*Arch. Biol. Sci.*, Belgrade, 67 (1), 201-211, 2015 DOI:10.2298/ABS141114025D

# DENDROINDICATION OF DROUGHT IN ROGATICA REGION (EASTERN BOSNIA)

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*Abstract* - The aim of this study was to investigate the possibility of using the dendrochronological method in drought prediction in eastern Bosnia. As an indicator of drought, the standardized precipitation index (SPI) was used. In the wider area of Rogatica (eastern Bosnia), 11 core samples from trees were taken. The best connection between the width of tree rings and drought was shown by the sample of a 67-year-old European silver fir (*Abies alba*) from the mountain Bokšanica. Removal of the biological trend (standardization) was performed by the autoregressive-moving-average (ARMA) method. Calculations showed that precipitation, i.e. drought in the summer months, is crucial for radial increment of the sample. The obtained results of our research have been confirmed in examples in the region and further.

*Key words*: dendrochronology; tree-ring width; fir; standardized precipitation index (SPI); Rogatica

**Received** November 14, 2014; **Accepted** November 25, 2014

## INTRODUCTION

Drought is a complex phenomenon that occurs due to prolonged lack of rainfall over an area. It is caused by the disruption of normal circulation of the atmosphere. Unlike the concept of aridity, which indicates a permanent deficit in relation to the normal values of precipitation in a region, drought represents mainly a short-term lack of rainfall accompanied by high air temperatures. In addition, drought also means a deviation in the current relationship between precipitation and evapotranspiration from the normal value for a perennial period of observation.

In terms of occurrence and intensity of drought, temporal variability and efficiency of rainfall have an important role. Other meteorological elements such as high temperatures, wind speed and low relative humidity are frequent companions of drought occurrence and, as such, can significantly aggravate its effects.

Worldwide, in the period 1980-2008, 410 regional droughts were recorded. 558 565 people dies, and over 1.5 billion were indirectly affected. The total damage amounted to 76 949 488 000 U.S. $ (Drought – Data and statistics Prevention Web, 2014). In order to obtain timely information on droughts in Europe, the Joint Research Center (JRC) has established an observatory for the monitoring, assessment and prediction of drought, the European Drought Observatory (EDO) (2014).

In the first national report of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Changes (Vukmir et al., 2009), the extreme and average monthly precipitation were analyzed in Tuzla, Sarajevo and Mostar. It was noted that significant changes could be seen in Mostar, where the average rainfall in the period 1982-2007 was considerably lower than in the period 1956-1981 in all months except in September. However, “it is not possible to draw conclusions about significant changes in the precipitation regime for continental part” (Vukmir et al., 2009).

The aim of this study was to investigate the possibility of using the dendrochronological method in the prediction of drought in eastern Bosnia.

## MATERIALS AND METHODS

In the wider area of Rogatica (eastern Bosnia), 11 core samples from trees of different ages were taken. For all samples, the characteristic geological substrate is Triassic limestone, highly karstified with predominantly skeletal soils on limestone. Upper Triassic is represented by a significant series of limestone and dolomite layers, a few hundred meters thick.

The Bokšanica, Devetak, Gnila and Žepska mountains, areas from the largest number of samples were taken, are characterized by complete karstification. It is a great arid region with sinkholes and sinkhole areas. Over large areas there are practically no surface flows. Only short streams with low flow rates occur, which end up in sinks, and water flows by underground roads to major rivers (Kochansky-Devide and Slišković, 1978).

The hilly area (up to about 750 m) makes a belt of oak and beech forests. Beech stands are on more mesothermal habitats, mainly taking shady sides from the southwest and north to northeast exposure. Oak occupies the sunny, more xerothermal habitats, often climbing to the ridge at the top of the altitude belt at a position above the beech forests. On contact, these two types are mixed.

In most of the cases, the belt of these forests is directly abutted to the belt of beech and fir (with spruce) forests and Scots pine forests in succession to the forests of beech and fir with spruce.

A feature of this area is the great participation of degradation forms of high and low forests, which is caused by very unfavorable habitat conditions in some parts of the region, and harmful anthropogenic impacts in the past. The share of areas of shrubs and bare land is also significant.

Locations from which we took samples for our analysis are mainly on soils of calcomelanosol type or mountain black soil and skeletal limestone soils (calcocambisol) with poorly developed soil horizons.

The best connection between the width of tree rings and drought was seen in the sample of European silver fir (*Abies alba*), aged 67 years. The sample comes from Mt. Bokšanica (eastern Bosnia). The elevation of the location is about 1 200 m, the geological substrate is limestone, and the terrain is gently rolling surface. The soil is of calcocambisol type. The tree grew in a mixed coniferous community of spruce, fir and pine.

The nearest weather station at approximately the same altitude (1 180 m) is in Han Pijesak, about 30 km northwest of Bokšanica. The coldest month is January with an average temperature of -4.5°C, and the warmest is July with 15.7°C. The mean annual temperature is 6.5°C. The growing period lasts from April to October. The average annual rainfall in the area of Han Pijesak is 1 220 mm. Of the total number of days with precipitation, 30% is snowfall and snow cover is maintained 120 days a year. Data refer to the period 1961-1990, but due to missing values, they should be interpreted with some caution.

The standardized precipitation index (SPI), which was developed for the purposes of defining and monitoring drought by McKee et al. (1994), was used as an indicator of drought. Based on long-term observations it is possible to analyze the occurrence of drought in a certain time interval (month, season, year, etc.), and compare these values with the values of any region. Longer periods are used to analyze the extreme precipitation. The start of drought is identified by observing the “step back”. Namely, the occurrence of drought has its confirmation only if it occurs continuously in series with the values SPI <= -1. The drought period stops when the value of the SPI becomes positive. Each drought is characterized by: i) the time interval (1, 2, 3, 6, 12, 24 months), i.e. number of consecutive appearances of the values of SPI <= -1; ii) the duration of drought, the time between the beginning and the end of drought; iii) the category of drought, which is determined by the value of the SPI (Table 1); iv) the size of drought, which is calculated by the sum of the SPI for each month from the beginning to the end of the dry season; and v) the intensity of drought, which is the ratio between the size and duration of the phenomenon.

The standardized precipitation index is based on the probability of the occurrence of rainfall. This index depends on the probability density function of rainfall and rainfall distribution function. Previous studies have shown that precipitation is subject to the law of Gamma distribution. To determine the scaling parameters and shape of the probability density function of rainfall, the entire period of observation at a meteorological station is used. The scaling parameters and shape of the probability density function of rainfall are separately defined for each station and each period. The SPI is also used to characterize wet, very wet and normal years. Limit values obtained from many studies are shown in Table 1.

The SPI is based on the cumulative probability of the occurrence of rainfall in a particular meteorological station in the selected segment of the time series using a Gamma distribution. The Gamma distribution of rainfall is defined by probability density function, which is as follows:

$$g(x)=\frac{1}{\beta^{a}\Gamma(\alpha)}x^{a-1}e^{\frac{-x}{\beta}} \qquad \text{for } x > 0$$

where $\alpha$ = shape parameter; $\beta$ = size parameter; x = amount of rainfall > 0; $\Gamma(\alpha)$ = gamma function which is defined as

$$g(x)=\frac{1}{\beta^{a}\Gamma(\alpha)}x^{a-1}e^{\frac{-x}{\beta}}$$

The calculation of the SPI requires adjusting the Gamma probability density function for a given frequency distribution of rainfall for the entire period of observation of rainfall, so that the parameters $\alpha$ and  are specified for each weather station and for each time interval (1, 2, 3, 6, 12, 24 months, etc.). The parameters $\alpha$ and $\beta$ are determined by the method of maximum authenticity, as follows:

$$\hat{\alpha}=\frac{1}{4A}\left(1+\sqrt{\frac{4A}{3}}\right)$$

$$\hat{\beta}=\frac{\overline{x}}{\overline{\alpha}}$$

where $A=\ln(\overline{x})-\frac{\sum\ln(x)}{n}$

and n = the interval of precipitation observation

The obtained parameters are further applied to determine the probability of certain cumulative rainfall for a given period in the time scale of all the observed rainfall of selected meteorological station. The cumulative probability can be written as:

$$G(x)=\int_{0}^{x}g(x)dx=\frac{1}{\hat{\beta}^{\hat{a}}\Gamma(\hat{a})}\int_{0}^{x}x^{\hat{a}-1}e^{\frac{-x}{\hat{\beta}}}dx$$

If it is taken that:

$$t=\frac{x}{\hat{\beta}}$$

the following equation becomes an incomplete gamma function:

$$G(x)=\frac{1}{\Gamma(\hat{a})}\int_{0}^{x}t^{\hat{a}-1}e^{-t}dt$$

Because the gamma function is undefined for x = 0, and the precipitation can be zero, the cumulative probability becomes:

$$H = q + (1 - q)G(x)$$

where q = probability of precipitation height of 0 mm. If *m* is the number that indicates how many times precipitation amounted to zero in the time series and *n* = number of observations of rainfall, then *q* can be determined by *m/n*. Cumulative probability H (*x*) is transformed into a standard normal random variable Z with mean zero value and variance one, which represents the value of the SPI. The main characteristics of this transformation is to convert the distribution of one form (e.g., Gamma) into another prescribed form (e.g., normal) in such a way that probability that is less than a given value of variable remains the same as probability that is less than the corresponding value of the transformed variable.

A tree, like many other living organisms, grows faster in the early stages of development, which is why in studies of this kind it is necessary to remove the biological trend component by mathematical methods. The removals of biological trends of diameter increment of trees are a classical problem of dendrochronology, which is solved by different methods of standardization of the original data series. Here, with the aim of standardization, we have applied the autoregressive-moving-average (ARMA) method in the software PAST.

ARMA models are mathematical models of the persistence, or autocorrelation, in a time series. ARMA models are widely used in hydrology, dendrochronology, econometrics, and other fields. In dendrochronology, ARMA modeling is applied to generate residual chronologies – time series of tree-ring width (TRW) index with no dependence on past values. This operation, called prewhitening, is meant to remove biologically related persistence from the series so that the residual may be more suitable for studying the influence of climate and other outside environmental factors on tree growth.

The autocorrelation time series method has also been used, which shows the extent to which members of a series are interconnected during the shift of time series for a step forward or backward. The autocorrelation is widely used in dendroclimatological research. By autocorrelation, we can see the recurrence to some extent of a part of a series of data with a certain “time-lag”. One series is correlated with itself, so that in each subsequent step a move is made for one time step.

## RESULTS

For the calculation of the link between tree-ring widths and meteorological elements we used data from the meteorological station in Sarajevo, about 80 km west of the location from which the sample was taken on Mt. Bokšanica (43° 55’ 35” N, 19° 06 ‘ 48” E). This weather station is the closest to having a complete data series. The urban heat island of the city of Sarajevo has no substantial influence on the results of our research. The calculations were made for the fifty-year period from 1961 to 2010.

Pearson’s correlation coefficient (R) for the original data series of the tree-ring widths of the sample of fir from Mt. Bokšanica with air temperature in Sarajevo showed the highest values in July (-0.475**) and August (-0.466**; significance at 0.01%). These are also the only months with statistically significant R values. Observed by season, the highest value was obtained for summer (-0.488**).

The correlation coefficient for the original data series of the tree-ring widths with precipitation in Sarajevo showed the highest values in July (0.360**). Months with statistically significant values of R were December (0.313*; Significance at 0.05%) and August (0.295*). Observed by season, the highest value was again obtained for summer (0.371**).

R is insignificant for annual values and the values of the growing period and temperature and precipitation. Based on these results, it can be concluded that the temperature conditions during summer are the most important for the diameter growth of the fir

**Table 1.** Classification of SPI values.

| SPI values | Classes | Cumulative value H($x$) |
|---|---|---|
| 2.0 and more | extremely rainy | $H(x)<0.023$ |
| 1.5 to 1.99 | very rainy | $0.023< H(x)<=0.067$ |
| 1.0 to 1.49 | moderately rainy | $0.067< H(x)<=0.159$ |
| -0.99 to 0.99 | within the normal limits | $0.159< H(x)<=0.841$ |
| -1.0 to -1.49 | moderately dry | $0.841< H(x)<=0.933$ |
| -1.5 to 1.-1.99 | very dry | $0.933< H(x)<=0.977$ |
| -2.0 and lower | extremely dry | $0.977< H(x)$ |

sample from Mt. Bokšanica, i.e. less growth is conditioned by higher temperatures, and *vice versa*.

However, the diameter growth during the period 1961-2010 showed a statistically significant downward trend (-0.230*) mm per decade, which would be, given the age of the cut sample (67 years), largely related to the biological trend component. This is indicated by the discrepancy between the extreme years of summer temperatures (maximum in 2003, minimum in 1976) and precipitation (maximum in 1989, minimum in 2000) and tree-ring widths (maximum in 1964 and 1969, minimum in 1991).

Therefore, before further calculations the biological removal of the trend (standardization) was done. The standardization was done by the autoregressive-moving-average (ARMA) method in the software PAST for the values of p (AR) = 2 and q (MA) = 0, as defined by default (Table 2).

The Pearson correlation coefficient for the thus obtained residual tree-ring chronology with air temperature in Sarajevo showed the highest values in July (-0.288*). This is the only month with a statistically significant R value. There are no statistically significant values of R either for the seasons or for the growing period.

The correlation coefficient for the residual ring-width chronology with precipitation showed statistically significant values for July (0.384**), August (0.367**) and January (-0.313*). The annual data connections are weak, but for the growing period (April-October), the correlation coefficient is statistically significant (0.327*). The highest value of R is reached in summer (0.503**).

Thus, the results for the residual chronology of the TRW show higher values for precipitation than for temperature, as opposed to the original series. The value of R with rainfall in summer (0.503**) is the highest calculated value, which undoubtedly indicates the dominant importance of precipitation in the ongoing diameter growth.

The contradiction of the obtained results for the original data series of tree-ring widths which shows the best correlations with summer temperature (-0.488**) and residual series that shows the best correlations with summer precipitation (0.503**) is apparent. This is a consequence of the fact that the biological component of the increment trend present in the original series was removed in a standardized series by the ARMA method. That the process of standardization is correct is shown in the matching of the years of the primary (2000) and secondary (1971) minimum of summer rainfall and tree-ring widths.

The Pearson correlation coefficient between the SPI 1 (monthly values) in Sarajevo and TRW of the residual series of the fir sample from Mt. Bokšanica showed the highest values in July (R = 0.423**) and August (R = 0.417**). A statistically significant value was also recorded in January, but with the opposite sign (R = -0.342*). It is obvious that the greatest impact on the width of tree rings is that of climatic conditions during summer, i.e., a summer drought in July and August is the limiting factor of the radial

**Table 2.** Tree-ring width (TRW) of European silver fir (*Abies alba*) from the mountain Bokšanica and climate data for Sarajevo over the period 1961-2010.

| Year | Original TRW (mm) | Residual TRW (mm) | Sarajevo summer temperature | Sarajevo summer precipitation | August SPI |
|---|---|---|---|---|---|
| 1961 | 3.6 | -0.026 | 18.2 | 141.9 | -1.33 |
| 1962 | 3.2 | -0.360 | 18.6 | 143.7 | -1.30 |
| 1963 | 4.4 | 1.012 | 19.2 | 346.4 | 1.31 |
| 1964 | 5.2 | 1.351 | 17.6 | 280.4 | 0.61 |
| 1965 | 4.0 | -0.820 | 18.6 | 144.6 | -1.28 |
| 1966 | 5.1 | 0.561 | 17.9 | 235.5 | 0.07 |
| 1967 | 4.4 | -0.185 | 18.2 | 244.9 | 0.19 |
| 1968 | 4.1 | -0.608 | 17.6 | 311.7 | 0.96 |
| 1969 | 5.2 | 0.969 | 17.1 | 433.5 | 2.11 |
| 1970 | 4.9 | 0.216 | 18.2 | 196.9 | -0.45 |
| 1971 | 3.9 | -1.121 | 19.2 | 116.3 | -1.82 |
| 1972 | 4.6 | 0.250 | 18.2 | 335.5 | 1.20 |
| 1973 | 3.5 | -0.772 | 18.5 | 152.8 | -1.14 |
| 1974 | 4.2 | 0.200 | 17.8 | 250.5 | 0.26 |
| 1975 | 5.0 | 1.122 | 17.3 | 281.2 | 0.62 |
| 1976 | 4.0 | -0.622 | 16.2 | 300.7 | 0.84 |
| 1977 | 5.0 | 0.551 | 18.0 | 259.4 | 0.37 |
| 1978 | 3.8 | -0.732 | 17.4 | 266.7 | 0.45 |
| 1979 | 4.2 | -0.142 | 17.7 | 263 | 0.41 |
| 1980 | 3.1 | -0.913 | 18.2 | 140.9 | -1.35 |
| 1981 | 3.5 | -0.105 | 17.9 | 251.2 | 0.27 |
| 1982 | 3.4 | 0.078 | 19.2 | 182.8 | -0.66 |
| 1983 | 3.5 | 0.050 | 18.0 | 306.7 | 0.90 |
| 1984 | 4.0 | 0.542 | 16.8 | 232.5 | 0.03 |
| 1985 | 3.5 | -0.271 | 18.7 | 180.4 | -0.69 |
| 1986 | 3.7 | -0.029 | 17.7 | 300.6 | 0.84 |
| 1987 | 2.7 | -0.910 | 19.5 | 134.4 | -1.47 |
| 1988 | 2.2 | -0.965 | 19.9 | 195 | -0.48 |
| 1989 | 3.0 | 0.554 | 17.2 | 466.8 | 2.39 |
| 1990 | 3.1 | 0.452 | 18.6 | 159.7 | -1.02 |
| 1991 | 2.0 | -1.063 | 18.3 | 258.5 | 0.36 |
| 1992 | 2.5 | -0.020 | 19.7 | 217.2 | -0.17 |
| 1993 | 3.4 | 1.110 | 19.2 | 218.3 | -0.15 |
| 1994 | 3.7 | 0.702 | 19.7 | 228.5 | -0.02 |
| 1995 | 3.8 | 0.235 | 18.4 | 331.6 | 1.16 |
| 1996 | 3.5 | -0.254 | 18.9 | 152.6 | -1.14 |
| 1997 | 3.6 | -0.039 | 18.8 | 185.1 | -0.62 |
| 1998 | 3.7 | 0.143 | 20.4 | 201.5 | -0.38 |
| 1999 | 4.4 | 0.745 | 19.3 | 257.7 | 0.35 |
| 2000 | 2.8 | -1.275 | 20.7 | 90.5 | -2.41 |
| 2001 | 3.6 | 0.065 | 19.2 | 256.3 | 0.33 |
| 2002 | 4.1 | 0.860 | 19.5 | 219.6 | -0.13 |
| 2003 | 3.1 | -0.769 | 21.3 | 167.1 | -0.90 |
| 2004 | 3.9 | 0.340 | 19.1 | 260.4 | 0.38 |
| 2005 | 4.0 | 0.464 | 18.1 | 328.3 | 1.13 |
| 2006 | 3.7 | -0.251 | 18.1 | 368.1 | 1.52 |
| 2007 | 3.0 | -0.836 | 21.2 | 150.6 | -1.18 |
| 2008 | 3.4 | 0.074 | 20.1 | 225.7 | -0.05 |
| 2009 | 3.8 | 0.576 | 19.6 | 293.2 | 0.76 |
| 2010 | 2.8 | -0.818 | 20.2 | 254.9 | 0.31 |

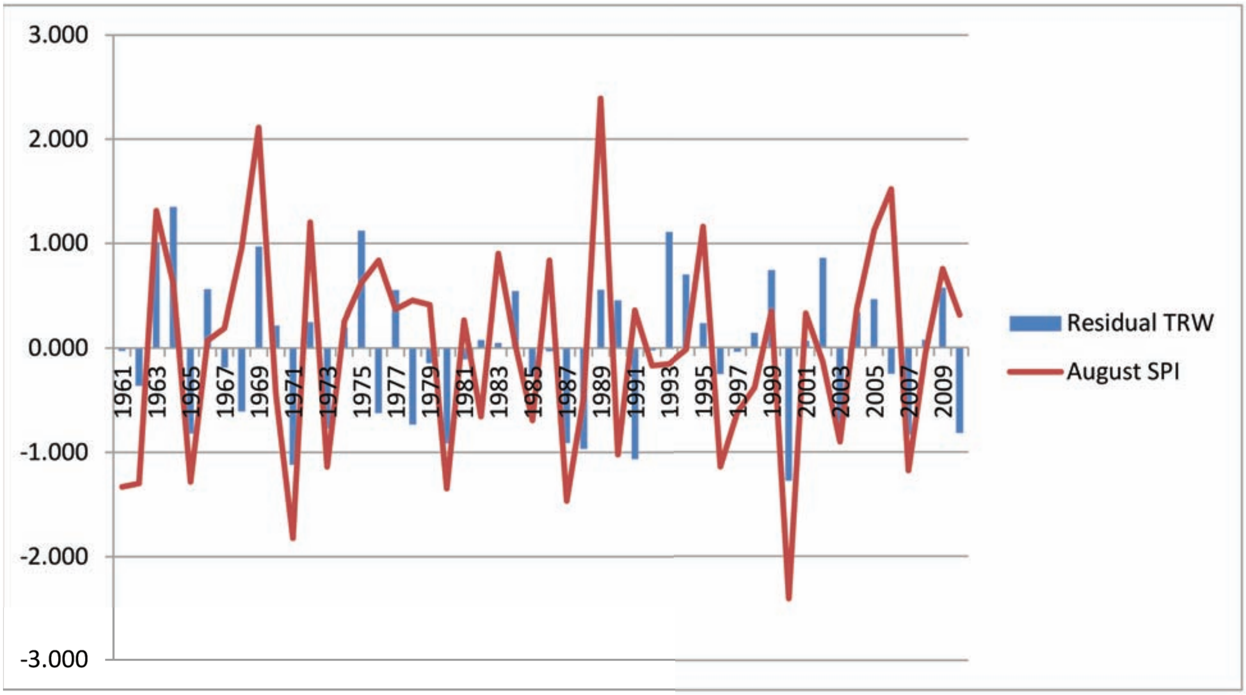

**Fig. 1.** Residual tree-ring width (TRW) of fir (*Abies alba*) from the mountain Bokšanica and August standardized precipitation index (SPI) for the Sarajevo over the period 1961-2010.

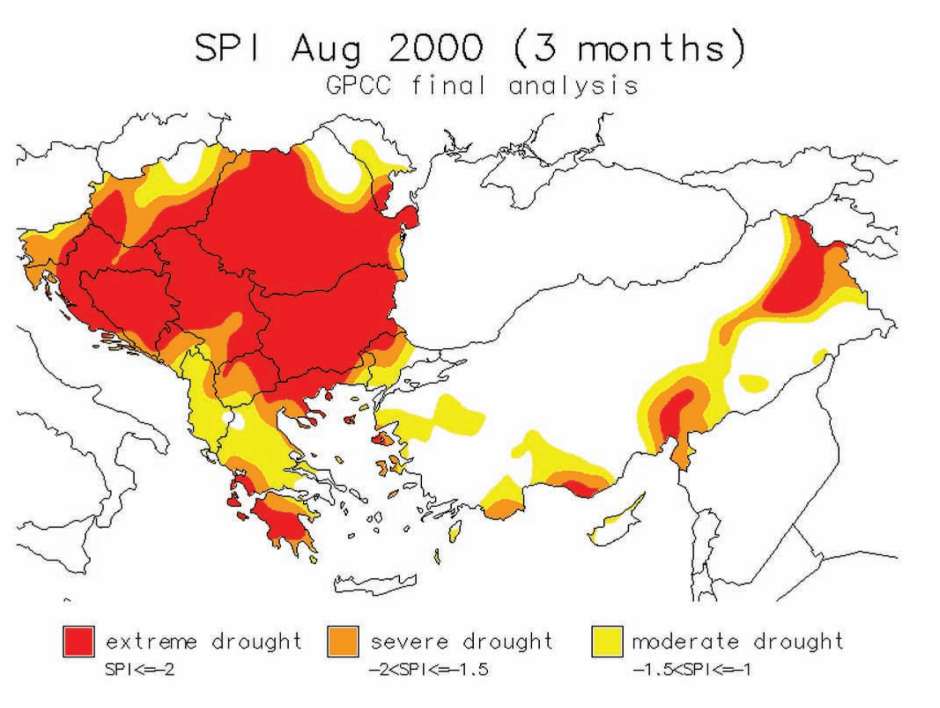

**Fig. 2.** SPI3 August 2000 drought distribution (Maps are based on data obtained from GPCC).

increment. The relatively high value of R in January could indicate the importance of winter water storage in the snow cover for growth in the vegetation period. Individual monthly values of R between tree-ring widths and SPI in the growing period (April - October) are low.

The correlation coefficient between the SPI 12 (twelve-month value) in Sarajevo and the TRW showed no significant relationship. R for the current year has a value of only 0.12. The highest value of R (0.178) was reached for the twelve-month period in August of the current year and in July of the previous year of, which is not statistically significant.

The Pearson correlation coefficient between the SPI 3 (three-month values) in Sarajevo and tree-ring widths of the residual series showed statistically significant values for July (0.350*), August (0.535**) and September (0.308*). Therefore, the maximum value of R was recorded in the summer months (August SPI3 refers to a three-month period June-August). This is the highest value of Pearson correlation coefficient in the overall calculations. This, on the one hand, points to the justification of the process of standardization, and on the other, precipitation, i.e., drought in the summer months is crucial for the radial increment of the sample of fir from Mt. Bokšanica. The matching of the years of the primary (2000) and secondary (1971) minimum SPI and tree-ring widths was also present here (Fig. 1).

The autocorrelation analysis shows that the value of the Pearson correlation coefficient is not statistically significant. Moreover, a change of sign of the correlation occurs. This undoubtedly shows that the climatic conditions of the previous year are not relevant for the increment of the current one. This could be linked to the limestone surface and porous soil that do not hold water.

## DISCUSSION

In this paper, an attempt was made to detect drought by dendrochronological method. As an indicator of drought, the standardized precipitation index (SPI) was used. Based on this index, it is possible to analyze the occurrence of drought in a given time interval (month, season, year, etc) and compare those values with the values of any region.

Govedar and Golijanin (2007) concluded that there was dendroclimatological research on the territory of Bosnia and Herzegovina, but at a very small scale. Poljanšek et al. (2012a) described the black pine (*Pinus nigra* Arnold) regional chronology for Bosnia and Herzegovina, based on seven sites from different parts of the country. They concluded that “Pointer-year analysis identified a common signal (possibly climate) in the site chronologies – at least five positive (1876, 1930, 1941, 1969) and nine negative pointer years (1874, 1880, 1891, 1931, 1943, 1963, 1971, 1987, 2000) are common to all seven studied sites”. Two of these negative pointer years (1971 and 2000) are also detected in our chronology.

Poljanšek et al. (2012b) on the basis of seven black pine (*Pinus nigra* Arnold) sites in Bosnia and Herzegovina found a “significant, positive influence of above-average January-March temperatures on 4 sites (Blace, Perućica, Šator, Konjuh) and a negative influence of above-average May-August temperatures and a positive relationship with an above-average sum of May-August precipitation on tree-ring width formation from 3 sites (Krivaja, Prusac, Šipovo)”.

Poljanšek et al. (2013) found statistically significant negative correlations of the samples of black pine from the same seven sites (Šator, Šipovo, Prusac, Blace, Perućica, Konjuh and Krivaja) with insolation in Osijek (Croatia) in a two-month period (June-July). In addition, the authors connected summers with extremely low insolation and volcanic eruptions. This is a good example of the complexity of the influence of climate and other factors on the diameter increment of trees. Poljanšek et al. (2013) noted that “summer sunshine is tightly connected with moisture stress in trees, because the moisture stress and therefore the width of tree rings are under the influence of the direct and interactive effects of sunshine duration (temperature, precipitation, cloud cover and evapotranspiration)".

Ćirković-Mitrović et al. (2013) found a strong positive correlation between the tree ring-width of Austrian pine trees from three artificially established stands at three sites in the Belgrade area in Serbia and precipitation in the growing period.

Tree tree-ring widths of black pine (*Pinus nigra*) from Slavynka Mts. (Bulgaria) show strong positive correlation for the May-July precipitation sums (R>0.45). Narrow rings are relevant to years associated with years with a dry summer or preceded by dry periods, such as 1908, 1918, 1928, 1945-47, 1984-88, 2000, which confirms the sensitivity to drought of the Black pine population from Slavynka Mts. (Shiskova and Panayotov, 2013). The most extreme year of negative deviation of the ring-width residual chronology for the sample from Bokšanica (2000) coincides with the last separate year of dry summers in the chronology from Slavynka Mts. This drought had a regional dimension (Fig. 2).

Levanič et al. (2013) made a 396-year-long drought sensitive ring-width chronology in southwestern Romania. It was done with *Pinus nigra* var. *banatica* (Georg. et Ion.) growing on steep slopes and shallow organic soil site in the only natural forest population of black pine in Romania, situated on the southern slope of the Cerna Valley near Mt. Domogled. July precipitation explains 29%, and summer SPI 34% of the total variance. The 1900-2009 period was characterized by the highest number of extreme events with three dry (1946, 1987 and 2000) years. The summer of 2000 figures in this chronology as extremely dry and one of the three driest summers in the 20th century.

In Slovakia, Büntgen et al. (2010) used tree-ring data to reconstruct decadal-scale fluctuations of the self-calibrated Palmer Drought Severity Index (scPDSI) over 1744-2006. Negative non-significant correlations are derived from the various temperature means, whereas positive significant correlations are obtained for summer precipitation. The highest correlations on the annual-scale (R=0.58) are obtained with summer scPDSI. On the decadal-scale, (R) grows to 0.88, but caution is advised because of highly auto-correlated data series.

Büntgen et al. (2010) concluded: "soil moisture availability is the primary factor limiting pine growth at this cliff site. Radial growth best reflects June-August soil water content, emphasized by an inverse growth response to warm season temperature, and positive relationships with precipitation".

Touchan et al. (2005) found a good correlation between the ring-width of four samples *Juniperus excelsa* from southwestern and south-central Turkey and SPI3 for July. Based on them, the reconstruction of the SPI was done up to 1251. The chronology contains 57 dry and 66 wet events, and their schedule by century is very uneven.

In the wider area of Rogatica (eastern Bosnia), 11 core samples from the trees were taken. The characteristic geological substrate for all samples is karstified limestone with predominantly skeletal soils. The best connection between the tree-ring widths and drought was shown by the sample of European silver fir (*Abies alba*), from Mt. Bokšanica, aged 67 years.

The Pearson correlation coefficient (R) for the original data series of the tree-ring widths (TRW) of the sample of fir from Mt. Bokšanica with air temperature in Sarajevo showed the highest values for summer (-0.488**). The correlation coefficient for the original data series of the tree-ring widths with the precipitation in Sarajevo showed the highest values for summer also (0.371**).

The Pearson correlation coefficient for the residual chronology of the TRW obtained by the standardization with the air temperature in Sarajevo showed the highest values in July (-0.288*). The statistically significant values of R were not obtained either for the seasons or the growing period. The correlation coefficient for the residual chronology of the tree-ring widths with the precipitation showed the highest value in summer (0.503**).

Therefore, the obtained results for the residual chronology of the TRW show higher values for precipitation than the temperature, as opposed to the original series. The value of R with rainfall in summer (0.503**) is the highest calculated value, which undoubtedly indicates the dominant importance of precipitation in the diameter growth.

The contradictory of the obtained results for the original data series of the tree-ring widths which shows the best correlations with summer temperature (-0.488**) and residual series that shows the best correlations with summer precipitation (0.503**) is apparent. It is the consequence of the fact that the biological component of the increment trend is present in the original series, which is removed in a standardized series by the ARMA method. That the process of standardization is correct also shows the matching of the years of the primary (2000) and secondary (1971) minimum of summer rainfall and tree-ring widths.

The Pearson correlation coefficient between the SPI 3 (three-monthly values) in Sarajevo and tree-ring widths of the residual series showed statistically significant values for July (0.350*), August (0.535**) and September (0.308*). Therefore, the maximum value of R was recorded in the summer months (August SPI3 refers to a three-monthly period June-August). This is the highest value of Pearson correlation coefficient in the overall calculations. There is also a matching of the years of the primary (2000) and secondary (1971) minimum SPI and tree-ring widths. This, on the one hand, points to the justification of the process of standardization, and on the other, precipitation, i.e., drought in the summer months is crucial for the radial increment of the sample of fir from Mt Bokšanica.

*Acknowledgments* - This study is financially supported by the Serbian Ministry of Education, Science and Technological Development (Grant # 47007).

## Authors' contributions

Vladan Ducić designed the study, analyzed and interpreted data and wrote the manuscript. Rade Ivanović collected samples, measured tree ring widths and took part in writing. Jovan Mihajlović searched literature and assembled input data. Rajko Gnjato organized the field trip, collected samples and searched literature. Goran Trbić analyzed output data and collected samples. Nina Ćurčić found and analyzed appropriate location for sampling and processed the figures.

## Conflict of interest disclosure

We claim that all authors agree to submission of the manuscript. This manuscript has not been published before and is not concurrently being considered for publication elsewhere. This manuscript does not violate any copyright or other personal proprietary right of any person or entity and it contains no statements that are unlawful in any way. If accepted, the manuscript will be not published elsewhere in the same form without the written consent of the Editor.

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