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COMPARATIVE ANALYSIS OF THE INFLUENCE OF CLIMATE FACTORS ON THE RADIAL GROWTH OF AUTOCHTHONOUS PINE SPECIES (*PINUS* SPP.) IN CENTRAL BOSNIA AND HERZEGOVINA-

USPOREDNA ANALIZA UTJECAJA KLIMATSKIH ČIMBENIKA NA RADIJALNI RAST AUTOHTONIH VRSTA BOROVA (*Pinus* spp.) U SREDIŠNJOJ BOSNI I HERCEGOVINI

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SUMMARY

In central Bosnia and Herzegovina, in the Zavidovići-Teslić area, the study of the radial growth of Austrian and Scots pine (autochthonous pine species) trees was conducted using the dendrochronological method in order to identify the differences between the species in terms of the influence of climatic variables on the tree ring formation. Trees were sampled in five experimental areas or five sites. The first site had a Scots pine stand, while the second had an Austrian pine stand, and the other three sites had mixed stands of Scots and Austrian pine. Cross-dating was conducted using visual on-screen techniques of CDendro software and statistical methods using Cofecha software. The tree ring series were standardized using the Arstan program and cubic smoothing spline. It produced Scots pine regional chronology, 145 years long (1870-2014), and Austrian pine regional chronology, 180 years long (1835-2014). Correlation analysis of the relationship between the index of tree-ring width and precipitation and temperature in the characteristic periods of the year showed a negative effect of temperature (except in winter months) and a positive effect of precipitation on the tree ring formation. The statistically significant dependence of the tree-ring width index on the SPEI indices indicates a significant impact of moisture deficiency on the tree ring formation in the period from June to August ($r = 0.33$ in June, $r = 0.45$ in July and $r = 0.47$ in August) for Scots pine and in the period from June to September ($r = 0.36$ in June, $r = 0.43$ in July, $r = 0.47$ in August and $r = 0.30$ in September) for Austrian pine. The analysis of the relationship between climatic parameters and the chronologies of Scots and Austrian pine shows similar relationships between radial growth and climate but the influence of climate is somewhat more pronounced in Austrian pine. In the study area, the radial growth of both tree species is significantly determined by climate conditions. In other words, the chronology of these species has a good climatic signal, especially the drought signal in the summer months.

KEY WORDS: dendrochronology; tree-ring width; Austrian pine; Scots pine; climate; Bosnia and Herzegovina

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INTRODUCTION
UVOD

Pine forests in Bosnia and Herzegovina, where Scots and Austrian pines are predominant species (> 95%), account for 136,000 ha or 8% of the area of high forests. The growing stock in pine forests amounts to 19,682,000 m^3 and wood increment to 582,000 m^3 (Čabaravdić et al. 2016). Austrian pine range of distribution includes southern Europe, northwestern Africa, and Asia Minor. Scots pine has a much more extensive range of distribution and covers the area of Europe and northern Asia. Parts of Bosnia and Herzegovina are included both in the Scots pine and Austrian pine ranges of distribution. There are also mixed stands of these tree species.

According to Speer (2010), dendrochronology is one of the most important techniques used to record natural processes and monitor human-caused changes in the environment. Dendrochronology provides temporal studies of the events stored in the structure of tree rings or dated using tree rings. The tree has become an instrument for monitoring the state of the environment since it provides a long-term bioindication that extends throughout its life. According to Worbes (2004), the analysis of tree rings significantly extends the period of tracking and monitoring back in the past and can be considered retrospective biomonitoring.

Dendrochronology as a scientific discipline provides tree-ring data that can be of great assistance in other scientific disciplines that have not used that data before. By combining dendrochronology with other scientific disciplines, several dendrochronology subdisciplines have been developed. One of the most important is dendroecology. The research field of dendroecology was developed by Theodor Hartig and Robert Hartig in Germany in the late 1800s (Schweingruber 1996). According to Amoroso et al. (2017), dendroecology is focused on how climate and other factors, directly and indirectly, influenced past tree-growth patterns. Dendroecological studies have fundamentally shaped contemporary views of forest ecology and forest dynamics of primarily temperate forests. The past few decades have seen a sharp increase in the rate of publishing dendroecological studies that have helped adapt existing forest management strategies to respond to and mitigate current and future global environmental changes.

Scots and Austrian pine species have been the research subject of many dendrochronological and dendroecological studies in Europe and the Balkans. Their results proved that these species are valuable and useful in dendroclimatological and dendroecological analyses (Cedro 2006; Kochanowski and Bednarz 2007; Poljanšek et al. 2012; Helama et al. 2014; Smiljanić et al. 2014; Stajić et al. 2020; Miklić et al. 2021).

This study aimed to establish chronologies of autochthonous pine species (Scots and Austrian pines) for the Zavidovići-Teslić area in central Bosnia and Herzegovina, analyze the influence of climatic variables on the tree-ring formation and identify differences between pine species in terms of the effects of climatic parameters.

MATERIALS AND METHOD
MATERIJALI I METODE

Study Area – *Područje istraživanja*

The influence of climatic factors on diameter growth, i.e. the formation of tree rings in Scots and Austrian pine trees, was investigated in central Bosnia and Herzegovina, in the Zavidovići-Teslić area, which belongs to the Inner Dinarides. According to the Ecological-Vegetation Regionalisation of Bosnia and Herzegovina (Stefanović et al. 1983), the territory of Bosnia and Herzegovina is divided into four relatively homogeneous areas: Pannonian, Transitional Illyrian-Moesian, Inner Dinarides, and Mediterranean-Dinaric. The Inner Dinarides is divided into six areas, one of which is the Zavidovići-Teslić area (Figure 1). The area is characterized by quite heterogeneous orographic conditions. It is located in a hilly-mountainous belt from 250 to 1320 m above sea level. During most of the year, the area has a modified humid continental climate. From July to August, there is a stronger influence of the Mediterranean climate. The growing season lasts from 180 to 190 days. The area belongs to the central Bosnian ophiolite zone with a very pronounced relief in which serpentinized peridotites, igneous rocks, and cherts predominate, and limestones are far less represented.

Scots and Austrian pines are native to the study area of the Zavidovići-Teslić, i.e. the study area is part of the range of distribution of both Scots and Austrian pine in Bosnia and Herzegovina (Fukarek 1958; Stefanović 1958). The fact that Scots and Austrian pine communities are present here is of particular importance for this research.

The research was conducted on five sites or five experimental areas with three different associations. The first site comprises the association of Abieti-Fagetum serpentinicum Beus 1980 on eutric cambisol overlaying serpentinites. Scots pine trees attain impressive heights at this site, but as a community of beech and fir grows in the understorey, Scots pine has no perspective here. The second site comprises the association of Erico-Pinetum nigrae serpentinicum Stef. 1962 on colluvium over peridotite. Austrian pine is the main edifying species, while sessile oak (Quercus petraea) often occurs in the understoreys. Association Pinetum sylvestris-nigrae Pavl. 1951 on eutric ranker over peridotite occurs at the third and fourth and eutric cambisol over peridotite at the fifth site. Austrian and Scots

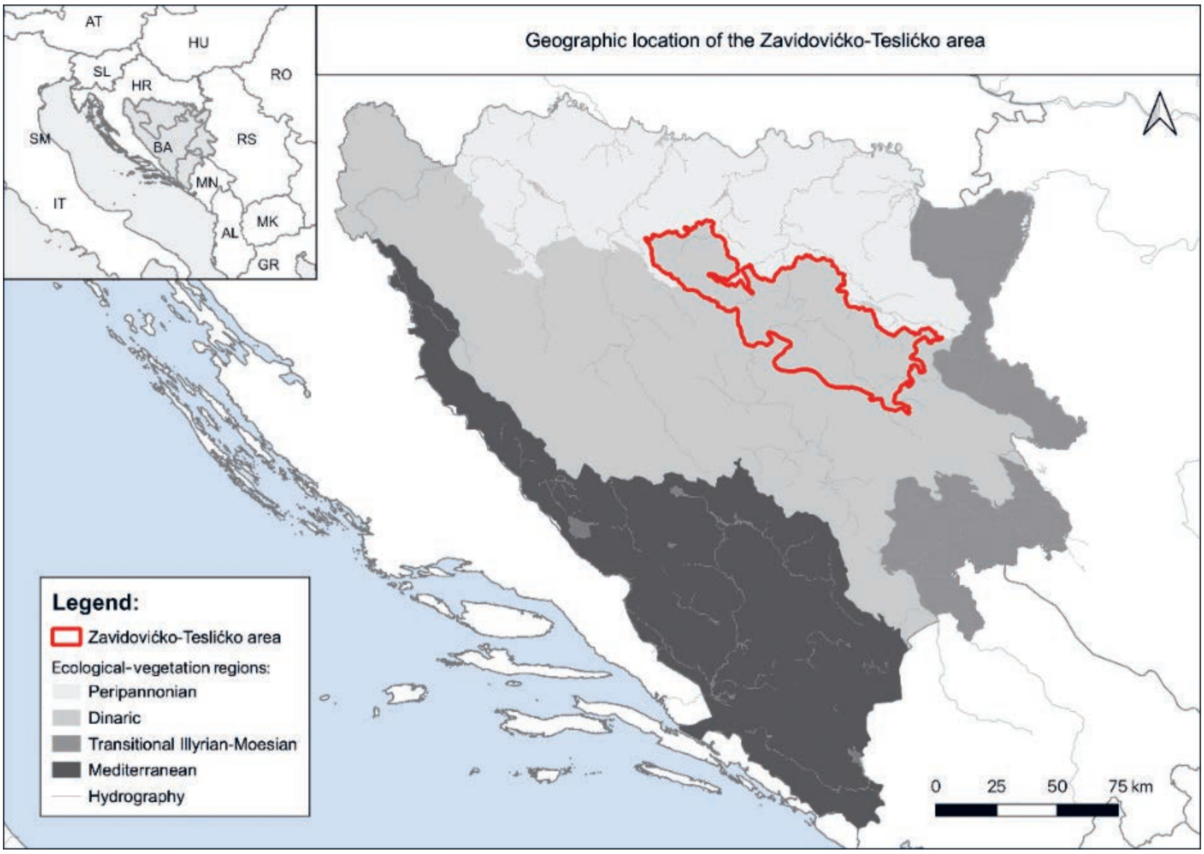

Figure 1. Geographical location of the study Zavidovićko – Teslićko area.
Slika 1. Geografski položaj istraživanog Zavidovićko - Teslićkog područja.

Table 1. Geographic coordinates and characteristics of the sampling sites.
Tablica 1. Geografske koordinate i karakteristike istraživanih lokaliteta.

Site/*Lokalitet*		1	2	3	4	5
Latitude/*Geografska širina*		17°38'45.91"	17°42'55.24"	17°52'15.06"	17°42'49.15"	17°41'20.24"
Longitude/*Geografska dužina*		44°39'22.36"	44°33'58.45"	44°30'12.80"	44°32'10.61"	44°36'41.08"
Altitude/*Nadmorska visina* (m)		435	490	330	700	365
Exposure/*Ekspozicija*		SE	WS	W	S	E
Slope/*Nagib* (°)		15	37	20	33	18
Site class/	P. sylvestris	1.7		3.5	4.2	1.7
Bonitet staništa	P. nigra		2.2	2.8	3.5	1.4

pines are edifying species in the overstorey with an even share but sparse canopy. The lower shrub layers are dominated by Erica carnea and Chamaecytisus heuffelii and the grasses Brachypodium pinnatum, Festuca rupicola, and Poa angustifolia. The altitude of the study sites ranges from 330 to 700 meters. Site classes, according to the local site quality classification for uneven-aged stands (Drinić et al. 1990), range from 4.2 (Site 4) to 1.7 (Site 1 and Site 5) for Scots pine and 3.5 (Site 4) to 1.4 (Site 5) for Austrian pine. In mixed stands, i.e. sites 3, 4, and 5, site conditions according to the local site quality classification are more favourable for Austrian pine trees (Table 1).

Sampling – *Uzimanje uzoraka*

In July 2015, on the five sampling sites of the Zavidovići-Teslić area, 72 Scots pine and 72 Austrian pine were sampled. The cores were drilled with the Pressler increment borer at breast height (two cores from opposite sides were extracted). The first site had 15 Scots pine trees, the second 15 Austrian pine trees, while the remaining three comprised mixed stands of these two species, with 15 Scots pine and 15 Austrian pine trees each. The number of trees to be drilled was determined following the research by several authors, according to which the minimum sample size to establish a good-quality individual site chronology is 15 standing trees, provided that two increment cores are taken from each tree (Fritts 1976; Accetto 1977; Levanič 1996). At each site, three additional trees were drilled to serve as a substitute in case samples got damaged in the measurement preparation or sampled trees had heart rot or atypical growth, or for some other reasons that could hinder cross-dating (missing or false tree rings).

Having been prepared in the laboratory, the cores were scanned using a high-performance scanner: the Epson Perfection V30 Photo Scanner. Each increment core that was used to make the chronology passed through the tree center, which provided accurate computation of the tree age. The tree-ring width (TRW) was measured using the Coo-Recorder 7.6 and CDendro 7.6 software (available at http://www.cybis.se/forfun/dendro/).

Chronology development – *Razvoj kronologije*

Site chronologies of Scots and Austrian pine were developed based on data obtained from tree-ring width measurements. This three-step procedure includes cross-dating, data standardization, and master chronology development. The accuracy of annual tree-ring dating, i.e. determining the calendar year in which it was formed, was verified using the cross-dating procedure. Cross-dating was done by using visual on-screen comparisons and statistical analysis. Visual on-screen techniques in the CDendro program and statistical methods of the Cofecha specialized software (Holmes 1983; Grissino-Mayer 2001) were used. According to Grissino-Mayer (2001), Cofecha software adds a high degree of confidence that tree-ring samples have been measured accurately and cross-dated correctly.

The standardization of tree-ring width time series essentially represents the elimination of the so-called age-related trend. It was performed using Arstan software (AutoRegressive STANdardization; MRWE Application Framework © 1997–2004 Absoft Corporation) and cubic smoothing spline (Cook and Peters 1981; Cook 1985; Cook and Holmes 1997). The processing in the Arstan program results in three versions of the chronology (tree-ring index): standard, residual, arstan, and a comprehensive overview of the results of statistical analysis. For the comparison with climatic parameters, the arstan chronology was used because the Arstan chronology has the best climate signal.

To assess the possibility of combining the obtained site chronologies to develop master chronologies of Scots and Austrian pine in the Zavidovići-Teslić area, t-values (t_{BP}) according to Baillie and Pilcher (1973) was calculated. The coefficient of agreement (Gleichläufigkeit) – GLK (Huber 1943; Eckstein and Bauch 1969) was also used. It measures the degree of overlap between two chronologies in the observed interval.

Meteorological data – *Meteorološki podaci*

Meteorological data (mean monthly temperatures and precipitation) used to analyze the impact of climatic parameters on radial growth was measured at the nearest meteorological station (Doboj, 146 m a.s.l, Longitude 44°44' and Latitude 18°06'). The climate in the region is generally characterised by strong temperature seasonality with a maximum in July and August. The maximum sum of precipitation occurs in June and the minimum in January and February. The mean annual air temperature is around 10.9°C and the mean annual sum of precipitation is about 932 mm, with fluctuations ranging from 502 to 1495 mm in the period from 1952 to 2014. The temperature has had an increasing trend in recent decades, while precipitation shows an increase in the variability of the annual sum of precipitation (Figure 2).

The cumulative effect of temperature and precipitation on radial growth was analysed using the Forestry Aridity Index (FAI) and Standardized Precipitation Evapotranspiration Index (SPEI). Higher Forestry Aridity Index values

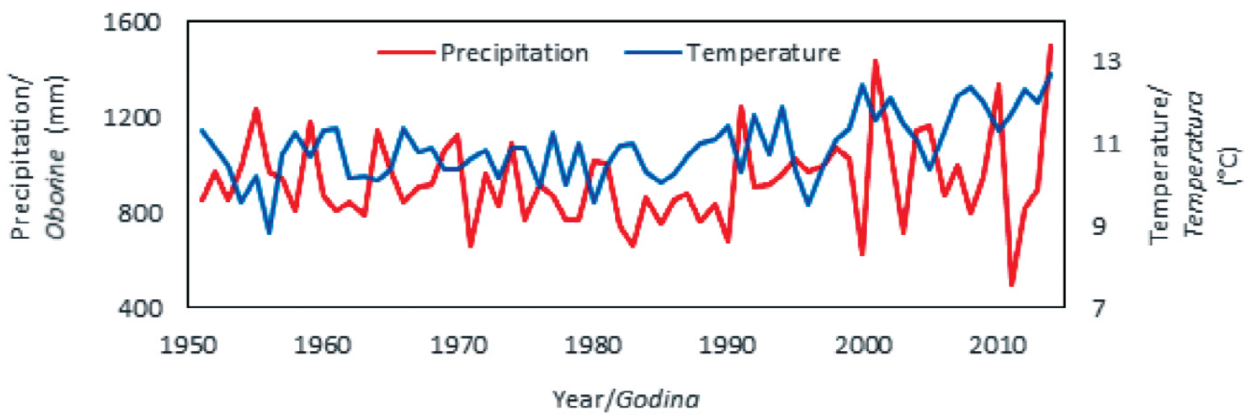

Figure 2. Annual precipitation and temperature of the nearest meteorological station Doboj.
Slika 2. Godišnje količine oborina i temperature najbliže meteorološke stanice Doboj.

point to a more arid climate (Führer et al. 2011). The SPEI was developed to quantify the drought conditions in the study area (McKee et al. 1993). It can be calculated for different time intervals (1, 3, 6, 9, 12, 24, and 48 months) and is based on monthly values of climate water balance calculated using the Thornthwaite method (Vicente-Serrano et al. 2010). Data on the SPEI for the study area were obtained from the global drought monitoring site (https://spei.csic.es/index.html).

RESULTS
REZULTATI

Table 2 shows the basic characteristics and dendrochronological-statistical parameters (calculated in the Cofecha program) of the analysed series of radial growth values of Scots pine trees per site. The mean diameter of the analysed trees ranged from 40.0 to 47.4 cm and the mean height from 18.7 to 28.4 m. The average tree age (determined by counting rings at breast height – the so-called developmental age) ranged from 99 to 113 years. The arithmetic mean of all the individual empirical series of tree-ring width (TRW) ranged from 1.53 mm (Site 4) to 1.84 mm (Site 1 and Site 5) and the serial intercorrelation of the empirical tree-ring widths from 0.288 (Site 5) to 0.438 (Site 1). The values of the mean sensitivity ranged from 0.227 (Site 1) to 0.254 (Site 4). Filtered (indexed) data were characterised by significantly different values of analysed parameters. High values of standard deviation (filtered series) that ranged from 0.283 (Site 3) to 0.329 (Site 4) indicated highly variable series and consequently higher sensitivity to environmental changes. The effect of autocorrelation was practically eliminated (all persistence within each series had largely been removed by detrending procedures), which

Table 2. The basic characteristics of trees and dendrochronological-statistical parameters of empirical series of tree-ring width - Scots pine.
Tablica 2. *Osnovne karakteristike stabala i dendrokronološko-statistički parametri analiziranih serija širina godova – Bijeli bor.*

Characteristics and parameters/ *Karakteristike i parametri*	Pure stand/*Čista sastojina*		**Mixed stands**/*Mješovite sastojine*	
	Site/*Lokalitet* **1**	**Site**/*Lokalitet* **3**	**Site**/*Lokalitet* **4**	**Site**/*Lokalitet* **5**
Diameter/*Promjer* (cm)	47.3 (33.5-54.0)	47.4 (30.4-60.3)	40.0 (28.8-51.6)	43.5 (33.4-59.8)
Height/*Visina* (m)	28.4 (23.3-34.1)	22.4 (18.2-26.0)	18.7 (15.0-22.4)	28.2 (22.7-34.1)
Age/*Starost* (Years/*Godine*)	107 (42-133)	113 (75-145)	111 (61-231)	99 (76-109)
Series intercorrelation/*Serijska korelacija*	0.438	0.379	0.419	0.288
	Unfiltered/Empirijski			
$TRW_{Mean/Prosjek}$ (mm)	1.84	1,67	1.53	1.84
Standard deviation/*Standardna devijacija* (mm)	1.073	0.852	0.648	1.213
Mean sensitivity/*Prosječna osjetljivost*	0.227	0.231	0.254	0.232
	Filtered/Filtrirani			
Standard deviation/*Standardna devijacija*	0.304	0.283	0.329	0.291
Autocorrelation/*Autokorelacija*	0.002	-0.007	0.004	0.003

Table 3. The basic characteristics of trees and dendrochronological-statistical parameters of empirical series of tree-ring width - Austrian pine.
Tablica 3. *Osnovne karakteristike stabala i dendrokronološko-statistički parametri analiziranih serija širina godova – Crni bor.*

Characteristics and parameters/ *Karakteristike i parametri*	**Pure stand**/Čista sastojina		**Mixed stands**/*Mješovite sastojine*	
	Site/*Lokalitet* **2**	**Site**/*Lokalitet* **3**	**Site**/*Lokalitet* **4**	**Site**/*Lokalitet* **5**
Diameter/*Promjer* (cm)	47.2 (25.6-74.0)	50.4 (21.8-70.0)	41.7 (33.7-56.9)	48.0 (35.6-66.1)
Height/*Visina* (m)	24.7 (13.4-31.5)	23.1 (14.8-28.6)	18.3 (15.9-23.0)	28.3 (21.6-34.2)
Age/*Starost* (Years/*Godine*)	140 (42-201)	98 (31-132)	78 (56-205)	101 (75-119)
Series intercorrelation/*Serijska korelacija*	0.516	0.558	0.560	0.391
	Unfiltered/Empirijski			
$TRW_{Mean/Prosjek}$ (mm)	1.36	2.05	2.09	1.93
Standard deviation/ *Standardna devijacija* (mm)	0.720	0.850	0.799	1.075
Mean sensitivity/ *Prosječna osjetljivost*	0.243	0.243	0.254	0.264
	Filtered/Filtrirani			
Standard deviation/ *Standardna devijacija*	0.301	0.295	0.311	0.339
Autocorrelation/ *Autokorelacija*	0.007	0.013	0.012	0.006

was confirmed by autocorrelation coefficients close to zero (from -0.007 to 0.004).

The mean tree diameter of Austrian pine trees per sampling site ranged from 41.7 to 50.4 cm and the mean height from 18.3 to 28.3 m. The average tree age ranged from 78 to 140 years. The arithmetic mean of all the empirical series of tree-ring widths ranged from 1.36 (Site 2) to 2.09 (Site 4) and the serial intercorrelation of the empirical tree-ring widths from 0.391 (Site 5) to 0.560 (Site 4). The values of the mean sensitivity ranged from 0.243 (Site 2 and Site 3) to 0.264 (Site 5). The standard deviation of the filtered series ranged from 0.295 to 0.339, while the autocorrelation coefficients close to zero (ranging from 0.006 to 0.013) indicated higher sensitivity to environmental changes (Table 3).

The average tree-ring width (TRW) series for Scots and Austrian pines per sampling site (Figure 3) show that the age-related growth trend is clearly observed for both species at all sites except Site 4. It is a site with the oldest individual trees of both species and the worst site conditions according to the local site quality classification.

The removal of age-related growth trends, i.e. the standardisation of the raw tree-ring width series was performed in the ARSTAN software. Raw ring-width series were detrended using cubic smoothing splines (Cook and Peters 1981) with a 50% frequency response cut-off. The adequacy of merging four sites' chronologies into one master chronology was determined based on t-values (t_{BP}) and GLK between site chronologies. Between sites with Scots pine trees GLK were statistically significant and t_{BP} values grea-

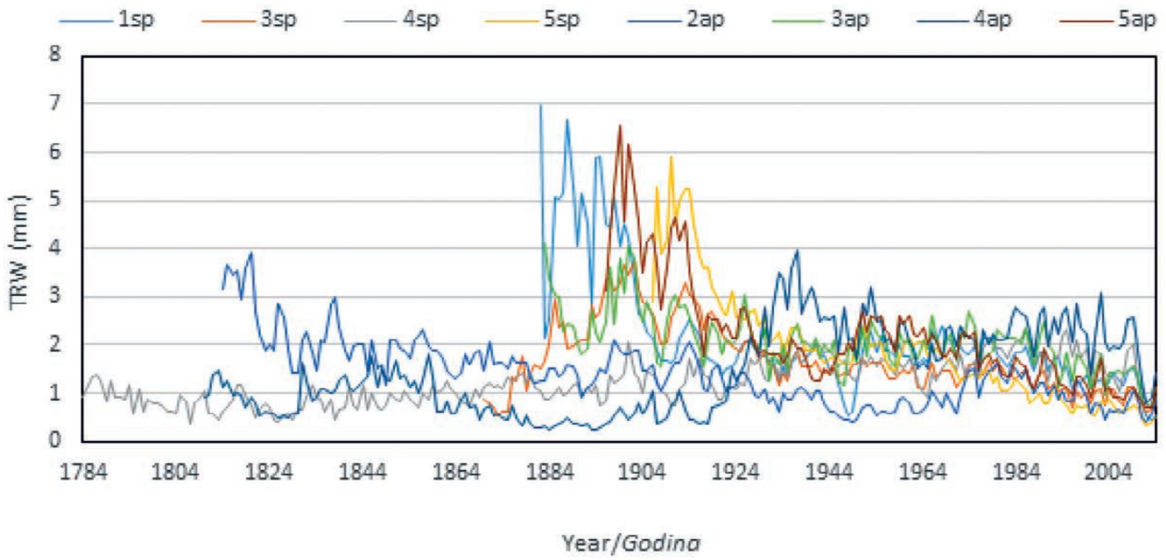

Figure 3. Average empirical TRW series per sampling sites for Scots pine (sp) and Austrian pine (ap).
Slika 3. Prosječne empirijske serije širina godova po lokalitetima za bijeli bor (sp) i crni bor (ap).

Table 4. Overlapping (Ovl), t-value (t_{BP}) and coefficient of agreement (GLK) between site TRW index chronology.
Tablica 4. Preklapanje (Ovl), t-vrijednost (t_{BP}) i koeficijenti podudarnosti (GLK) između kronologija indeksa širina godova po lokalitetima.

Ovl, t_{BP}	**Pure stands/***Čiste sastojine*		**Mixed stands/***Mješovite sastojine*		
–	**Site/***Lokalitet* **1**	**Site/***Lokalitet* **2**	**Site/***Lokalitet* **3**	**Site/***Lokalitet* **4**	**Site/***Lokalitet* **5**
GLK		* ($p < 0.05$)		** ($p < 0.01$)	
			Scots pine / *Bijeli bor*		
Site/*Lokalitet* **1**	-	-	Ovl = 119, t_{BP} = 4.9	Ovl = 119, t_{BP} = 6.8	Ovl = 105, t_{BP} = 4.6
Site/*Lokalitet* **3**	GLK = 0.705**	-	-	Ovl = 130, t_{BP} = 3.9	Ovl = 105, t_{BP} = 4.6
Site/*Lokalitet* **4**	GLK = 0.658**	-	GLK = 0.645**	-	Ovl = 105, t_{BP} = 3.8
Site/*Lokalitet* **5**	GLK = 0.612**	-	GLK = 0.607*	GLK = 0.553*	-
			Austrian pine / *Crni bor*		
Site/*Lokalitet* **2**	-	-	Ovl = 116, t_{BP} = 10.9	Ovl = 116, t_{BP} = 8.5	Ovl = 105, t_{BP} = 9.5
Site/*Lokalitet* **3**	-	GLK = 0.645**	-	Ovl = 74, t_{BP} = 7.4	Ovl = 105, t_{BP} = 10.2
Site/*Lokalitet* **4**	-	GLK = 0.986**	GLK = 0.799**	-	Ovl = 74, t_{BP} = 7.0
Site/*Lokalitet* **5**	-	GLK = 0.689**	GLK = 0.748**	GLK = 0.646**	-

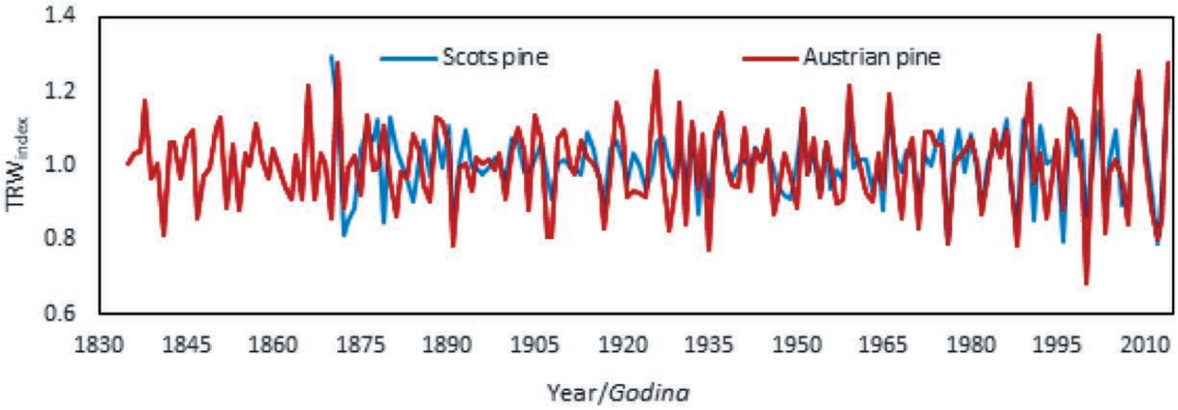

Figure 4. Regional TRW index chronologies of Scots pine and Austrian pine in Zavidovići – Teslić area.
Slika 4. Regionalne kronologije indeksa širina godova bijelog i crnog bora u Zavidovićko-Teslićkom području.

ter than 3.5. The calculated t_{BP} ranged from 3.8 (between Site 4 and Site 5) to 6.8 (between Site 1 and Site 4) and GLK from 0.553 (between Site 4 and Site 5) to 0.705 (between Site 1 and Site 3). Coefficients GLK between sites of Austrian pine trees were also statistically significant and t_{BP} values greater than 3.5. The calculated t_{BP} ranged from 7.0 (between Site 4 and Site 5) to 10.9 (between Site 2 and Site 3) and GLK ranged from 0.645 (between Site 2 and Site 3) to 0.986 (between Site 2 and Site 4). The determined coefficients were higher than the coefficients calculated for Scots pine trees (Table 4).

These results obtained both for Scots pine and Austrian pine trees showed that there was a high similarity and a significant harmonisation between the obtained chronologies at different sites. This indicated that these chronologies were suitable to develop a regional chronology for Scots pine and a regional chronology for Austrian pine in Zavidovići-Teslić area.

According to Wigley et al. (1984), a year with a minimum of 5 series of tree rings was taken as the first year of chronology. A 145-year-long regional chronology of Scots pine was obtained. The first year of the chronology was 1870 and the last 2014 (Figure 4). The average value of the tree-ring width index was 1.006, the standard deviation of the tree-ring width was 0.122, the asymmetry coefficient -0.028, and the flattening coefficient 4.967. The mean sensitivity was 0.134. In order to evaluate the quality and reliability of the obtained chronology for the analysis of the influence of climatic parameters on the formation of tree rings, the values of the EPS (Expressed Population Signal) coefficient were calculated and analysed. This parameter ranged from 0.861 to 0.952 in the period in which the influence of climatic parameters was analysed (from 1952 to 2014). The total length of the obtained regional chronology of Austrian pine was 180 years. The first year of the chronology was 1835 and the last 2014 (Figure 4). The average value of the tree ring-width index was 1.001, the standard deviation of the tree-ring width was 0.117, the asymmetry coefficient 0.099, and the flattening coefficient 3.255. The mean sensitivity was 0.136. The EPS coefficient values ranged from 0.947 to 0.956 in the period in which the climate impact was analysed.

The analysis of the relationship between the obtained chronologies of Scots and Austrian pine, i.e. t-value (t_{BP} = 8.5) and the coefficient of agreement (GLK = 0.7330; p = 0.00) revealed a very good agreement between the obtained chronologies. It meant that a significant impact of climatic conditions on tree radial growth could be expected.

In order to determine the influence of climatic parameters on radial growth or formation of tree rings, we further conducted a correlation analysis of the relationship between the tree-ring index and the sum of precipitation and temperature in certain characteristic periods of the year: September and October of the previous year (so), period from November of the previous year to March of the current year (ndJFM), April and May (AM), June, July, and August (JJA), September and October (SO) and growing season (GS). The growing season at the study sites lasts from April to October. Both tree species experienced a negative effect of temperature on the formation of tree rings in the study periods, except in the period from November of the previous year to March of the current year, i.e. in the winter months, when higher temperatures positively affected radial growth. According to the correlation coefficient for Scots pine trees, the dependence of the radial growth index on temperature was statistically significant for the period from June to August. Besides the same period, Austrian pine showed statistically significant dependence for September and October of the previous year and the growing season. The influence of winter temperatures was also statistically significant in Scots pine (Figure 5).

In contrast to temperature, a positive effect of precipitation was found (Figure 6). In both tree species, the correlation between the tree-ring width index and precipitation was statistically significant for the following periods: September

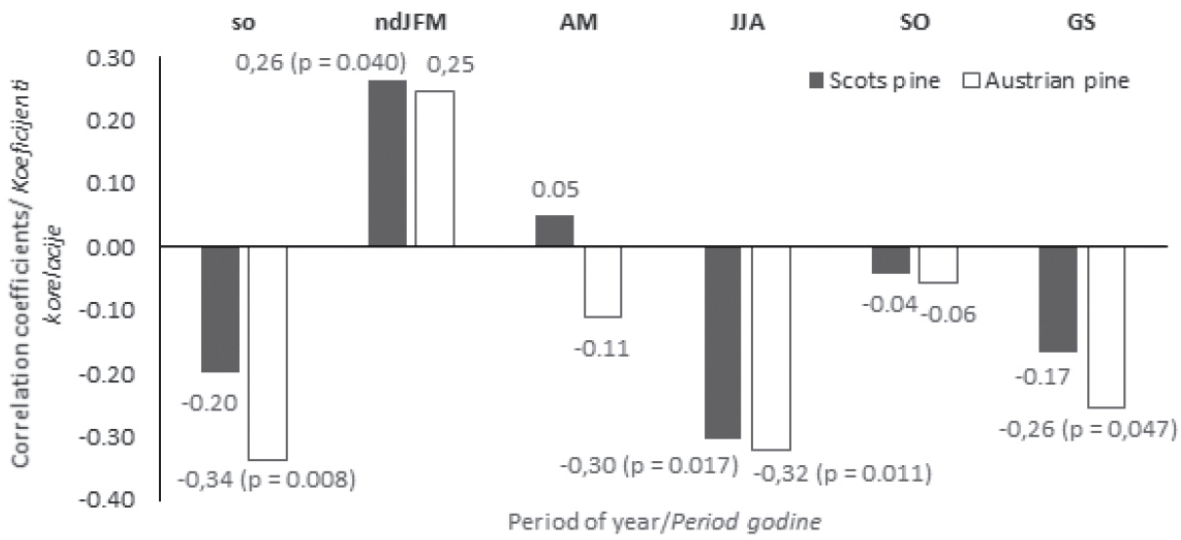

Figure 5. Correlation coefficients between TRW index chronologies and temperature. so - September and October of the previous year, ndJFM - period from November of the previous year to March of the current year, AM - April and May, JJA - June, July and August, SO - September and October, GS - growing season

Slika 5. Koeficijenti korelacije između kronologija indeksa širina godova i temperature. so - rujan i listopad prethodne godine, ndJFM - razdoblje od studenog prethodne do ožujka tekuće godine, AM - travanj i svibanj, JJA - lipanj, srpanj i kolovoz, SO - rujan i listopad, GS - vegetacijsko razdoblje

and October of the previous year, June, July, and August, and the growing season. For Austrian pine, the correlation was also significant for the period April-May. As with temperature, there was little difference between the two species in terms of its influence on the formation of tree rings. Generally, the influence of precipitation is somewhat stronger in Austrian pine.

In order to fully understand the relationship between Scots and Austrian pine in terms of the influence of climate variables on the formation of tree rings, it was necessary to test the temporal stability of the climate signal in the period for which temperature and precipitation data was available. The correlation between the tree-ring width index and temperature (ap – t and sp – t) and precipitation (ap – p and sp – p) in the period from June to August was analysed. The temporal stability of the correlation was analysed using a moving correlation with a 30-year-time span and a one-year step. Both species had approximately the same flow of correlation coefficient values both for precipitation and temperature. The correlation coefficient for precipitation in both species

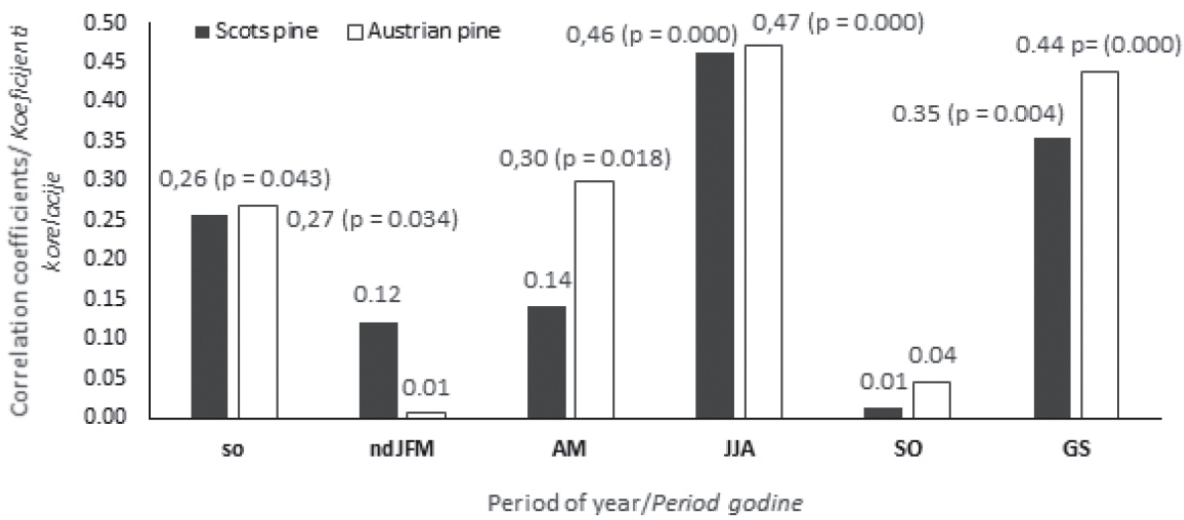

Figure 6. Correlation coefficients between TRW index chronologies and precipitation. so - September and October of the previous year, ndJFM - period from November of the previous year to March of the current year, AM - April and May, JJA - June, July and August, SO - September and October, GS = growing season

Slika 6. Koeficijenti korelacije između kronologija indeksa širina godova i oborina. so - rujan i listopad prethodne godine, ndJFM - razdoblje od studenog prethodne do ožujka tekuće godine, AM - travanj i svibanj, JJA - lipanj, srpanj i kolovoz, SO - rujan i listopad, GS - vegetacijsko razdoblje

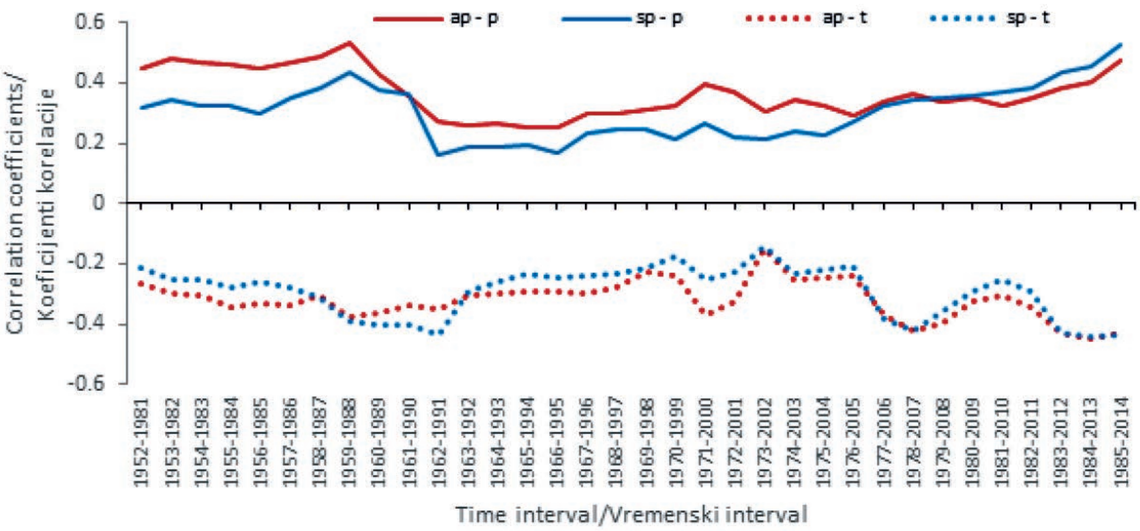

Figure 7. Moving correlation for the total precipitation from June to August and average air temperature from June to August for the period 1952. – 2014.

Slika 7. Rezultati pomičnih korelacija za ukupnu količinu oborine od lipnja do kolovoza te za prosječnu temperaturu zraka od lipnja do kolovoza za razdoblje od 1952. – 2014. godine.

decreased from 1988 to 1991, then stagnated for a long time and increased in the last decade (Figure 7).

In order to eliminate the influence of the so-called multicollinearity, i.e. intercorrelations between temperature and precipitation (higher precipitation causes lower temperatures and vice versa), which makes it difficult to draw reliable conclusions about the individual influence of these two climatic elements on tree growth, drought indices were used in the analyses of the climate impact on the tree ring formation. The FAI index and SPEI index were selected as suitable for this analysis. The obtained value of the correlation coefficient between the FAI index and the index of the tree-ring width, i.e. the chronology of Scots pine was - 0.46 ($p < 0.00$) and - 0.54 ($p < 0.00$) of Austrian pine. The SPEI index, which was developed to define and monitor drought conditions, has been increasingly used in dendrochronological research. In the period from June to September for Austrian pine and June-August for Scots pine, there was a strong and statistically significant dependence of the tree-ring width index on the SPEI index (calculated for a three-month time interval), i.e. lack of moisture had a significant influence on radial growth in the study period (Figure 8).

The pointer year was defined as a year in which more than 90% of the series (in a sample of 10 or more individual tree-

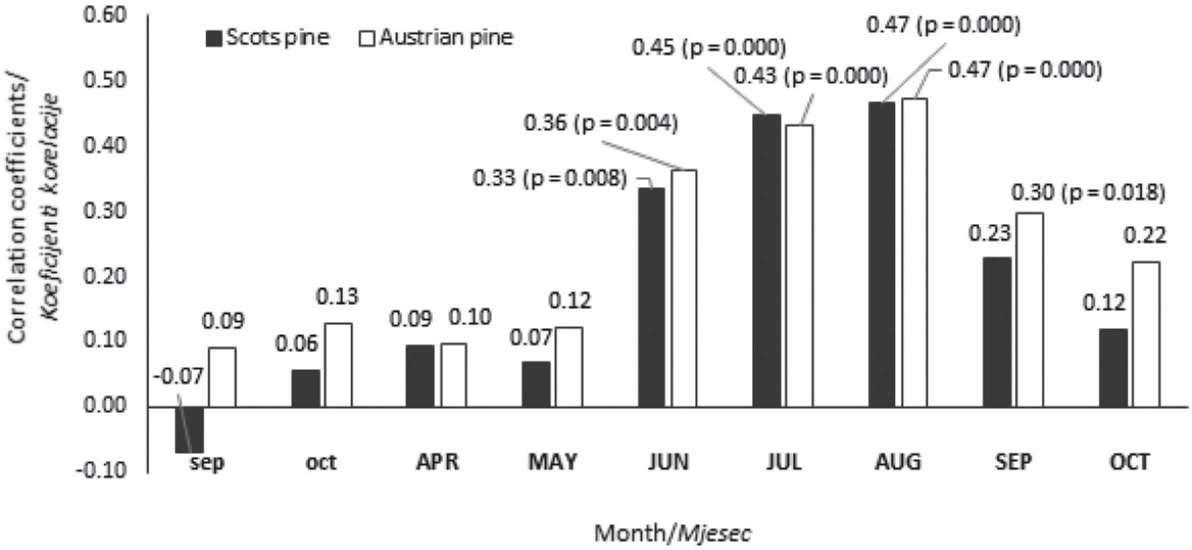

Figure 8. Correlation coefficients between TRW index chronologies and SPEI index.

Slika 8. Koeficijenti korelacije između kronologija indeksa širina godova i SPEI indeksa.

ring series) responded with the same increasing or decreasing trend in tree-ring width compared to the previous year (Schweingruber 1983, Schweingruber et al. 1990). Pointer years were determined for the period for which meteorological data were available. For Scots pine, 1989 and 1997 were identified as positive pointer years and 1976, 1996, 2000, and 2011, as negative i.e. a total of six pointer years were identified. Regarding Austrian pine, 1989, 1997, and 2014 were identified as positive pointer years, and 1976, 2000, and 2003 as negative, i.e. a total of six pointer years.

DISCUSSION
RASPRAVA

Based on the characteristics and dendrochronological-statistical parameters of the analysed series of empirical values of radial growth of Scots pine and Austrian pine trees by site, it can be stated that the data related to the tree-ring width or radial growth made good material for chronology development in Zavidovići-Teslić area. The serial correlation between the empirical values and the master chronology of radial growth by site ranged from 0.288 to 0.438 for Scots pine and 0.391 to 0.560 for Austrian pine. Following the guidelines of Grissino-Mayer (2001), the values of the mean sensitivity were in the category of "intermediate". In filtered (indexed) data, as expected, the effect of autocorrelation was practically eliminated, which was confirmed by autocorrelation coefficients close to zero.

Standardisation, i.e. the removal of the age-related trend from the tree-ring series was performed in the Arstan program. The coefficient of agreement (GLK) and t-value (t_{BP}) showed similar patterns of tree rings in Scots and Austrian pine trees, i.e. matching of site chronologies was good enough to develop a master chronology of Scots pine and master chronology of Austrian pine for the Zavidovići-Teslić area. The determined parameters indicate that Austrian pine trees had a better matching of the obtained site chronologies and that the effect of mixedness did not manifest itself, i.e. no difference was found between pure and mixed stands.

A 145-year-old Scots pine master chronology and a 180-year-old Austrian pine master chronology were obtained. In the period from 1952 to 2014 (when the influence of climatic parameters was analysed), the values of the EPS coefficient (statistical measure showing the level of common signal among the samples used to obtain the chronology) were significantly above the lower limit of chronology certainty and reliability for both chronologies. According to Wigley et al. (1984), this limit amounts to 0.85.

Correlation analysis of the relationship between the radial growth index and precipitation and temperature in certain characteristic periods of the year revealed a negative effect of temperature (except in winter months) on the tree-ring formation in both species. In Scots pine, the dependence of the radial growth index on temperature was statistically significant for the period from June to August. Besides the same period, Austrian pine showed statistically significant dependence for September and October of the previous year and the growing season. The influence of winter temperatures was also statistically significant in Scots pine. In contrast to temperature, precipitation had a positive effect. Both tree species exhibited significant statistical dependence of radial growth on precipitation for the following periods: September and October of the previous year, June, July, and August, and the growing season. April and May were also significant in Austrian pine trees. As with temperature, there was little difference between the two species in terms of the influence of precipitation on the tree-ring formation, but we can conclude that the influence was generally more pronounced in Austrian pine.

The analysis of the temporal stability of the climate signal showed that the precipitation signal, in both species, exhibited a significant decline in the period from 1988 to 1991 and a growing trend in the last decade. Regarding the temperature signal, neither species had any significant increasing or declining trends in the past period, i.e. the signal was stable. Dendrochronological research of Austrian pine in the Northern Velebit National Park (Croatia) showed that the impact of precipitation was confirmed as stable and relatively high during the study period. Unlike precipitation, the temperature signal dropped significantly after 1996 (Miklić et al. 2021).

The determined value of the coefficient of correlation between the FAI index and the tree-ring width index for both Scots and Austrian pine was statistically significant and negative, which was to be expected because a higher value of the index indicates arid climate conditions (-0.46 for Scots pine and -0.54 for Austrian pine). In the study period, the study area had an average value of the FAI index of 4.86 (p = 0.05, confidence intervals: 4.42 and 5.29). According to Matović (2013), based on the value of this index, the upper and lower limits of the potential area of distribution were 2.97 and 6.10 for Austrian pine and 2.80 and 4.10 for Scots pine. The obtained average value and confidence interval of the FAI index indicates that Scots pine is an endangered species in the study area. The survival of Scots pine in these areas may be threatened by the changes expected to occur in the coming period and increase the drought index. Based on the climate and site conditions in the study area, we can conclude that Scots pine is close to its ecological threshold. Unlike Scots pine, Austrian pine grows in different climate conditions, and its distribution is primarily determined by other site conditions.

In the period from June to September for Austrian pine and June to August for Scots pine, high and statistically significant dependence of the tree-ring width index on the SPEI index pointed to the significant impact of moisture deficiency on radial growth of both tree species. Based on the research results related to the dieback of Siberian pine forests, Kharuk et al. (2013) conclude that the SPEI index is likely to be useful as an early warning indicator of climate-related mortality across forests in other areas and regions, especially those composed of drought-sensitive species.

The response of Austrian pine in the study area in terms of the dependence of radial growth on climate is similar to the response of Austrian pine in the surrounding countries, which are characterised by similar climate conditions. According to Miklić et al. (2021)**,** dendrochronological research in the Northern Velebit National Park (Croatia) showed that the main limiting factor for the growth of Austrian pine trees was the lack of moisture in summer. The correlation between the chronology and the sum of summer precipitation from 1954 to 2015 was significant and positive ($R = 0.60$, $p = 0.0099$), which made the signal in the tree-ring width stable and thus suitable for the reconstruction of precipitation. Studies of the impact of temperature and precipitation on the growth of Austrian pine trees in Serbia showed that Austrian pine was in the given conditions very sensitive to summer precipitation. On the other hand, its growth varied much less with temperature variations (Stajić and Kazimirović 2018; Stajić et al. 2020). According to the study of the Austrian pine chronology for the area of the western Balkan Peninsula, i.e. the Dinarides in Bosnia and Herzegovina (Poljanšek and Levanič 2012; Poljanšek et al. 2013), radial growth proved to be more dependent on temperature than precipitation. Different results here obtained can be explained by the fact that the study area in the Dinarides is at a significantly higher altitude than the study area in Zavidovići-Teslić area (the altitude is on average about 600 meters higher).

Unlike Austrian pine, research studies dealing with the dependence of Scots pine radial growth on the climate conducted in the neighbouring countries that are characterised by similar climate conditions, are few. Using the dendrochronological method, Bouriaud and Popa (2009) compared the influence of climatic parameters on radial growth of the three main conifer species in the Romanian Carpathians (Scots pine, Norway spruce, and Silver fir) in mixed stands. Scots pine was the most sensitive to precipitation and the series of Scots pine tree-rings widths could be used for climate reconstruction with an emphasis on precipitation.

Dendrochronological analysis of Scots and Austrian pine in the Słowinski National Park and neighbouring forests showed a positive effect of high air temperature in the winter months (December, February, and March) and a negative effect of air temperature in September of the previous year on the radial growth of Scots and Austrian pine. Growth responses to the temperature of the winter months and September of the previous year were similar in both pine species. A stronger correlation was found in the populations that grew in better sites. In contrast to temperature, precipitation had no significant effect (Kochanowski and Bednarz 2007). A comparative analysis of the influence of climatic parameters on the growth of Scots and Austrian pine trees in northwestern Poland showed that the two species differed in terms of the relationship between radial growth and climate, despite the significant agreement (harmonisation) of the formed chronologies. Scots pine showed high sensitivity to heat conditions in winter (especially in February) and early spring, while the sum of precipitation in the growing season was less important. In contrast, the cambial activity of Austrian pine largely depended on the sum of precipitation during the growing season (Cedro 2006). Unlike northwestern Poland where Scots pine is an autochthonous and Austrian pine an allochthonous species, in the study area of Zavidovići-Teslić, both species are autochthonous and stands in the investigated sites are of natural origin.

A total of six pointer years were identified in Scots pine and a same number of pointer years in Austrian pine in the period for which meteorological data were available. Of the six pointer years identified in Scots pine, four years or 66% match the pointer years (of the same sign) identified in Austrian pine. The identified pointer years in the Austrian pine chronology for the areas of the western part of the Balkan Peninsula, i.e. the Dinarides in Bosnia and Herzegovina (Poljanšek et al. 2012) do not match the identified pointer years in this study (except 2000). As already mentioned, there is a significant difference between these studies in terms of the average altitude of the investigated sites.

Unlike the research that has shown that the climate signal is not strong enough if only the tree-ring width is observed and it is necessary to use other parameters of tree rings such as density, latewood width and isotope content (Trouet et al. 2012; Klesse et al. 2015; Levanič et al. 2020), the series of tree-ring width indices obtained in this research had a favourable climate signal, especially the drought signal in the summer months.

CONCLUSION
ZAKLJUČAK

The analysis of Scots and Austrian pine tree growth, which aimed to determine the similarity of growth patterns of these two tree species and the nature of the impact of climatic parameters on tree growth patterns, was conducted in the Zavidovići-Teslić area using data obtained at five sites. Based on the analysis of the presented characteristics and dendrochronological-statistical parameters of the series of tree rings, it was concluded that the data represent a good material for the development of site chronologies. The obtained local chronologies had quite similar growth patterns and there was a statistically significant agreement (harmonisation) between the developed site chronologies of both Scots and Austrian pine. However, it is evident that Austrian pine exhibited better agreement.

Significant agreement of the developed site chronologies enabled the development of regional chronologies of Scots and Austrian pine for the Zavidovići-Teslić area. A chronology of Scots pine with a total length of 145 years (1870-2014) and a chronology of Austrian pine with a total length of 180 years (1835-2014) were produced.

Analysis of the relationship between climatic parameters (temperature, precipitation, forestry aridity index, standardized precipitation evapotranspiration index) and the chronologies developed for Scots and Austrian pine indicated similar radial growth-climate relationships, with a more pronounced influence of climate variables on Austrian pine.

Similar relationships between radial growth and climate and significant matching of identified pointer years showed that the radial tree growth of both tree species in the study area was significantly determined by climate conditions, i.e. chronologies of these species had a good climate signal, especially the summer drought signal.

Based on the climate and site conditions in the study area, we can conclude that Scots pine is close to its ecological threshold. That is not the case with Austrian pine. Austrian pine grows in different climate conditions, and its distribution is primarily determined by other site conditions. This should be taken into account when drafting forest management plans for the observed area, and especially when planning the establishment of new forests.

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SAŽETAK

U Zavidovićko - Teslićkom području, u središnjoj Bosni i Hercegovini, dendrokronološkom metodom je proučavan radijalni rast stabala crnog i bijelog bora, autohtonih vrsta u pomatranom području. Cilj je bio identifikacija razlika između spomenutih vrsta glede utjecaja klimatskih čimbenika. Uzorci su uzeti iz stabala s pet lokaliteta. Na prvom lokalitetu je sastojina bijelog bora, na drugom crnog bora, a na ostala tri lokaliteta su mješovite sastojine. Standardizacija serija širina godova (radijalnih prirasta) obavljena je primjenom Arstan programa. Dobivena je regionalna kronologija bijeloga bora dužine 145 godina (od 1870. do 2014.) i regionalna kronologija crnoga bora dužine 180 godina (od 1835. do 2014.). Ispitivanje zavisnosti između indeksa širine goda i oborina odnosno temperature u pojedinim karakterističnim periodima godine, pokazalo je negativan utjecaj temperature (osim u zimskim mjesecima) na formiranje goda i pozitivan utjecaj oborina. Statistički značajna zavisnost indeksa širine goda od SPEI indeksa ukazuje na značajan utjecaj nedostatka vlage u periodu lipanj – kolovoz ($r = 0,33$ u lipnju, $r = 0,45$ u srpnju i $r = 0,47$ u kolovozu) za bijeli bor i periodu lipanj - rujan ($r = 0,36$ u lipnju, $r = 0,43$ u srpanju, $r = 0,47$ u kolovozu i $r = 0,30$ u rujnu) za crni bor na formiranje godova. Analiza odnosa klimatskih parametara i formiranih kronologija bijeloga i crnoga bora pokazuje slične odnose između širine goda i klime, ali je utjecaj klimatskih čimbenika nešto više izražen kod crnog bora, kojemu više odgovaraju uvjeti staništa na promatranom području. U promatranom području radijalni prirast stabala obje vrste drveća značajno je uvjetovan klimatskim čimbenicima, odnosno kronologije navedenih vrsta imaju dobar klimatski signal, a posebno signal suše u ljetnim mjesecima.

KLJUČNE RIJEČI: dendrokronologija, širina goda, crni bor, bijeli bor, klima, Bosna i Hercegovina