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Dendrochronological research and quantification of climate-tree relations on fir, spruce and stone pine in Rarău-Giumalău mountain area, Romania

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Abstract. This study is located in two neighboring mountain sites, Rarău and Giumalău in Bucovina area. Here, were made four dendrochronological series, two series on spruce and one on fir and stone pine. The studies related a tight connection and a significantly correlation between radial growth and studied climatic parameters.

Key Words: Dendrochronological series, radial growth, climate–tree relation, correlation.

Rezumat. Studiul este localizat în două masive muntoase învecinate, Rarău și Giumalău, din zona Bucovinei. Aici s-au realizat patru serii dendrocronologice, două serii pe molid și cate una pe brad și zâmbru. Cercetările au arătat o strânsă legătură și o corelație semnificativă între creșterile radiale și parametri climatici luați în studiu.

Cuvinte cheie: Serii dendrocronologice, creşteri radiale, relaţia climat-arbore, corelaţie.

Introduction. The annual ring can cover a lot of information about the climate, the anthropic factors, the pollutants, but also interactions with other trees. So the growth of trees is influenced by a complex series of interactions between genetic and environmental factors (light, temperature, wind, water supply, air and soil pollution) (Stokes & Smiley 1996; Duduman et al 2010). By applying special techniques of dendrochronology the climate signal can be separated from other disturbing signals. The annual ring width is influenced in different ways and intensities by abiotic factors. It is almost impossible to prove the influence of only one factor because the tree growth is influenced by their composed action (Popa 2004). The annual ring width varies from year to year and this is mainly due to weather conditions and previous to the active growth period (Popa 2004). Trees which vegetate at higher altitude, have temperature as the main limiting factor.

The cells across the annual ring are not homogeneous. The cells formed during spring, in rapid radial growth have a bigger lumen and thinner walls and those formed during fall have the walls thicker and smaller lumen. The seasons determinate the annual ring formation (Stokes & Smiley 1996). It can be said that the tree writes its own history, it stores not only the number of years, but the weather (Giurgiu 1979).

This article aims a quantification and comparative analysis of climate – tree relationship for spruce, fir and stone pine in the upper limit of Giumalău–Rarău mountain area. Also a climate reconstruction in the range of lenght series is intended for this area.

Reasearch was conducted in the Rarău-Giumalău mountain area. The eastern boundary of Rarău – Giumalău mountain range group climbs up the Puzdra valley and down along the Sandru stream. In the north is boardered by the Moldova river and by the Putna stream (see Figure 1). The boundary delimitation of Rarău area from Giumalău lies between Zugreni and Pojorâta, going over, trough the a saddle of 1308 m altitude. Rarău unlike Giumalău consists of conglomerates and limestones. It is characterized by steep ridges, such as those from “Caselor valley”, or vertical limestone towers that consists the “Pietrele Doamnei” (1648 m) (Anonymous 1965).

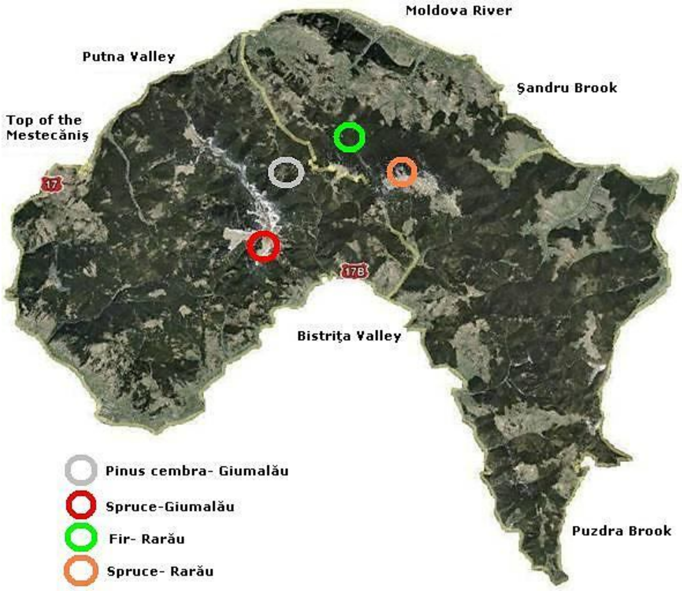

Figure 1. The map of study area.

Table 1

Distribution of dendrochronological series

Code	Location	Species	Latitude	Longitude	Altitude (m a.s.l)
RMo	Rarău	*Picea abies*	47.453392	25.564542	1506
RBr	Rarău	*Abies alba*	47.468447	25.539322	1078
GPa	Giumalău	*Picea abies*	47.426297	25.479581	1603
GPc	Giumalău	*Pinus cembra*	47.451292	25.498942	1421

Material and Method. Field research began after a research of the management plans documentation of the two units. This had the purpose to identify the trees at the upper limit of vegetation that have advanced age and which were not affected by any kind of forestry intervention.

In the making of the reference dendrochronological series, for each series were chosen according to the dendrochronological principles (Fritts 1976; Cook & Kairiukstis 1990; Popa 2004), approximately 30 trees. These trees were sampled with Pressler drill from a height of 1,3 m from the ground in the direction of the steepest slope line. Thus, four dendrochronological series were developed in two representative areas:

- two dendrochronological series one for spruce and one for fir at the upper limit (natural and cultivated plots) of Rarău mount;
- and Giumalău mount, a series for spruce in the upper limit and a series for stone pine from a stand planted outside the natural area (natural area of stone pine) presented in (Table 1).

After extraction, the sample cores were placed in special paper tubes for slowly drying. The tubes were noted with the series name followed by the serial number. After drying, samples were mounted in wooden supports (planks) with adhesive and then were polished with abrasive tape to highlight the annual rings. The annual rings were measured using the system LINTAB 6 in the laboratory. TSAPwin program, with an accuracy of 0.001 mm was used. The crossdating of the growth series was realized with TSAPwin program (Rinntech 2005), using the graphic method of comparing the series, individualy. Radial growth to average growth series and the reliability of crossdating was performed using the COFECHA program (Holmes 1983; Cook et al 1997) by correlation analysis on interleaved sub-periods for 50 years (Holmes 1983).

The growth series were individually standardized to remove non–climatic signals and to maximize climate information in dendrochronological series. For this task was used the ARSTAN program (Grissino-Mayer et al 1996).

For each dendrochronological series were used 11 methods of standardization. Were chosen those methods with the biggest signal–to–noise ratio (SNR). When two methods were equal, they were differentiated by the main component.

Characteristic years were calculated using the Weiser program (González 2001), and noted only those years in which they respond at least 75% of the number of trees in a dendrochronologial series. Quantification of the climate–tree relation was performed using DENDROCLIM 2002 program (Biondi & Waikul 2004), by interpreting the correlation of the response function.

The review of the tree–climate relation was made using the next meteorological parameters:

- temperatures (average, high and low) monthly and seasonal;
- rainfalls monthly and seasonal;
- rainfalls maximum in 24 hours and seasonal.

The corelation between meteorological parameters and the dendrochronological series elaborated was made for individual values, from June the year before the tree ring formed to August current year and on the four seasons (winter–December previous year, January, February current year; spring–March, April and May; summer–June, July and August; autumn–September, October and November). The response functions where obtained through eliminating the autocorrelation between climatic parameters. The climate parameters (average, high and low temperatures, maximum rain in 24 hours) were obtained from weather station Rarău, with data covering a period between the years 1961 – 2000.

Results and Discussion. There were elaborated a number of four dendrochronological series. Analyzing the chart (Figure 2), we can see that the longest dendrochronological series is performed on fir in Rarău area. At GPa dendorochronological series were recorded the highest amplitudes of residual growth indices (RES). The smallest growth index amplitude (RES) is recorded in GPc series. The homogeneous dendrochronological series regarding the core samples length is GPc, where most of the core samples have the same length because they belong to a stone pine (*Pinus cembra*) plantation plot dating from the Austro-Hungarian government period.

Statistical parameters of the series can be observed on Table 2.

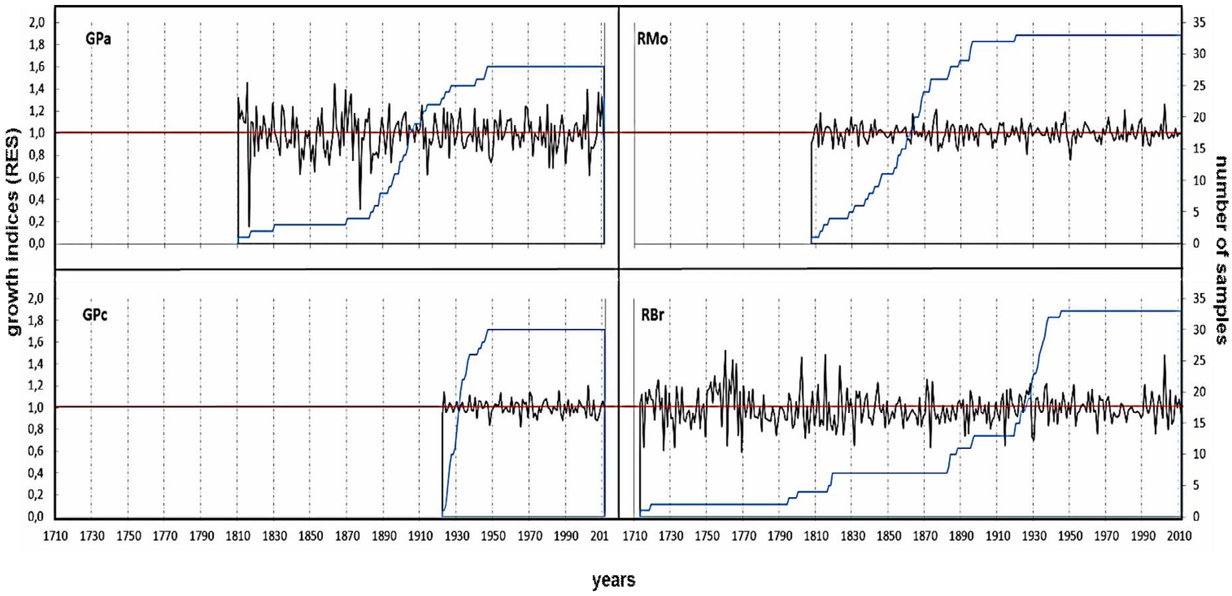

Figure 2. Elaborated dendrochronological series.

Table 2

Statistical parameters of the series

Code	Common period (years)	Medium Age±std	Medium Growth±std (mm·year $^{-1}$)	AC1	SENS	Pc1 (%)	SNR
RMo	116	154±26	1.505±0.367	0.850	0.174	40.6	19.779
RBr	74	120± 63	2.281±0.700	0.852	0.174	40.8	19.611
GPa	98	115±33	1.515±0.500	0.819	0.203	49.8	19.436
GPc	74	80±6	2.179±0.280	0.825	0.183	31.4	9.980

The biggest common part is recorded in RMo dendrochronological series of 116 years, also here is recorded the smallest average growth of only 1.505 mm/year which shows that the limitative climate conditions are best presented here. The highest average sensibility is recorded in GPa series of 0.203 which means that trees answer to climate factors is a significant one. At this series is recorded the highest common variability explained by the first principal component (Pc1-49.8%) which indicates the total amount of the influence exerted by climatic factors.

A summary of the common characteristic years, in which reacted at least two dendrochronological series, can be seen in the Table 3.

Table 3

Common characteristic years of dendrochronological series

Years	Series			
	GPa	RMo	RBr	GPc
1821		-	-	
1837		-	+	
1871	+		+	
1872	-	-	-	
1876	-	-		
1881	+	+		
1889	+	+		
1893		-	-	
1910	+		-	
1913	-	-	-	
1921	-	-		
1925	-	-		+
1927	+	+	+	
1929	-		-	
1936			+	+
1943	-	-		
1946	+	+		
1948	-	-		
1949	-	-		
1964			-	-
1968	+		-	-
1969				
1975	+	+		
1979	+	+		
1987	+			-
1989	-	-		
2001	+	+	+	

As we can see (in Table 3), there is no single year in which all dendrochronological series react. Three series reacted negatively in 1872 and 1923 and positively in 1927 and 2001. Between 1925 and 1968 a series reacted positively and two series reacted negatively. In most cases only two dendrochronological series reacted.

Climate – tree relation

The climate – tree relations (Table 4, 5) are analyzed based on residual growth indices correlated with every dendrochronological series and climate parameter.

In spruce dendrochronological series from Rarău is noted a negative correlation, very significant between residual growth indices and rainfalls (autumn). A positive correlation between average temperatures and radial growth is recorded in October, previous year and July present year (the year when the tree ring was formed).

The growth indices of dendrochronological spruce series from Giumalau correlates and has a positive response and significance with the average summer temperatures. Monthly is noted a positive correlation with average temperatures, in October the previous year and radial growth in July present year. Positive correlation is very significant with the low temperatures from July present year (the year when the tree ring was formed).

Table 4

The correlation between growth and climatic indices to spruce series

	Spruce-Rarău series					Spruce-Giumalău series				
Climatic parameters	T. med	T. max	T.min	Precip.	Precip. Max 24h	T. med	T. max	T. min	Precip.	Precip. Max 24h
Months										
P_June*						-0.34				
P_July			-0.32							
P_August			-0.33							
P_September										
P_October	0.21					0.37				
P_November										
P_December										
January										
February										
March										
April										
May										
June	0.32					0.47				
July								0.44		
August										
Seasons										
winter										
spring										
summer						0.32		0.41		
autumn				-0.39	-0.38					

*P_- previous year

The growth of fir (Table 5) from Rarău mountain area correlates positive and significant with the autumn temperatures and negative with the summer and autumn rainfalls. In conclusion we can say that the temperatures and rainfalls can be considered as the main limiting factors for tree to average altitude of 1100 m.

In what concerns stone pine (Table 5) from Giumalău area, the average, low and high temperatures of August from the previous year are higher, the growth in the present year decreases, and the precipitations from February and June correlates positively with the growth from the present year. The radial growth for stone pine responds negatively at rainfall in August present year. Analyzing the seasons, the rainfalls in autumn have a negative correlation with the annual ring growth.

On radial growth of fir, Rarau mountain area, a positive and significant influence have the maximum temperatures in August, and the maximum temperatures in autumn. A negative reaction and a quite significant impact on the annual ring have the minimum temperatures in July in the previous year. Regarding precipitations, the fir responds positive and significant to rainfall (and rainfall in 24 hours) in September of the previous year.

Stone pine in Giumalău has a negative reaction (Table 5) at average temperatures in August previous year and in June present year. The rainfalls in August, present year influences negatively and significant the annual growth. Also high amount of the rainfalls in 24 hours during autumn have a negative influence on radial growth. The stone pine has a strong reaction because it vegetates in suboptimal area.

Table 5

The correlation between growth and climatic indices to fir and stone pine series

Climatic parameters	Fir-Rarău Series					Stone pine-Giumalău Series				
	T. med	T. max	T. min	Precip.	Precip. Max 24h	T. med	T. max	T. min	Precip.	Precip. Max 24h
Months										
P_June*		-0.3								
P_july			-0.38			-0.35				
P_august						-0.49	-0.34	-0.31		
P_september										
P_october						0.34				
P_november										
P_december										
january										
february									0.3	
march										
april								-0.33		
may										
june						-0.43			0.32	0.3
july		-0.21								
august				-0,37	-0.36			0.27	-0.3	
Seasons										
winter	0.37									
spring										
summer				-0.28	-0.26					
autumn		0.3		-0.34					-0.3	

*P_- previous year

From the analysis made on those three species (spruce, fir, stone pine), we could say that the spruce from Rarău and Giumalău, has the highest response against the climatic changes. The correlations between growth indices and climatic parameters, included in the study, are very high.

The growth on high altitude spruce from Giumalău is more sensible against low temperatures in the summer and the growth on spruce from Rarău is more sensible against autumn precipitations. Similar results had been obtained by Zang and his collaborators regarding the correlation between growth and climatic parameters. They demonstrated that the case of the spruce found in lower regions of Bavaria, south Germany, the ring width correlates with precipitation and summer temperatures especially on the older trees (Zang et al 2012). Meanwhile Maxime and Hendrik have shown that the spruce growth from Mont Ventoux area, south of France, is more sensible against extreme events for example: heat waves (Maxime & Hendrik 2011).

In this study we have showed the dependance between annual growth and temperatures/precipitations. Thereby the higher average temperatures from June intensify the growth on spruce from Rarău and Giumalău. Mäkinen obtained similar results in a study concerning the annual growth variations on spruce and its dependence on temperatures and precipitations in 13 highly damaged areas and 12 healthy areas from south of Finland. He shows that high temperature of May intensifies radial growth of healthy trees and June precipitations intensify the radial growth in damaged trees (Mäkinen et al 2001).

According to environment stratification performed by Metzger, the data which is underlying this paper corresponds to ALS (Alpine South) area and ALS2 layer.

At European level was performed an environmental stratification (ENS - Environmental Stratification of Europe). This is formed of 84 layers, aggregated in 13 medium areas. At its basis stands the climatic data, data regarding oceanic influences and geographical positions. This stratification was made for easing the random sampling process of ecological resources, for the representative site selection for the entire continent and for easing the European-wide reporting (Metzger et al 2005).

Conclusions regarding the dendrochronological series

The longest dendrochronological series, as we take into account the stabile period of this series (with a number bigger than 10 trees), is the spruce from Rarău (1844-2010) with a length of 167 years. The longest dendrochronological series, taking into account the total length of the series it's a fir tree from Rarău (1712-2010) with a length of 299 years.

The average radial growth of the individual series *RBr* (2.281 mm/year) is the biggest of all elaborated dendrochronological series. Close to it is the average growth of individual series *GPc* (2.179 mm/year), explained by the fact that this series was elaborated on a plot located outside its natural area of growth. Meanwhile the average radial growth for the dendrochronological series *RMo* (1.505 mm/year) is the smallest, aspect explained by the fact that the plot from which this series was realized is at the altitudinal limit of Rarău Mountain, and has as main limiting factor, temperature.

From the analysis made on radial growth we can say that the dendrochronological series on spruce (Giumalău) are distinguished through a strong disturbance around the year 1880, most likely produced by a windfall. The dendrochronological series fir-Rarău presents also a disturbance around year 1908 produced by an anthropical intervention in the plot area. Some minor disturbances were observed in the ranges of 1881-1893 and 1969-1981, the disrupter being of climatic nature knowing the last period as a rainy one.

For the dendrochronological series elaborated for spruce in both mountain areas Rarău and Giumalău we have the next common negative characteristic years: 1872, 1876, 1913, 1921, 1925, 1943, 1948, 1949 and 1989. Some of those have a climatic determination (1913 – in which the months of June, July and August where extremely cold and rainy, 1921 - previous autumn was dry, 1948 – very dry year, 1949 - previous autumn was dry) (Topor 1963). Regarding the series elaborated on stone pine – Giumalău - and fir – Rarău - we can say that there are only two negative common characteristic years (1964 and 1968) both known as dry years.

Conclusions regarding the analysis on climate-tree relation

The spruce from Giumalău responds significantly and positively to average and low temperatures of summer and the spruce from Rarău has a negative response at autumn precipitations. The fir from Rarău area responds significantly and positively to maximum temperatures of August and the stone pine responds negatively to June temperatures.

Conclusions regarding the vegetation conditions

Regarding the vegetation conditions for the analyzed species from Rarău–Giumalău mountain areas we may say that all the species considered in this study are vegetating at the limit between optimal and suboptimal area.

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