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Tree-Ring Chronology of Pedunculate Oak (*Quercus robur*) and its Potential for Development of Dendrochronological Research in Croatia

Kronologija godova hrasta lužnjaka (*Quercus robur*) i njezin potencijal za razvoj dendrokronoloških istraživanja u Hrvatskoj

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ABSTRACT • *We present the local tree-ring chronology of pedunculate oak (Qercus robur) from Kobiljak near Zagreb, Croatia (16º09' E, 45º49' N, 140 m a.s.l.). The chronology is based on 17 trees and is 127 years long and covers the period of 1883-2009. The well replicated part of the residual version of the ARSTAN chronology with SSS>0.80 (interval of 88 years, period 1922-2009) was used for dendroclimatological analysis, which showed that June precipitation has positive and temperature has negative effect on tree-ring variation. Comparison with 40 available oak chronologies from the surrounding countries confirmed its good teleconnection with 2 local oak chronologies from Austria, 2 from Hungary, and 3 from Slovenia. It also exhibits good heteroconnection, i.e. similarity with chronologies of beech (Fagus sylvatica), from various sites in Slovenia. The similarities can be ascribed to response to common climatic factors. The results indicate that the chronology could be a good reference point for constructing a longer regional chronology in Croatia and surrounding countries, which could be used for different purposes including dating of objects of cultural heritage.*

Keywords: *dendrochronology, pedunculate oak (Quercus robur), dendroclimatology, teleconnection, heteroconnection*

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SAŽETAK • *U radu je predstavljena lokalna kronologija godova hrasta lužnjaka (Qercus robur) iz Kobiljaka pokraj Zagreba, Hrvatska (16º09' E, 45º49' N, 140 m n.m.). Temelji se na 17 stabala i obuhvaća 127 godina, i to razdoblje od 1883. do 2009. Za dendroklimatološku analizu primijenjen je optimalan replicirani dio rezidualne inačice kronologije ARSTAN sa SSS>0,80 (dužina 88 godine, razdoblje 1922. – 2009.). Analiza je pokazala pozitivan učinak lipanjskih oborina na promjene širine godova, dok je učinak temperature u istome mjesecu negativan. Usporedba s 40 dostupnih hrastovih kronologija iz okolnih zemalja potvrdila je telekonekciju s dvije lokalne kronologije hrasta iz Austrije, dvije iz Mađarske i tri iz Slovenije. Ona također pokazuje dobru heterokonekciju, tj. sličnost s kronologijama bukve (Fagus sylvatica) s različitih staništa u Sloveniji. Sličnosti se mogu pripisati odgovoru na zajedničke klimatske čimbenike. Rezultati upućuju na zaključak da ta kronologija može biti dobro polazište za izradu dulje regionalne kronologije hrasta u Hrvatskoj i susjednim državama, koja bi onda mogla imati različite namjene, uključivši i datiranje objekata kulturne baštine.*

Ključne riječi: *dendrokronologija, hrast lužnjak (Quercus robur), dendroklimatologija, telekonekcija, heterokonekcija*

1 INTRODUCTION
1. UVOD

Numerous wood science laboratories in the world develop dendrochronology, which as a rule includes investigations of tree ring widths and wood structure. Oak (*Quercus* sp.) is considered the most important wood in European dendrochronology. It is mainly represented by the pedunculate oak (*Quercus robur* L.) and sessile oak (*Q. petraea* Liebl.), which cannot be differentiated by their wood anatomy. Despite different ecological requirements of the two species, their tree-ring patterns usually show good agreement. Therefore, they are often treated together as European oak or simply oak (*Quercus* sp.).

Since the 1990s, when the construction of the first multimillennial oak chronologies was completed (Baillie, 1995), oak dendrochronology has made considerable progress. The longest tree-ring chronology in the world is the oak chronology of the laboratory in Hohenheim reaching back to 8480 BC (Friedrich *et al*., 2004). There are several other millennial chronologies, which have been constructed all over the western and central Europe (e.g., for review see Haneca *et al*., 2009). Oak research has been at the same time extended also to areas, which were for a long time considered as less optimal for dendrochronology, like Flanders/Belgium (Haneca *et al*., 2006). It has also been extended to the areas east, and southeast of traditional oak research (e.g. Wimmer and Grabner, 1998; Gryaneus, 1996, 2003; Geihofer *et al.,* 2005; Morgos, 2005; Pukiene and Ožalas, 2007; Szántó *et al*., 2007; Čufar *et al.,* 2008a, 2010: Kern *et al*., 2009a, b; Grabner *et al*., 2011; Kolar *et al.,* 2012).

Long tree-ring chronologies have been used for investigating the past and for predicting future changes in the climate and environment (e.g. Friedrichs *et al.,* 2009a, b; Kern *et al.,* 2009; Haupt *et al.* 2011; Levanič *et al.,* 2011). In addition, they were used for dating of archaeological wood and artefacts from historic constructions and archaeological sites (e.g., for review see Čufar, 2007; Haneca *et al.,* 2009).

In Slovenia, a neighbouring country of Croatia, which has similar climate regimes to some extent (Alpine, Mediterranean and continental), the first local tree ring chronologies of oak were constructed in the 1990s (Čufar and Levanič, 1999), but their tree-ring patterns seemed to have no similarity with oak chronologies from other countries, such as those north of the Alps. Recently, a 548 years long regional oak chronology has been constructed in SE Slovenia, showing a good supra-regional signal reflected in the radius of ca. 500 km, which demonstrated to be climatic in its nature (Čufar *et al*., 2008a). It enabled reconstruction of climate for the span of the chronology, indicating that hot and dry June conditions limit the growth of oak in the area (Čufar *et al*., 2008b). Reconstructed years with extremely hot-dry and wet-cool conditions could be confirmed by the reports in archived documents. Interestingly, the extreme years did not agree with those reconstructed from oak tree-rings in Western Europe (Kelly *et al.,* 2002). The Slovenian oak chronology, which showed good teleconnection with the chronologies of the surrounding countries, has also been successfully used for dating the wood of the objects in Slovenia as well as the objects of the Croatian cultural heritage (Čufar and Šimek, 2008; Čufar *et al*., 2006, 2008c).

Since the tree-ring chronologies can be considered 'living organisms', it is necessary to work to improve and prolong the existing ones and to construct the new ones, especially in Croatia and neighboring countries where dendrochronological research still needs to be developed.

The objectives of this study are (1) to construct a local oak chronology for the site near Zagreb, Croatia, (2) to show how climatic factors influence tree-ring variation of oak in the sampling area, (3) to find out if there exists teleconnection of this chronology with oak chronologies in the surrounding countries (4) and if there exists heteroconnection of Croatian oak with other tree species. All of this would provide useful information to develop a strategy to improve dendrochronological research in Croatia.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Study Area and Wood for Tree-Ring Research
2.1. Područje i drvo obuhvaćeno istraživanjem

The sampling area Kobiljak (16º09' E, 45º49' N, 140 m a.s.l.) is located 20 km east of Zagreb. The sampling trees originated from the forest association *Genisto elatae-Quercetum roboris* Ht. 1938 composed of pedunculate oak (*Quercus robur* L.) mixed with big greenweed on the area where the level of ground water is high. The age of trees was estimated to 140-150 years.

2.2 Dendrochronological analysis
2.2. Dendrokronološka analiza

For dendrochronological investigations, disks from 17 felled *Quercus robur* trees (DBH 40 ± 5 cm) were taken at 4 m above ground. The wood was polished and tree-ring widths were measured along the mean diameter, i.e. two radii, to the nearest 0.01 mm using TSAP-Win program (Frank Rinn, Heidelberg, Germany). The tree-ring series were visually and statistically crossdated and compared with each other by calculating the *t*-values according to Baillie and Pilcher (1973) and coefficient of agreement (Gleichläufigkeit - Glk) (Eckstein and Bauch 1969) using TSAP-Win program. Tree-ring series, two per each tree, were crossdated, and series of 33 radii were found acceptable for further analyses.

Crossdated tree-ring series of individual trees were assembled into a chronology using the program ARSTAN (Holmes 1994). We calculated ARSTAN chronologies, a non-detrended - raw-data, and a detrended residual chronology.

2.3 Tree rings and climate
2.3. Godovi i klima

The climatic influence on tree growth was studied using the residual version of the ARSTAN chronology (expressed as tree-ring indexes vs. time), for which the original tree-ring width series were standardized in a two-step procedure. First, the long-term trend was removed by fitting a negative exponential function (regression line) to each tree-ring series. Second, a more flexible detrending was made by a cubic smoothing spline with a 50 % frequency response of 30 years to further reduce non-climatic variance. Subsequently, autoregressive modelling of the residuals and biweight robust estimation of the mean were applied (Cook and Peters, 1997).

The climatic data (average monthly temperatures and monthly sums of precipitation for the period 1922 to 2009) were obtained from the meteorological station Grič, Zagreb (Figure 1). The station is representative for the sampling area.

The climate/growth relationships were calculated using the program DendroClim2002 (Biondi and Waikul 2004), whereby the residual version of the tree-ring chronology was the dependent variable and the regressors were the monthly mean temperatures and monthly sums of precipitation for each biological year from the previous October to the current September over the time axis from 1922 to 2009. DendroClim2002 uses correlation functions and response functions, which are the most common statistical models used in dendrochronology. The term 'function' indicates a sequence of coefficients computed between the tree-ring chronology and monthly climatic variables, which are ordered in time from the previous-year growing season to the current one. In 'correlation' functions, the coefficients are univariate estimates of Pearson's product

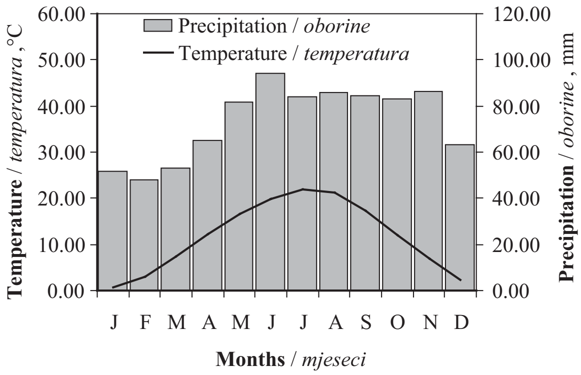

Figure 1 Bagnouls Gaussen Climatic Diagram, mean monthly average temperature (line) and mean monthly sum of precipitation (bars), of meteorological station Grič, Zagreb for the period 1922-2009; the mean annual precipitation is 879 mm and the mean annual temperature is 11.76 ºC
Slika 1. Dijagram klime, prosječne mjesečne temperature (linija) i prosječnog zbroja mjesečnih oborina (stupići) u meteorološkoj postaji Grič, Zagreb, za razdoblje 1922. – 2009.; prosjek godišnjih oborina iznosi 879 mm, a prosjek godišnje temperature 11,76 ºC

moment correlation, while in 'response' functions, the coefficients are multivariate estimates from a principal component regression model (Biondi and Waikul, 2004). The program applies a bootstrap process according to Guiot (1991) to assess the statistical significance of the correlation and response function.

The stability in time of the climate/growth relationships was checked by moving the correlation and response function, calculated for a 60-year time window, over the chronological life span from 1883 to 2009 (Biondi 1997).

2.4 Teleconnection and heteroconnection
2.4. Telekonekcija i heterokonekcija

The residual oak chronology of Kobiljak was tested for teleconnection. It was compared with oak chronologies from Austria, Hungary, Slovenia and Serbia (Čufar *et al*., 2014). For this purpose, we prepared residual chronologies of 40 sites (27 from Austria, 9 from Hungary, 3 from Slovenia and 1 from Serbia) according to the same procedure described above.

In addition, we also tested the residual oak chronology of Kobiljak with 15 available tree-ring chronologies of beech (*Fagus sylvatica* L.) (Čufar *et al.* 2008d) prepared according to the same procedure.

Comparison of the chronology of Kobiljak and others was made by calculating the *t*-values and coefficients of agreement (Gleichläufigkeit - Glk) using TSAP-Win.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Chronology
3.1. Kronologija

The obtained oak chronology of Kobiljak (abbreviation HR1) is based on tree-ring data from 17 trees (33 radii). It is 127 years long and covers the period 1883-2009 (Figure 2), however its optimally replicated

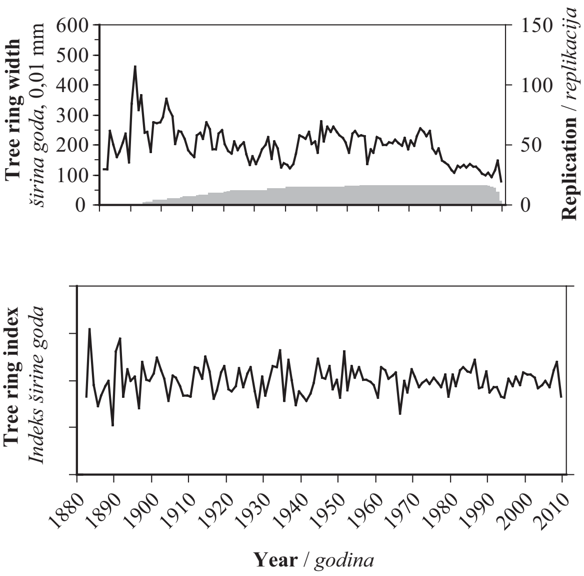

Figure 2 Oak tree-ring chronology of Kobiljak near Zagreb (HR1): raw-data chronology with replication (above) and detrended residual chronology (below); the optimally replicated part of the chronology extends from 1922 to 2008 and is 88 years long. It is based on 17 trees with subsample signal strength (SSS) >0.80

Slika 2. Kronologija godova hrasta iz Kobiljaka pokraj Zagreba (HR1): kronologija nestandardiziranih širina godova s replikacijom (iznad) i rezidualna kronologija (ispod); optimalno replicirani dio kronologije proteže se od 1922. do 2008. i dug je 88 godina, temelji se na 17 stabala sa signalom jakosti poduzorka (SSS)>0,80

Table 1 Descriptive statistics of Kobiljak near Zagreb (HR1) oak chronology, period 1922-2009, based on 17 trees

Tablica 1. Opisna statistika kronologije hrasta iz Kobiljaka pokraj Zagreba (HR1), razdoblje 1922. -2009., utemeljene na 17 stabala

Chronology type *Tip kronologije*	**Raw** *Neobrađeno*	**Residual** *Rezidual*
Mean, mm *Prosjek, mm*	2.0055	0.9975
Median, mm *Median, mm*	2.0270	1.0038
Mean sensitivity *Srednja osjetljivost*	0.1561	0.1655
Standard deviation, mm *Standardna devijacija, mm*	0.6070	0.1540
Autocorrelation order 1 *Autokorelacijski red 1*	0.6959	-0.0508
Autocorrelation order 2 *Autokorelacijski red 2*	0.1672	-0.0602
Autocorrelation order 3 *Autokorelacijski red 3*	0.0686	0.0079
Mean correlation between trees *Prosječna korelacija između stabala*	0.220	0.241
Signal-to-noise ratio *Omjer signal-šum*	3.360	4.118
Variance in first eigenvector, % *Varijanca prvog svojstvenog vektora, %*	32.92 %	30.44 %

part, based on 13 or more trees, extends from 1922 to 2009 and reaches the subsample signal strength (SSS) > 0.80. The statistics of the raw-data and residual chronologies HR1 is given in Table 1.

3.2 Climatic signal in chronology
3.2. Klimatski signal u kronologiji

Below-average temperature and above-average precipitation in June, i.e. a cool and moist June, are the most significant factors favoring oak growth on the site (Fig. 3). The correlation (r) between the residual tree-ring chronology and June precipitation is 0.333, while the correlation with June temperature series is -0.325.

In addition, both precipitation and especially temperature showed a consistent stability over a period of about 60 years (Fig. 4).

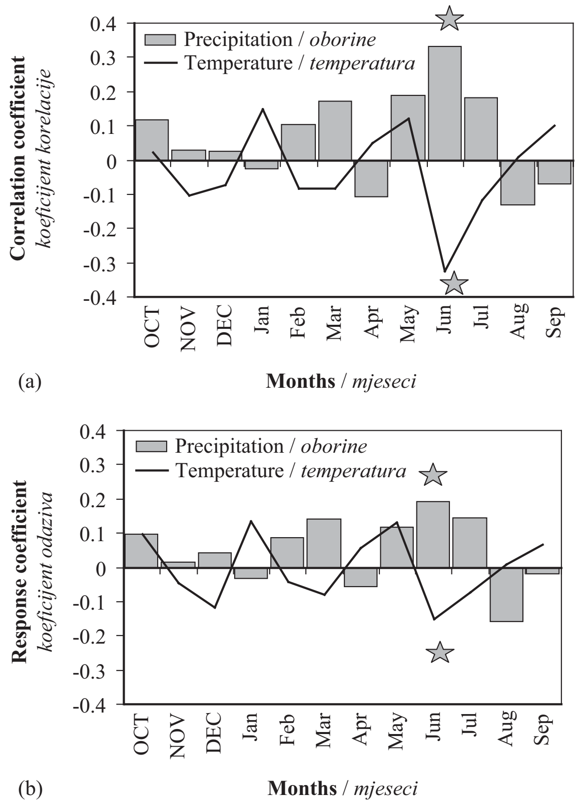

Figure 3 Correlation (a) and response coefficients (b) calculated between the residual version of oak chronology of Kobiljak near Zagreb (HR1) and monthly temperature (line) and precipitation (bars) from previous October to current September for the period 1922-2009; stars indicate significance at 95 % level

Slika 3. Koeficijenti korelacije (a) i odaziva (b) izračunani iz rezidualne kronologije hrasta iz Kobiljaka pokraj Zagreba (HR1) te mjesečnih temperatura (crta) i oborina (stupići) između prethodnog listopada i tekućeg rujna za razdoblje 1922. – 2009.; zvjezdice upućuju na značajnost pri razini vjerojatnosti od 95 %

3.3 Teleconnection
3.3. Telekonekcija

The results of teleconnection of the HR1 chronology with the chronologies from Austria, Hungary, Slovenia and Serbia is given in Table 2. Although the comparison of HR1 was made with 40 residual chronologies prepared according to the same standardiza-

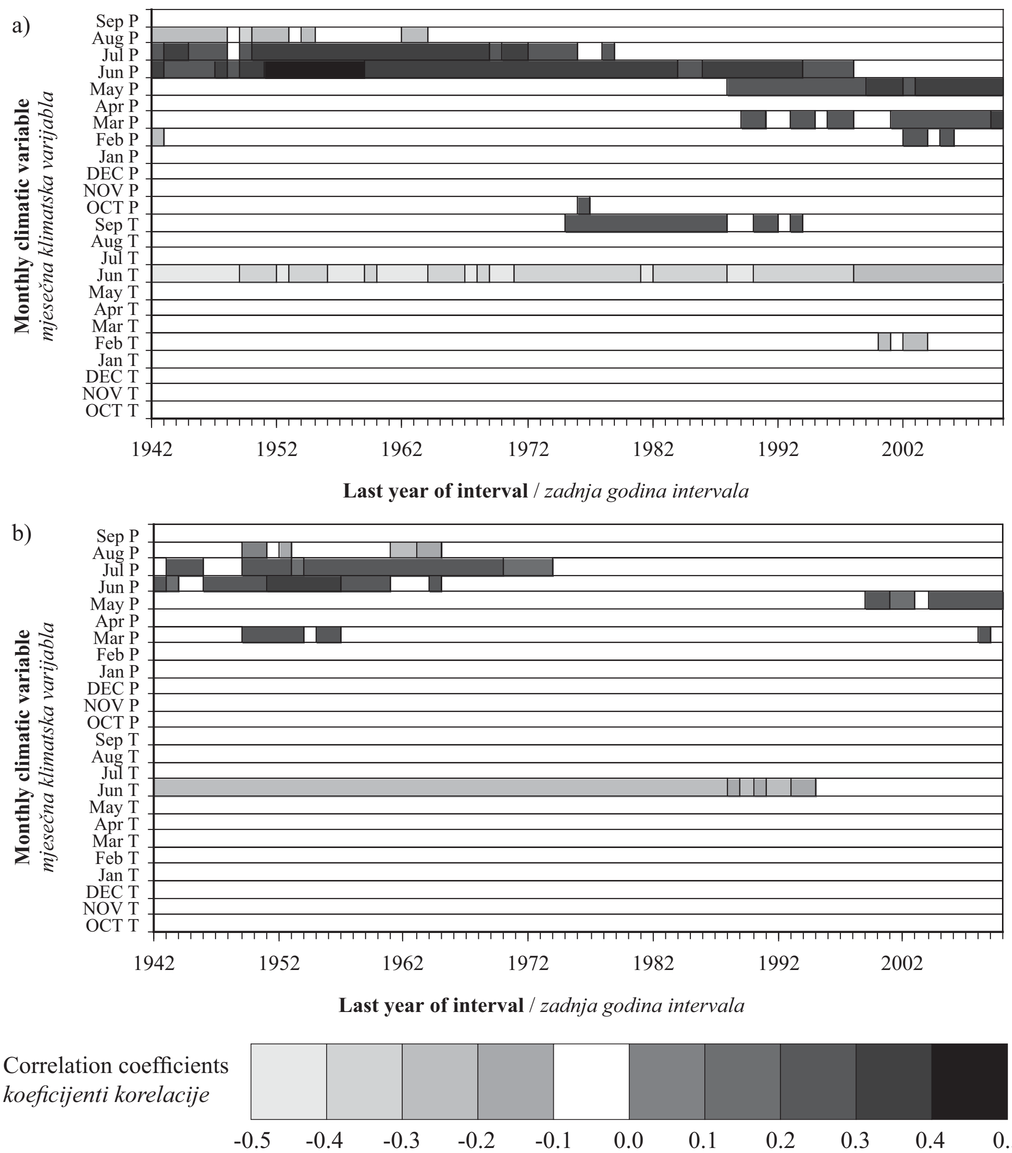

Figure 4 Moving correlation values (a) and response values (b), computed with DendroCLIM2002 (interval of 60 years); the first interval is from 1922 to 1981 and the last from 1950 to 2009; months written in capitals mean months of the previous year (*i.e.* DEC). Only significant values are shown.
Slika 4. Pomične korelacijske vrijednosti (a) i vrijednosti odaziva (b) (duljina intervala 60 godina); prvi se interval proteže od 1922. do 1981., a zadnji od 1950. do 2009.; mjeseci pisani velikim slovima znače mjesece prethodne godine (*npr.* DEC) . Prikazane su samo značajne vrijednosti.

Table 2 Crossdating parameters for comparison of the residual chronology of oak from Kobiljak near Zagreb, Croatia (HR1) with local residual oak chronologies from Austria (A*), Hungary (U*), Slovenia (SI*); for the locations, compare Fig. 5 (parameters: overlapping – Ovl, coefficient of agreement – Glk% and t-value – t_{BP})
Tablica 2. Parametri za usporedbu rezidualne kronologije hrasta iz Kobiljaka pokraj Zagreba, Hrvatska (HR1) s lokalnim rezidualnim kronologijama hrasta iz Austrije (A*), Mađarske (U*), Slovenije (SI*); lokacije usporediti sa slikom 5. (Ovl – preklapanje, Glk – koeficijent slaganja, t_{BP} – *t* vrijednost)

Comparison with oak chronology HR1, period 1922-2008, Longitude16º09’ E, Latitude 45º49’ N, Altitude 140 m a.s.l. *Usporedba sa kronologijom hrasta HR1, razdoblje 1922. - 2008., zemljopisna dužina 16º09 E, zemljopisna širina 45º49’ N, visina 140 m n.m.*								
Code *Oznaka*	Ovl	t_{BP}	Glk (%)	Location *Mjesto*	Country *Zemlja*	Longitude *Dužina*	Latitude *Širina*	Altitude (m a.s.l.) *Visina (m n.m)*
U02	80	6.6	70.9	Zamárdi	Hungary	17.90°	46.83°	204
SI1	82	6.0	77.8	Novo mesto	Slovenia	15.18°	45.80°	220
SI2	82	5.1	75.9	Celje-Kozjansko	Slovenia	15.25°	46.25°	240
SI3	75	4.8	73.0	Ljubljana	Slovenia	14.48°	46.07°	299
U06	80	4.8	64.6	Bürüs	Hungary	17.77°	45.97°	120
A04	86	4.3	64.7	Fehring	Austria	16.02°	46.93°	270
A14	87	4.2	69.8	Baumgarten an der March	Austria	16.53°	48.31°	145

Figure 5 Teleconnection of Kobiljak near Zagreb oak chronology (HR1) with local oak chronologies from Austria, Hungary, Slovenia and Serbia; the chronologies showing $t_{BP} \geq 4$ are indicated with progressively large points and labels, small points without label represent chronologies with $t_{BP} < 4$; for details of teleconnection see Table 2
Slika 5. Telekonekcija kronologije hrasta iz Kobiljaka blizu Zagreba (HR1) s lokalnim kronologijama hrasta iz Austrije, Mađarske, Slovenije i Srbije. Kronologije koje pokazuju $t_{BP} \geq 4$ naznačene su oznakom i postupno većim točkama, a male točke bez oznake predočuju kronologije s $t_{BP} < 4$; statistički parametri telekonekcije navedeni su u tablici 2.

tion procedure, we list only the statistically significant agreements with $t_{BP} \geq 4$.

Out of 40 chronologies used for comparison, 7 showed significant similarity ($t_{BP} \geq 4$) with HR1 chronology in its well replicated part (1922-2009). The chronologies showing similarity are located NE, N and NW from Kobiljak. The most distant chronology A14 is from Baumgarten in Austria ca. 270 km away (as a crow flies), and the nearest one is SI1 from the area of Novo mesto in Slovenia ca. 60 km away. The highest agreement ($t_{BP} = 6.7$) was obtained with the U02 chronology of Zamárdi in Hungary, which is ca. 230 km away from Kobiljak. The values of coefficients of agreement were in all cases above 64 %. It should be noted that the chronology of the surroundings of Sremska Mitrovica, Serbia, had *t*-value 3.8 and Glk 69.1, which is just slightly below the significance value.

The similarities among the chronologies could be ascribed to a common positive response to climate, especially June temperatures (Čufar *et al.,* 2008, 2014). Besides the chronologies used in this study, great importance of June temperatures was also identified in Turkey oak (*Quercus cerris*) on sites in Central Italy (Corona *et al.,* 1995; Romagnoli and Codipietro, 1996) ca. 500 km away from Kobiljak, which could indicate that even teleconnection with Italian chronologies might be possible.

3.4 Heteroconnection
3.4. Heterokonekcija

The results of heteroconnection of the HR1 oak chronology with beech chronologies from 14 locations in Slovenia (Čufar *et al.* 2008d) showed agreement with 5 beech chronologies (Table 3, Figure 6). The locations of the chronologies are SE of Celje, near Novo

Table 3 Crossdating parameters for comparison of the residual chronology of oak from Kobiljak near Zagreb, Croatia (HR1) with local residual chronologies of beech (*Fagus sylvatica*) from various sites in Slovenia; for the location, compare Figure 6 (parameters: overlapping – Ovl, coefficient of agreement - Glk% and t-value – t_{BP})
Tablica 3. Parametri za usporedbu rezidualne kronologije hrasta iz Kobiljaka pokraj Zagreba, Hrvatska (HR1) s lokalnim rezidualnim kronologijama bukve (*Fagus sylvatica*) iz različitih staništa u Sloveniji; lokacije usporediti sa slikom 6. (Ovl – preklapanje, Glk – koeficijent slaganja, t_B – *t* vrijednost.

Comparison with oak chronology HR1, period 1922-2008, Longitude16º09' E, Latitude 45º49' N, Altitude 140 m a.s.l. *Usporedba sa kronologijom hrasta HR1, razdoblje 1922-2008, zemljopisna dužina 16º09' E, zemljopisna širina 45º49'N, visina 140 m n.m.*								
Code *Oznaka*	Ovl	t_{BP}	Glk (%)	Location *Mjesto*	Country *Zemlja*	Longitude *Dužina*	Latitude *Širina*	Altitude (m a.s.l.) *Visina (m n.m.)*
17	78	5.8	72.1	Mokronog	Slovenia	15.20º	45.91º	400
5	72	4.9	68.3	Celje A	Slovenia	15.54º	46.08º	300-600
6	72	4.6	67.6	Celje B	Slovenia	15.37º	46.11º	300-600
2	76	4.2	60.0	Gorjanci	Slovenia	15.29º	45.76º	300-600
16	78	4.0	71.4	Pivka	Slovenia	14.16º	45.80º	640

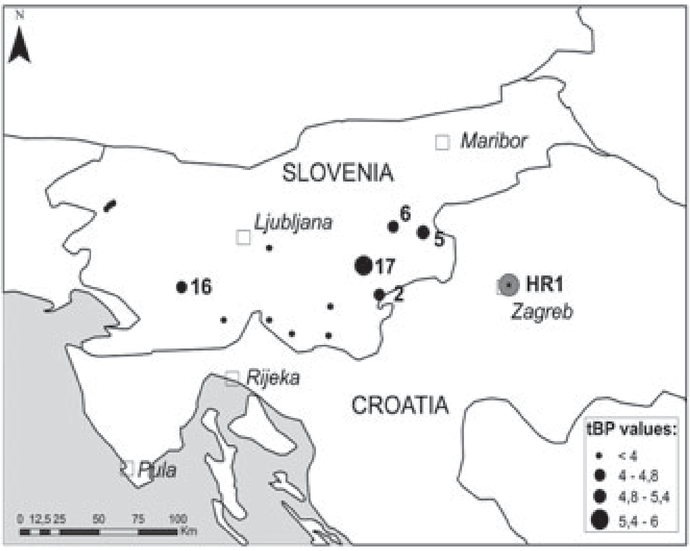

Figure 6 Heteroconnection of oak (*Quercus robur*) chronology of Kobiljak near Zagreb (HR1) with local beech (*Fagus sylvatica*) chronologies from Slovenia; the chronologies showing $t_{BP} \geq 4$ are labelled with numbers, small points without label represent chronologies with $t_{BP} < 4$; for details see Table 3

Slika 6. Heterokonekcija kronologije hrasta (*Quercus robur*) iz Kobiljaka pokraj Zagreba (HR1) s lokalnim kronologijama bukve (*Fagus sylvatica*) iz Slovenije; kronologije koje pokazuju $t_{BP} \geq 4$ naznačene su oznakom i postupno većim točkama, a male točke bez oznake predočuju kronologije s $t_{BP} < 4$; statistički su detalji navedeni u tablici 3.

mesto and near Postojna, at the distance of 60 – 150 km from Kobiljak.

3.5 Potential for improving chronology and different applications
3.5. Potencijal za usavršavanje kronologije i njezine različite primjene

Croatia has rich wooden cultural heritage, which also includes archaeological wood from the distant past. In the past two decades, the Croatian archaeologists contacted wood scientists from the University of Zagreb and Ljubljana to investigate archaeological wood from their excavations. They pointed out that dendrochronological dating of their artifacts was needed.

The archaeologists Tatjana Tkalčec and Tajana Sekelj Ivančan from the Institute of Archeology in Zagreb requested analyses and dating of wood from three different sites. The first investigations gave no encouraging results. Poor preservation of archaeological wood and low number of tree-rings were the main obstacles for dendrochronological dating (Čufar *et al.,* 2006). However, instructions of wood scientists as to how to properly collect and prepare the material soon led to first successfully dated timbers in the old town of Varaždin (Čufar and Šimek, 2008) and in Torčec gradić (Čufar *et al.,* 2008c). The timbers from Varaždin were dated to 1415 (*terminus post quem*) and those from Torčec gradić to 1263 (*terminus post quem*). In both cases, the Slovenian regional oak chronology was used as well as the over 800-year long regional oak chronology of the laboratory of the University of Natural Resources and Applied Life Sciences in Vienna (Wimmer and Grabner, 1998). Since the Austrian and Slovenian regional chronologies crossdate well ($t_{BP} = 9.7$) (Čufar *et al.,* 2008a), successful dating of archaeological wood showed that the chronologies from Austria and Slovenia could act as important reference points to develop dendrochronology in Croatia. Enhanced co-operation, also including other countries like Hungary, could help to develop a longer regional oak chronology in Croatia and to establish a chronology network in the area south and southeast of the Alps.

4 CONCLUSION
4. ZAKLJUČAK

The investigated wood from living trees of pedunculate oak in Kobiljak near Zagreb enabled us to build a 127 years long chronology spanning the period 1883-2009. The sufficiently replicated part is 88 years long and spans the period 1922-2009.

Dendroclimatological analysis showed positive effect of June precipitation and negative effect of June temperatures on tree-ring variation. Both signals are stable over time.

Although relatively short, the chronology exhibits good teleconnection, i.e. similarity with other oak chronologies of Austria, Hungary, and Slovenia. The parameters of agreement with the chronology of the surroundings of Sremska Mitrovica, Serbia were just slightly below the significance value.

Surprisingly, the oak chronology of Kobiljak also exhibits good agreement with some beech chronologies from Slovenia, which indicates that it has good potential for heteroconnection, i.e. similarity with chronologies of other species.

Good teleconnection and heteroconnection could be ascribed to a common factor - the climate.

The presented results indicate that the development of dendrochronology in Croatia would help to fill the spatial and chronological gaps to establish a better network of regional oak chronologies in the wider region.

The presented chronology could be improved and prolonged by including more trees and possibly additional sites and wood from the objects of cultural history. An improved chronology could be used for different purposes including dating objects of cultural heritage. Interest has arisen for this type of use.

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