON *et al.*, 1996; THEURILLAT & GUISAN, 2001).

The high altitude limit of forests, commonly referred to as treeline, timberline or forest line, represents one of the clearest vegetation boundaries. However, a transitional belt known as the treeline ecotone exists between closed canopy mountain forests and treeless alpine vegetation (KÖRNER & PAULSEN, 2004).

Trees in this environment are exposed to a range of stresses including low temperatures, prolonged frost events, high irradiation and limited soil nutrition (LEHNER & LÜTZ, 2003). The progressive increase in global mean temperature (0,74 ± 0,18 °C, in the last 100 years until 2005 - IPCC 2007), with a marked rise since the early 1980s (BENISTON *et al.*, 1997), influences tree ecophysiology, productivity and distribution.

Alpine plants have been shown to respond to climate warming by expanding their altitudinal range or by increasing their growth rates (GINDL, 1999; PAULSEN *et al.*, 2000; MOTTA & NOLA, 2001). In conjunction with climatic influences, land use changes, such as spontaneous recolonization of forest ecosystems, following the abandonment of human activities (grazing, mining, cutting), affects the Alpine treeline ecotone; it is often occupied by prostrate shrubs *(krummholz)* that represent as a transition zone between closed forests and alpine meadows.

The study of tree growth responses to climatic change allows assessing future forest productivity, vegetation dynamics, plant diversity and species richness, and evaluating tree-rings based on temperature reconstructions (BRIFFA *et al.,* 1998, BÜNTGEN *et al.,* 2006). A valid approach is measuring tree-ring width at the tree line, which provides information on past growth rates in a sensitive environment (BÜNTGEN *et al.*, 2007); radial growth of trees from higher elevations generally reflects temperature variations, whereas radial growth of trees from lower elevations generally mirrors precipitation changes (SCHWEINGRUBER, 1996).

The subject of this research is the population of *Pinus mugo* Turra ssp. *mugo* (dwarf pine, mountain pine) located on the Dolomiti Bellunesi National Park. At the treeline, mountain pine grows adjacent to the soil, forming the «krummholz mat»; this ecotone, in alpine environments, was subject to the traditional practice of grazing and continuous cuts, to produce charcoal that was used in nearby mines. These activities shaped the growth of subalpine and alpine vegetation until 1993, when the Dolomiti Bellunesi National Park was established, including these mountain pine populations, since then subject to environmental custody.

In order to reconstruct the population dynamics of mountain pine treeline forests on Alpine environments, we studied its structural and dendrochronological characteristic. In this paper, the preliminary results obtained during the first sampling campaign are shown.

2. Methods

2.1. Study area

Pinus mugo, which occurs in the mountains of the Central and southern Europe, has a disjunctive range divided into several islands. In the Alps, the dwarf mountain pine grows between 1500 and 2500 m a.s.l., with the maximum at 2700 m (Montacchini & Caramiello, 1968; Montacchini, 1968; Boratyńska *et al.*, 2005).

In the Dolomiti Bellunesi National Park, over the top range of distribution of the arboreal vegetation, subalpine bush formations may be found. Their composition varies according to sunlight exposure, soil humidity, and the nature of the rocks. The dolomitic limestone cliffs and debris cones are colonized by mountain pine, which may form thick and impenetrable scrubs (Monti del Sole, Piani Eterni, Ramezza). In mountain pine formations, *Rhododendron hirsutum* and the *Clematis alpina* may frequently be found. However, mountain pine formations are also common in low altitude rocky environments.

In this first survey, we considered the scrublands of mountain pine on the Monti del Sole (Fig. 1), which represents the most inaccessible area of the Park, the real "wild heart" of Dolomiti Bellunesi. The highest peak is Piz de Mezzodì or Pizzon (2.240 m). Several gorges and narrow lateral valleys edge the sides of Monti del Sole, making their access difficult, as well as their high landscape heritage.

2.2. *Sampling and analysis methods*

One sampling site was selected at Col Bel (12° 01' 11.752"E, 46° 12' 55.113"N), as a possible site with older mountain pine, where three circular plots (Plot 1, Plot 2 and Plot 3 top-down), of 5 m radius, were made along an altitudinal gradient between 1850 and 2000 m a.s.l. (Fig. 2), with the same northwestern aspect. For each plot the N° of trees was recorded and for each trees present the diameter (cm) at the base of the trunk was measured, as well as the position (distance and azimuth from the centre of the plot). DBH could not be observed due to the prostrate habit of the mountain pine.

Finally, phytosociological surveys were carried out on vegetation to describe the typical species of the plant community. The plots were identified by applying phytosociological-sigmatista methodology, described by Braun-Blanquet, using the abundance-dominance coefficient.

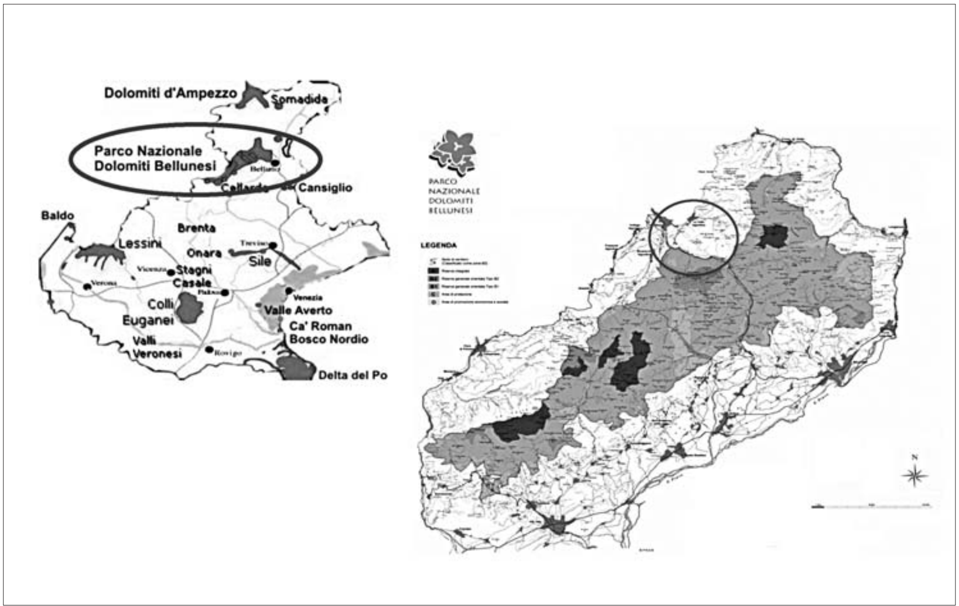


Figure 1 – Localization of the Dolomiti Bellunesi National Park in the Veneto Region, and the study area of Monti del Sole within the Park.

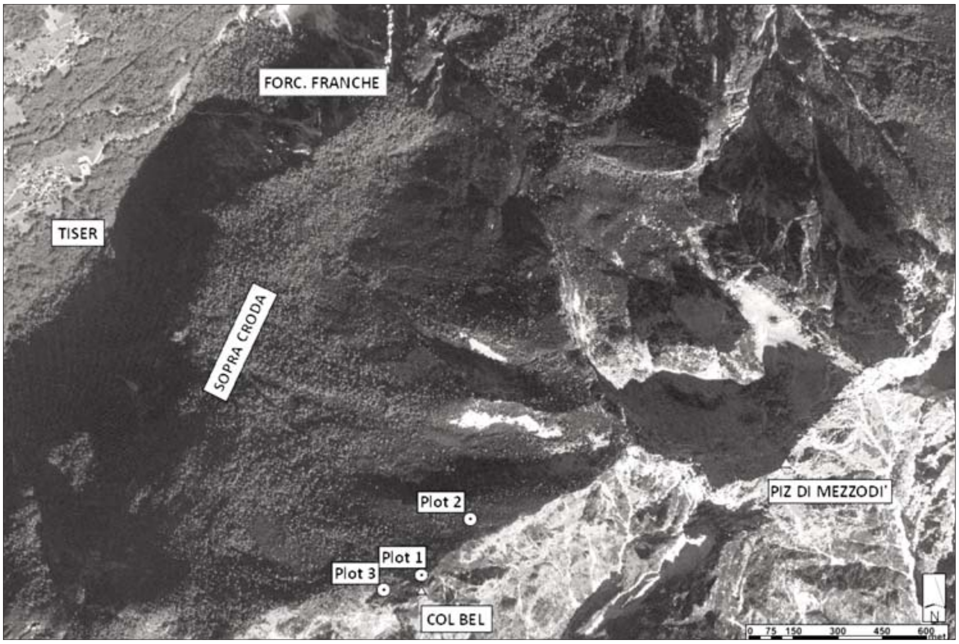


Figure 2 – Location of three plots in the sampling sites (Col Bel) on the basis of the digital ortophotos, 2006 (PCN - www.minambiente.it).

To construct age-class frequency distributions and to develop tree-ring growth chronologies, all stems at the base of the trunk were cored. One core per stem was usually sampled, but some stems were re-cored if the first core missed the pith. Cores were mounted and sanded using progressively finer grades of sandpaper until the growth rings were clearly visible (Fig. 3).

Tree-ring widths were measured to the nearest 0.01 mm with LINTAB-measurement equipment coupled to a stereomicroscope (Leica S4E, Germany) and Time Series Analysis Program (TSAP) software (Frank Rinn, Heidelberg, Germany). Cross dating of all the tree-ring chronologies was verified and corrected with the Program COFECHA, which assesses the quality of cross dating and measurement accuracy of tree-ring series using the segmented time-series correlation technique (HOLMES, 1983).

The successfully cross-dated raw chronologies per tree were averaged to obtain a mean raw chronology per plot. The raw chronologies per tree were standardized using ARSTAN (COOK & KRUSIC, 2005) to remove variability due to age or size of mountain pine, and other non-climatic site factors. The low frequency variability (inter-annual trend) linked to climate was preserved by standardization of the raw chronologies per tree into dimensionless indexed chronologies with a mean value of 1.0 using smoothing spline curves and dividing the ring-width measurements by the values obtained from the equation of the fitted curve. In addition, mean standard chronologies per plot were created by ARSTAN. Smoothing spline with 30 years (10 years for

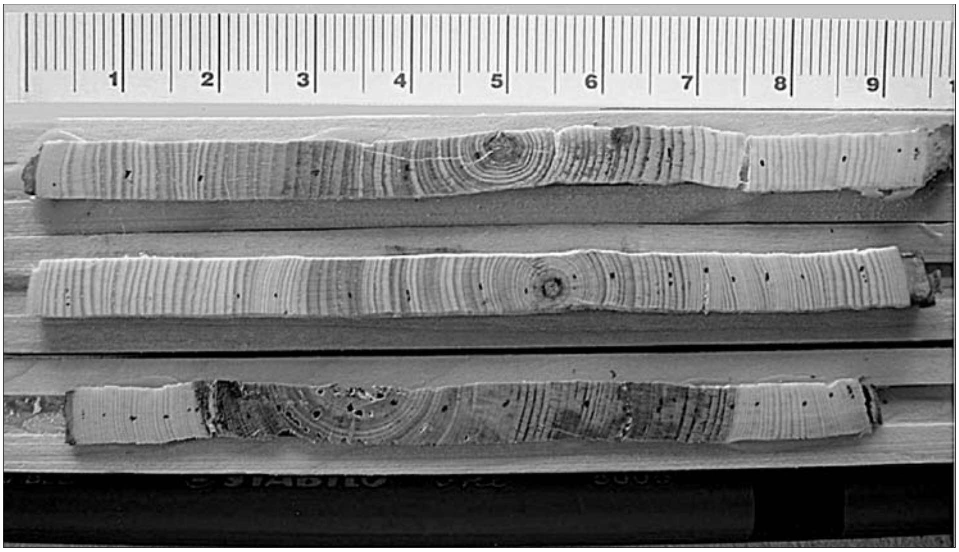


Figure 3 – Three cores samples from the three different plots.

Plot 2, because of the shorter mean chronology) and arithmetic mean was used to develop a mean standard chronology (STD) per plot.

The raw and standard chronologies of the three plots were correlated with each other by Pearson's correlation coefficient, and Student's t-test was used to determine the degree of correlation.

Chronology statistics were obtained to show the statistical characteristics of the tree-ring chronologies: mean sensitivity (MS) and standard deviation (SD) to assess the high-frequency variations (FRITTS, 1976); mean correlation coefficient (RBAR) for all possible pairings of tree-ring series from individual cores over a common time interval (BRIFFA, 1995); expressed population signal (EPS), which is a often used threshold indicating an acceptable level of coherence in dendrochronology (WIGLEY *et al.*, 1984). An EPS over 0.85 is considered a generally acceptable threshold for reliable chronologies; RBAR and EPS values were computed using a 30-year moving window with a 15-year overlap.

3. RESULTS AND DISCUSSION

3.1. Plot characteristics

The prostrate habit of mountain pine results in a dense and impenetrable cover over the whole area; the main difficulty was to distinguish individuals' stems from the branches.

The Plot 1 (46°12'56.652"N; 12°01'12.188"E), the highest in elevation, is located at 1966 m a.s.l. with 30° slope (Fig. 4a). In this plot we recorded 11 trees (the tree n. 1 was a branch) with 7,4 cm mean diameter and 1,8 m mean height, the density of the plot is 1401 trees/ha.

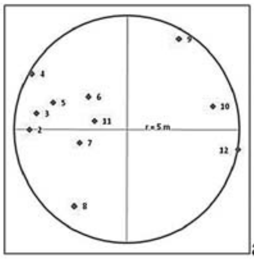
The Plot 2 (46°13'02.568"N; 12°01'19.992"E) is located at 1926 m a.s.l. with 25° slope (Fig. 4b). Here we recorded 10 trees with 9,75 cm mean diameter and 2 m mean height, the density of the plot is 1274 trees/ha.

Finally, the Plot 3 (46°12'55.200"N, 12°01'05.944"E) is located at 1895 m a.s.l. with 40° slope (Fig. 4c). In this plot we recorded 13 trees with 8,8 cm mean diameter and 1,8 m mean height, the density here is 1656 trees/ha.

3.2. Age population and tree-ring chronology

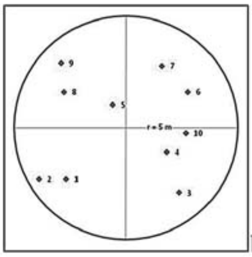
For each core a raw chronology was obtained that was averaged in raw mean chronologies for each plot (Fig. 5). The Plot 3 exhibit significant ($P < 0.001$) correlation coefficients in their mean chronologies with Plot 1 and Plot 2, respectively with $r = -0.443$ and $r = 0.650$ for raw chronologies, and $r = 0.306$ and $r = 0.257$ for standard chronologies ($n = 71$). The raw mean chronology of Plot 1 followed the typical exponential negative trend

ID Trees	Age of trees (Years)	Diameter at the base (cm)
2	67	4
3	68	5
4	82	8
5	73	4
6	72	5
7	63	8
8	97	7
9	125	11
10	86	9
11	79	13
12	90	7



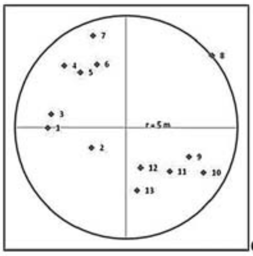
a

ID Trees	Age of trees (Years)	Diameter at the base (cm)
1	46	5
2	> 32	7
3	> 38	9
4	> 34	9
5	61	11
6	73	8
7	> 20	6
8	> 42	15
9	> 71	17.5
10	> 56	10



b

ID Trees	Age of trees (Years)	Diameter at the base (cm)
1	> 69	11
2	105	7
3	> 57	5.5
4	79	10
5	78	12
6	78	12
7	101	7
8	> 90	8
9	> 56	8
10	> 91	11
11	> 96	7.5
12	88	7
13	> 47	8.5



c

Figure 4 – Site pictures, structural parameters and spatial distribution of mountain pine in Plot 1 (a), Plot 2 (b) and Plot 3 (c), of 5 m radius.

related to biological growth development, while raw mean chronologies of Plot 2 and Plot 3 illustrate an increasing growth trend starting from early 1950s, which decreases suddenly in the early 1990s. The age structure (Fig. 5) showed similarities for Plot 1 and Plot 3, where there are the oldest individuals and the number of samples increased gradually from 1900s to 1950s; whereas, Plot 2 had younger individuals and the number of samples increased gradually from 1940s to 1970s. All the mean chronologies showed an age trend characterized by a gradual growth increase. Grater ring widths in Plot 2 are probably linked to higher young tree establishment; in Plot 3, the increase in ring width occurred during a period without young tree establishment, which suggests that the tree growth was mainly driven by localized events, such as tree cutting in the surrounding area (Fig. 5).

The decreasing growth trend observed in mean raw chronologies in the 1990s was strongly attenuated when considering the mean standard chronologies (Fig. 6), probably depending on causes other than climate, i.e. the biological growth development in the senescence phases of the trees. The statistics for the tree-ring chronologies are shown in Table 1. The values of mean sensitivity varied from 0.139 to 0.173 among the tree plots, indicating that ring-width variability was relatively low.

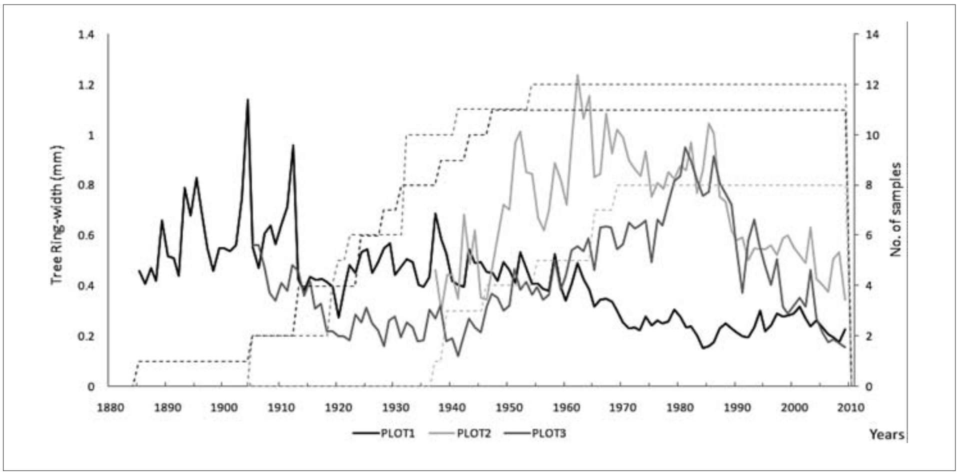


Figure 5 – Mean raw chronologies of mountain pine trees on the Col Bel site; the *dotted lines* show the number of samples included in the record.

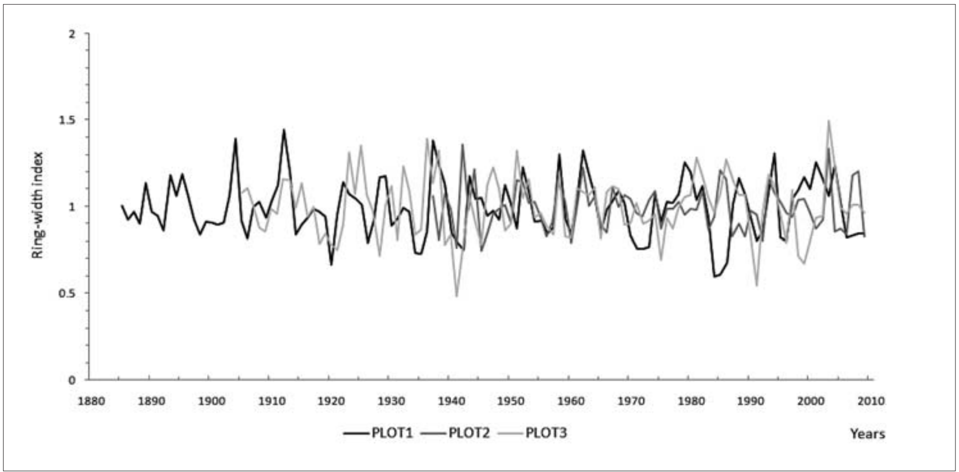


Figure 6 – Mean standard chronologies of mountain pine trees on the Col Bel site

Table 1 – Descriptive statistics for mountain pine mean standard chronologies at Col Bel; * calculated with a smoothing spline of 10 years (otherwise with smoothing spline of 30 years).

Descriptive statistics	Plot 1	Plot 2*	Plot 3
Full period covered (years)	1885-2009	1937-2009	1905-2009
Total years	125	73	105
Mean tree ring-width (mm)	0.417	0.721	0.426
Mean tree index-width (STD)	0.991	0.990	0.995
Standard deviation (SD)	0.164	0.139	0.177
Mean sensitivity (MS)	0.139	0.173	0.173
Expressed Population Signal (EPS)	0.788 (1920)	0.704 (1970)	0.827 (1940)

3.3. Phytosociological classification

The phytosociological survey was conducted in Plot 1 and Plot 2; the flora species and their abundance-dominance index are shown in Table 2. Probably the list of species is incomplete, because of the sampling period just after the snowmelt, but sufficient to identify the vegetation association.

In Plot 1, a full and multilayered coverage was detected, with a presence of bryophytes estimated 60%, which also include the genus *Sphagnum*. Species close to the plot were *Larix decidua, Salix appendiculata, Alnus viridis; Erica carnea* and *Rhododendron hirsutum,* found only near the trail.

In Plot 2 the same coverage was detected, but with a presence of bryophytes estimated 40%; here the soil is generally shallow and relatively less acid than Plot 1. It was found the presence of basophiles species. Only *Larix decidua* was recorded close to Plot 2.

We may include these mountain pine scrublands in the *Sorbo chamaemespili-Pinetum mugi* association (MINGHETTI, 1996), widespread

Table 2 – Phytosociological survey in Plot 1 (a) and in Plot 2 (b), showing the species located in the plots with their index of abundance-dominance.

Species	A/D index
Pinus mugo	5
Sorbus aria	+
Rhododendron ferrugineum	4
Juniperus nana	+
Vaccinium myrtillus	3
Lycopodium annotinum	2
Calamagrostis villosa	2
Vaccinium vitis-idaea	1
Homogyne alpina	+

(a)

Species	A/D index
Pinus mugo	5 (no>85%)
Salix appendiculata	+
Juniperus nana	2
Rhododendron ferrugineum	2
Rhododendron hirsutum	1
Vaccinium myrtillus	2
Vaccinium vitis-idaea	1
Lycopodium annotinum	2
Luzula sieberi	+
Calamagrostis villosa	1
Huperzia selago	+
Erica carnea	+
Sesleria caerulea	+

(b)

over the eastern Alps, on carbonate soils subjected to leaching, causing the acid humus formation. In fact, deep and acid soils were found, mark of late evolutional stage.

The presence of basophilic species indicates a degree of less progressed association; this developmental stage was found in Plot 2 and in peak areas (more eroded) and refers to older mountain pine scrublands attributable to *Rhododendro hirsuti - Pinetum prostratae* association (ZÖTTL, 1951 nom. Inv.).

Colonization of carbonate substrates with basophilic species was observed in the Dolomitic area. Their progressive reduction and the significant development of *Rhododendron ferrugineum* indicate soil acidification, thus pointing to an evolution of the association level (POLDINI, 2004).

The abundance of *Sphagnum* species confirms the presence of acid soils and defines microthermal conditions with low solar radiation.

4. CONCLUSIONS AND PERSPECTIVES

The copper mine of Valle Imperina, located on the foothills of the Monti del Sole, was closed only in the 1960s. Therefore, the human pressure, due to the production of fuel for mines, has gradually decreased during the second half of the past century, and nowadays ceased entirely. This could have induced the observed pattern in tree-ring width chronologies in Plot 2 and Plot 3, after 1950. This mountain pine population forms rather stable persistent woodlands, despite the current land-use and climatic changes, in this high sensitive region.

A similar research was conducted on the mountain pine scrublands of the Majella National Park, here this ecotone is a relict formation; it is a living testimony of what could be the climax vegetation of the subalpine belt of the central Apennines. In the past, the mountain pine vegetation on the Majella massif was drastically reduced with clearance for intensively grazed meadows, or to produce charcoal; the human activities have strongly influenced the tree growth and this is proved by dendrochronological analyses (PALOMBO, 2009). The same study also showed that the mountain pine growth was influenced by the climate change, confirmed by the positively correlation found between standard tree-ring chronology and maximum temperature during spring months.

In order to obtain a comparable data set for the mountain pine scrublands of PNDB, thoughtful analyses of climate and land-use changes at this treeline warrant further research on aerial photos and climate series, as well as comparison with other mountain pine populations, including those relicts on the Apennines. Climate and land-use changes are forcing structure and productivity of Mediterranean mountains, and additional information is important to understand current patterns and to predict future trends of forest dynamics at the tree-line ecotone.

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RIASSUNTO

Caratterizzazione strutturale e dendrocronologica di popolamenti persistenti di pino mugo nei Monti del Sole - Parco Nazionale delle Dolomiti Bellunesi

Gli ecosistemi d'alta quota, situati al limite della distribuzione geografica delle specie, possono fornire importanti informazioni sulla risposta degli accrescimenti legnosi ai cambiamenti climatici e d'uso del suolo. Al fine di fornire una descrizione iniziale sull'ecotono della mugheta, situato nella *treeline* alpina, sono stati realizzati tre *plot* lungo un gradiente altitudinale nei Monti del Sole (Parco Nazionale delle Dolomiti Bellunesi, Veneto), con esposizione nord-occidentale in un *range* altitudinale compreso tra i 1850 e i 2000 m. Per ricostruire le recenti dinamiche del *Pinus mugo* Turra ssp. *mugo* che caratterizza questa fascia ecotonale, è stata condotta un'analisi dendroecologica, che ha permesso di ricostruire la struttura delle età del popolamento. Le cronologie medie grezze del Plot 1 seguono il tipico andamento esponenziale negativo, mentre le cronologie medie grezze dei Plot 2 e Plot 3 mostrano un *trend* di crescita in aumento, a partire dai primi anni cinquanta del XX secolo. Si evidenziano ampiezze anulari maggiori nel Plot 2, rispetto agli altri plot. Questi popolamenti di pino mugo appartengono all'associazione vegetazionale *Sorbo chamaemespili - Pinetum mugi* e originano formazioni persistenti.

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