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DROUGHT IMPACT ON FOREST TREES IN FOUR NATURE PROTECTED AREAS IN SERBIA

UTJECAJ SUŠE NA ŠUMSKO DRVEĆE U ČETIRI ZAŠTIĆENA PRIRODNA PODRUČJA U SRBIJI

HORÁK, Rita,[1] BORIŠEV, Milan,[1] PILIPOVIĆ, Andrej,[2] ORLOVIĆ, Saša,[2] PAJEVIĆ, Slobodanka,[1] NIKOLIĆ, Nataša[1]

Summary

Important predictions of climate change propose a correlated increase in frequency of extreme temperature and precipitation patterns. Period of extremely low precipitation occurred during the vegetation season of 2011 at four mountain forest localities of the Balkan region. Influence of this extreme event was correlated with photosynthetic and transpiration intensity, and content of photosynthetic pigments in forest populations of beech (Fagus sylvatica L.), spruce (Picea abies (L.) Karsten) and fir (Abies alba Mill) on four sites, with specific locality properties. Significant reductions in CO_2 assimilation along with decrease in water use efficiency, were determined by water deficit. It seems that drought occurrence will influence forests in site specific manner, having the most negative impact on forest populations located in the altitude proximity of mountain reefs and peaks. This process leads to decrease in tree mass and reduced forest cover on such sites. Such environmental conditions will lessen possible acclimation of trees to elevated atmospheric CO_2 concentration and upward migration to higher altitudes determined by global temperature increase.

KEY WORDS: climate change, water deficit, beech, common spruce, silver fir

INTRODUCTION
Uvod

Main elements of global climate change are temperature increase, rise of atmospheric CO_2 and redistribution of precipitation patterns which at some sites lead to more frequent drought occurrence during the vegetation season. Change of all this elements at a global level dictate an increase in their variability at a local level on specific sites (Schär et al., 2004).

Elevated atmospheric CO_2 levels can have stimulative effect on plant productivity. However, prerequisite for such model is a sufficient water supply in the root zone (Brouder and Volenec, 2008). Forests are noted as an important terrestrial carbon sinks that partially compensate global increase of atmospheric CO_2. Increased CO_2 assimilation by forests is predicted to be especially significant in the first half of the 21st century (Woodward and Lomas, 2004; Schulze et al. 2010). Global rise in temperature can act as a stimulator of photosynthetic processes and determines a shift of forest species toward higher mountain altitudes (Saxe et al., 2001;

[1] Msc. Horák Rita,Dr. sc. Nataša Nikolić, Dr. sc. Milan Borišev,: University of Novi Sad, Faculty of Sciences, Department of Biology and Ecology, Trg Dositeja Obradovica 3, 21000 Novi Sad, Serbia

[2] Dr. sc. Andrej Pilipovic, Dr. sc. Saša Orlović: Univesity of Novi Sad, Institute of Lowland Forestry and Environment,Antona Cehova 13,21000 Novi Sad, Serbia
Corresponding author: horakrita83@gmail.com

Lenoir et al., 2008; Ruiz-Labourdette et al., 2012). However, it seems that all these ecological roles of forests, that act as a stabilizers of a changing climate, depend on a stabile water regime at specific sites. Extensive drought occurrence during growing season could significantly reduce plant acclimation to higher temperatures or increased CO_2 levels (Saxe et al., 2001; van Mantgem et al., 2009; Peñuelas et al., 2011).

Most predictions of climate change suggest that some site-specific water and temperature stress will occur more often in the future (Boisvenue and Running, 2006). In Balkan region, an unusual, extensive drought period occurred during the second half of the summer in the year 2011 and 2012. The aim of this paper was to determine the impact of this drought occurrence in 2011 to net photosynthetic assimilation, pigment content and transpiration intensity in forest populations located at four protected mountain areas, which are different and specific in their position and available water supply.

MATERIAL AND METHODS
Materijali i metode

Four localities chosen for survey are situated in protected mountain forest areas of Serbia (Figure 1). All localities were chosen in mature forests, with following species: beech (*Fagus sylvatica* L.), spruce (*Picea abies* (L.) Karsten) and fir (*Abies alba* Mill). Site 1 (Vidlič) is Nature reserve at the slope of the Stara mountain in Eastern Serbia (altitude 1 097 m), with beech was observed as the dominant species. Site 2 (Kopaonik) is in the creek valley between two slopes of the Kopaonik National Park (Southern Serbia, altitude 1447 m), where beech and spruce populations were measured and observed. Site 3 (Tara) is on a humid plain section, between several elevated peaks of the Tara National Park (Western Serbia) on altitude of 1 077 m, where the fir and spruce populations were observed as dominant species. Locality 4 is at the reef edge of Fruška Gora National Park (Norhern Serbia, altitude 473 m) where beech trees as part of the mixture with sessile oak were observed. Site description of investigated localities can be found in table 1.

All measurements were conducted at three time points during the growing period of 2011. First measurement was between 29th June and 1st July (Term 1), second between 1st and 3rd August (Term 2) and third between 13th and 15th September (Term 3).

Rates of photosynthesis (P) and transpiration (T) were measured using LC pro+ Portable Photosynthesis System, manufactured by ADC BioScientific Ltd. Measurements were performed instantaneously on six 3–5 meters high per site, on three leaves on each tree with three replications. Water use efficiency (WUE) was calculated as ratio between pho-

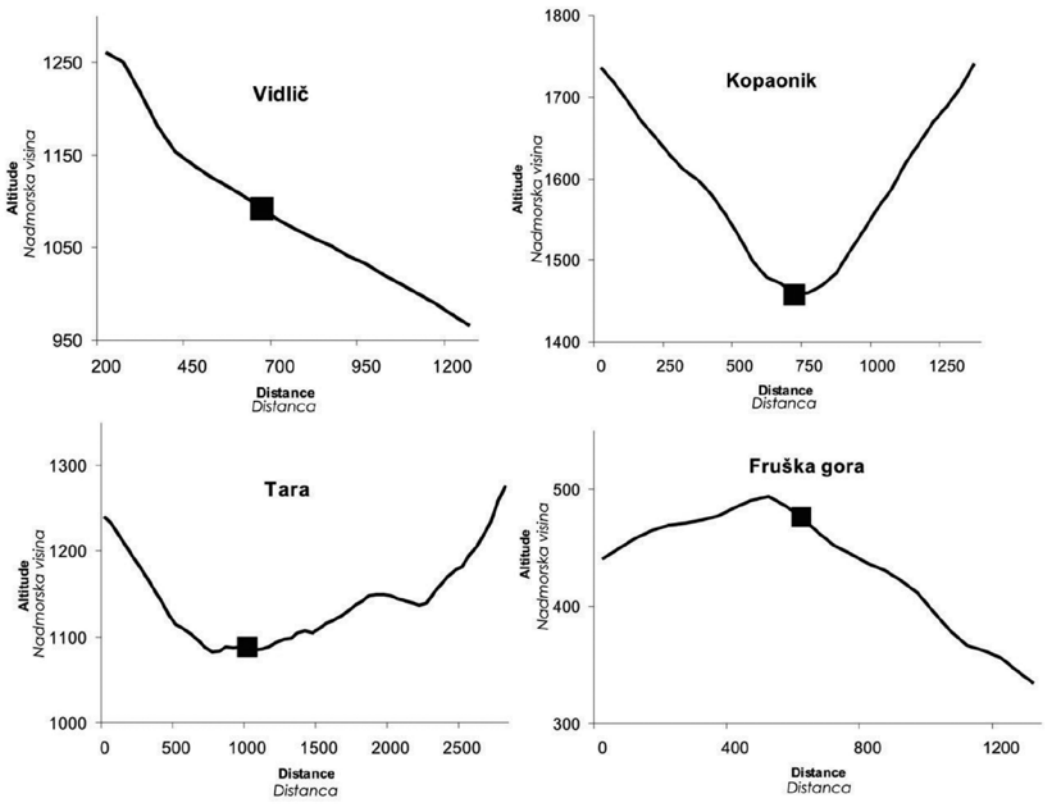

Figure 1. Altitude profiles of four survey localities (■ – locality position at the mountain profile)

Slika 1. Visinski profili 4 pokusne plohe (■ – lokacija položaja ploha na planinskim profilu)

Table 1. Site description of investigated localities
Tablica 1. Opis staništa na odabranim lokalitetima

Locality *Lokalitet*	Assocoation *Sveza*	Alititude (m) *Nadm. Visina (m)*	Exposition *Ekspozicija*	Inclination *Nagib*	Geological substrate *Geološka podloga*	Soil type *Tip tla*	Species *Vrste*
Vidlič	*Fagenion moesiace montanum*	990–1080	N–NE	15–20°	limestone	brown forest soil	beech
Metođe – Kopaonik	*Piceeto– Fagetum drymetosum*	1260–1660	E–NE	31–35°	complex of sandstone, marl and limeston in degradation	distric ranker and acid brown forest soil	spruce nad beech
Mitrovac – Tara	*Piceo – Abieti – Fagetum typicum*	1070–1085	SE	5°	organogenic limestone	pseudogley	spruce and silver fir
Fruška gora	*Quercetum montanum typicum*	475–505	SE	16–20°	marl and limestone	acid brown forest soil and lessivared brown forest soil	beech

tosynthetic and transpiration rates (P/T). Light conditions for photosynthesis were set using the LCpro+ light unit, which emitted photosynthetically active radiation (PAR) at 1 000 µmol m^{-2} s^{-1}. The air supply unit provided a flow of ambient air to the leaf chamber at a constant rate of 100 µmol s^{-1}. Temperature, humidity and CO_2 concentration were at ambient levels.

Concentrations of acetone extracted leaf pigments were assesed by spectrophotometry (Wettstein, 1957). Pigment concentrations were calculated using 9 replicates and expressed as mg · g^{-1} of dry plant weight. All analyses were conducted on leaves at lower branches, 1–1.5 meters above the soil surface.

Precipitation and temperature data were obtained by the Republic Hydrometeorological Service of Serbia on the Meteorological stations closest to the measuring localities. Precipitation was calculated as a total sum during four weeks before each measurement. Temperature was calculated as a daily average, using data collected during four week period before each measurement.

All data were analyzed using Duncan's multiple range test at the level of significance $p<0.05$. Values shown are arithmetic means. Significance level used was $p<0.05$. The average values shown in table columns followed by the same letter did not differ significantly. Linear correlations (r) were calculated between measured parameters using average values obtained at each survey locality.

Table 2. Measurement results made on beech (*Fagus sylvatica*), P – net photosynthetic rate (µmolCO_2 m^{-2} s^{-1}), T – net transpiration rate (mmolH_2O m^{-2} s^{-1}), WUE– the rate of water use efficiency
Tablica 2. Rezultati mjerenja P-neto fotosinteze (µmolCO_2 m^{-2} s^{-1}), T-neto transpiracije (µmolH_2O m^{-2} s^{-1}) i WUE- učinkovitost korištenja vode kod bukve

Species *Vrsta*	Locality *Lokalitet*	Term *Termin*	P	T	WUE
beech	Vidlič	1	5.697 c	0.897 bc	6.366 b
bukva		2	4.768 cd	0.975 b	4.897 c
		3	1.958 e	0.622 d	3.149 e
	Kopaonik	1	7.036 b	0.589 d	12.151 a
		2	5.459 c	0.796 c	6.867 b
		3	8.387 a	2.309 a	3.627 de
	Fruška gora	1	9.204 a	2.351 a	3.928 cde
		2	3.765 d	0.809 c	4.615 cd
		3	3.787 d	0.815 bc	4.643 cd

Values followed by different letters in the same column were significantly different at $p<0.05$
Vrijednosti sa različitim slovima u istom stupcu tablice značajno su se razlikovale pri $p<0.05$

RESULTS
Rezultati

The rate of photosynthesis – *Intenzitet fotosinteze*

At localities Vidlič and Fruška gora, beech had the highest photosynthetic rate at the end of June (Table 2). CO_2 assimilation was significantly reduced further during the vegetation season, in August on Fruška gora, and later in September also on Vidlič. Lowest photosynthetic rates were measured in September, after a drought period, also on spruce at Tara, and Kopaonik where the highest CO_2 assimilation was determined in August. (Table 3). However, this dynamic was not established by results obtained on Kopaonik for beech, and on Tara for fir.

The rate of transpiration – *Intenzitet transpiracije*

Comparing the measurements made on Vidlič and Fruška gora at the end of June with those made at the beginning of September, it could be observed that the rate of the transpiration decreased significantly (Tables 2 and 3). At Kopaonik, it was at its highest in September, while on Tara it depended on analyzed species.

Table 3. Measurement results made on spruce (*Picea abies*) and fir (*Abies alba*), P – net photosynthetic rate ($\mu molCO_2 m^{-2} s^{-1}$), T – net transpiration rate ($mmolH_2O\ m^{-2}\ s^{-1}$), WUE- the rate of water use efficiency
Tablica 3. Rezultati mjerenja P-neto fotosinteze ($\mu molCO_2 m^{-2} s^{-1}$), T-neto transpiracije ($\mu molH_2O\ m^{-2}\ s^{-1}$) i WUE- učinkovitost korištenja vode kod smreke (*Picea abies*) i jele (*Abies alba*)

Species *Vrsta*	Locality *Lokalitet*	Term *Termin*	P	T	WUE
spruce	Kopaonik	1	4.85 c	0.62 b	7.80 b
smreka		2	11.40 a	0.55 b	19.52 a
		3	4.48 c	0.61 b	7.19 b
	Tara	1	10.29 ab	0.63 b	17.80 a
		2	8.33 bc	0.87 a	9.60 b
		3	3.35 c	0.37 c	9.23 b
fir	Tara	1	8.30 a	0.30 b	22.25 a
jela		2	6.40 bc	0.66 a	9.78 c
		3	7.92 ab	0.68 a	11.68 b

Values followed by different letters in the same column were significantly different at $p<0.05$
Vrijednosti sa različitim slovima u istom stupcu tablice značajno su se razlikovale pri $p<0.05$

Water use efficiency – *Učinkovitost korištenja vode*

WUE (P/T) on Fruška gora locality did not change significantly during the season, because reduced photosynthetic intensity was followed by correlated reduction of transpiration. However, on all other localities, statistically lowest value of WUE was determined later during the season, mostly in September (Tables 2 and 3). Increase of WUE was observed for spruce at Kopaonik in August, and for fir at Tara in September.

Photosynthetic pigments – *Fotosintetski pigmenti*

The content of all analyzed photosynthetic pigments did not change significantly between end of June and August (Tables 4 and 5). However, in September, content of Chl*a* was reduced in all species. This reduction was significant for beech at Vidlič and for spruce at Tara. In the case of Chl*b*, Chl*a*+*b* and carotene statistical decrease was determined only on Vidlič in a beech population.

Average daily temperature had a general increase in all localities during the season (Figure 2). Precipitation during

Table 4. Content of photosynthetic pigments Chl a, Chl b, Chl a+b and carotene (mg g^{-1}) in beech (*Fagus sylvatica*)
Tablica 4. Sadržaj fotosintetskih pigmenata Chl a, Chl b, Chl a+b i karotena (mg g^{-1}) kod bukve (*Fagus sylvatica*)

Species *Vrsta*	Locality *Lokalitet*	Term *Termin*	Chl*a*	Chl*b*	Chl*a*+*b*	Carotene *Karoteni*
beech	Vidlič	1	12.475 a	4.624 a	16.432 a	3.311 a
bukva		2	11.149 ab	4.044 ab	15.193 ab	3.199 a
		3	8.145 c	2.983 c	11.128 c	2.267 b
	Kopaonik	1	8.678 bc	2.758 c	11.437 bc	2.594 ab
		2	9.174 bc	3.135 bc	12.309 bc	2.643 ab
		3	8.061 c	2.877 c	10.938 c	2.31 b
	Fruška gora	1	9.639 abc	3.172 bc	12.81 abc	2.657 ab
		2	9.149 bc	2.988 c	12.137 bc	2.526 ab
		3	7.946 c	2.711 c	10.657 c	2.183 b

Values followed by different letters in the same column were significantly different at $p<0.05$
Vrijednosti sa različitim slovima u istom stupcu tablice značajno su se razlikovale pri $p<0.05$

Table 5. Content of photosynthetic pigments Chl *a*, Chl *b*, Chl *a*+*b* and carotene (mg g^{-1}) in spruce (*Picea abies*) and fir (*Abies alba*)
Tablica 5. Sadržaj fotosintetskih pigmenata Chl a, Chl b, Chl a+b i karotena (mg g^{-1}) kod smreke (*Picea abies*) i jele (*Abies alba*)

Species *Vrsta*	Locality *Lokalitet*	Term *Termin*	Chl*a*	Chl*b*	Chl*a*+*b*	Carotene *Karoteni*
spruce	Kopaonik	1	4.048 a	0.809 a	4.857 ab	1.311 a
		2	3.904 a	1.67 a	5.574 a	1.084 ab
		3	3.598 ab	1.571 a	5.169 ab	1.079 ab
	Tara	1	4.063 a	0.883 a	4.946 ab	1.274 ab
		2	3.701 ab	1.278 a	4.979 ab	1.056 ab
		3	2.409 b	0.876 a	3.285 b	0.779 b
fir	Tara	1	3.37 a	0.802 a	4.172 a	1.097 a
		2	2.935 a	1.079 a	4.014 a	0.863 a
		3	2.413 a	1.269 a	3.349 a	0.754 a

Values followed by different letters in the same column were significantly different at $p<0.05$
Vrijednosti sa različitim slovima u istom stupcu tablice značajno su se razlikovale pri $p<0.05$

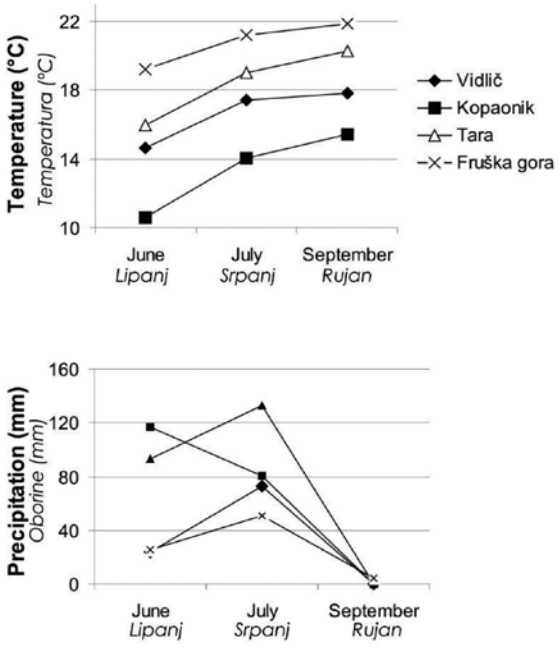

Figure 2. Average daily temperatures and total precipitation during four week period before each measurement at each survey locality (data by Republic Hydro meteorological Service of Serbia)
Slika 2. Srednja dnevna temperatura i ukupna količina oborina mjerena u četiri tjedna prije svakog mjerenja na svim lakalitetima (podaci su dobiveni iz Republičkog Hidrometeorološkog Zavoda Srbije)

four weeks before each measurement had a sudden drop during late August and first half of September. During this severe drought period, at Vidlič and Kopaonik, there was no rainfall 4 weeks prior to measurement date while on Tara and Fruška gora it had minimal values of total 0.2 mm and 4.4 mm, during four weeks.

Joined correlation for all localities and species was positive and significant between the rate of photosynthesis (P) and WUE (Table 6). The WUE was in a significant positive correlation with the four week precipitation, but it was negatively correlated with the transpiration rate. Precipitation was in significant negative correlation with the four week average temperature.

Table 6. Significant correlations between P, T, WUE, temperature and precipitation
Tablica 6. Značajne korelacije između P, T, WUE, temperature i padaine

	P	T	WUE	Temp.	Precipitation
P	1.00	0.27	0.64*	–0.22	0.35
T	0.27	1.00	–0.51*	0.11	–0.29
WUE	0.64*	–0.51*	1.00	–0.27	0.49*
Temp.	–0.22	0.11	–0.27	1.00	–0.49*
Precipitation	0.35	–0.29	0.49*	–0.49*	1.00

*Correlation significant for $p<0.05$
*Razina značajnosti $p<0.05$

DISCUSSION
Rasprava

The correlation between low amount of rainfall, and reduced photosynthetic activity was most obvious on two localities which are positioned on the upper slope or top ridge of the mountain (Vidlič and Fruška gora). Due to their elevated position, water runoff and water leaching from these localities is significant, and soil water saturation highly depends on temperature and atmospheric precipitation. Beech populations showed their maximum net photosynthetic rate during the highest precipitation levels in the vegetation season, at the end of June on Vidlič and Fruška gora. The lowest level of photosynthesis was observed in September, after a period of low rainfall, in spite of more optimal temperatures. At Tara, a humid site, similar results were obtained for spruce, but not for fir, related to sustained soil humidity, achieved by additional water drainage from surrounding hills. At Kopaonik, where beech and spruce population were located on the slope of the mountain, in a small creek valley, where water supply also is not highly dependent on recent rain fall, rate of photosynthesis was not significantly reduced in September, when precipitation was at its lowest point. These photosynthetic reductions influenced by drought occurrence were certainly expected and previously confirmed in many studies (Daly et al., 2003; Guo, 2010; Liu et al., 2010). Correlations of environmental conditions with CO_2 assimilation, seasonal dynamic also can have significant influence, depending on plant species and climatic region. However, the same species (beech) had different photosynthetic alterations during the season at three different localities (Vidlič, Kopaonik and Fruška gora). On Kopaonik, where gradual increase of photosynthesis during the season was measured on beech population and more stabile photosynthetic rates were measured on spruce population, long drought could not affect these plants in such significant extent, since this locality had additional water source from a running creek. However, highest temperature during measurements determined in September, could have important positive influence. Similar results were observed in relation to temperature in the work of Frolking et al. (1995), on spruce population.

Content of photosynthetic pigments decreased at the end of the vegetation season at all localities, (except in the case of Chl *b* on Kopaonik and for the fir on Tara and in the case of Chl *a*+*b* on Kopaonik for spruce) although this decrease had statistical significance on the beech population at Vidlič, and on the population of spruce, in the case of Chl *a* at Tata. Similar results were obtained in the experiments of Arunyanark et al. (2008) on peanuts, where significant effects of seasonal period were determined in relation to the chlorophyll content. Reduced pigment content in September could therefore be related with the onset of the seasonal decline of pigment contents occurring as the end of vegetation approaches. Reduction of photosynthetic pigment contents is also often related with drought (Liu et all 2010, Nikolaeva et all 2010, Guo et al. 2010). Number of researchers have confirmed positive correlations between photosynthetic rates and photosynthetic pigment concentrations in woody species (Berveiller et al. 2007; Reis et al., 2009; Saxe et al., 2001; Waring and Landsberg, 2011). However, in this paper, similar correlations were not statistically significant, due to specific properties of each site. Kopaonik and Tara localities were not strongly dependent with recent rain fall for water supply, thus holding high levels of photosynthetic assimilation during the reduced precipitation period, in spite of the small decline in pigment concentrations.

WUE was in general positively correlated with the precipitation and the rate of photosynthesis, but in negatively correlated with temperature, proving that water usage is significantly disturbed by intense drought occurrence which was followed by increased temperatures. Insufficient water supply causes stomata to be closed early during the day. The intensity and duration of drought, along with temperature levels, determines if the water loss will be lower or higher than the reduced carbon availability and fixation (Daly et al., 2003). It seems that plants more tolerant to drought have the ability to increase WUE in drought to some extent (Edwards et al., 2012). At Fruška gora, WUE remained at the same level during the observed period, in spite of signi-

ficant decrease of CO_2 assimilation, suggesting that beech population was successful in saving water. At Vidlič, low precipitation in September caused significant disturbances in water regime thus significantly reducing WUE and photosynthesis. On humid localities, at Kopaonik (beech) and Tara (fir), WUE decrease was correlated with high transpiration rates. We speculate that additional water availability at these localities, apart from precipitation, along with elevated temperatures, provided sufficient capacity for stabile transpiration flow.

Extremely reduced amount of rain fall during the vegetation season, as a consequence of disturbed climate, certainly has a direct impact reflected in reduced CO_2 assimilation and therefore potentially smaller bioproduction. Our results indicate that influence of such climate change depends on terrain configuration and plant species. It has been reported that the impact of global warming to plants is greater at mountain regions than at low altitudes (Beniston 2006). Strong evidence already exist that forest species (both herbs and woody plants) have already started to migrate upwards in response to climate change (Ruiz-Labourdette et al., 2012; Lenoir et al., 2008). Our results suggest that negative impact of drought at mountains will be more evident in tree populations located on ridges and higher areas of mountain slopes, where water runoff and leaching is faster. Since these localities are mostly positioned at higher relative altitudes, drought periods will slow down shift of forest covers toward sites at higher mountain slopes, which could be the consequence of temperature increase. Suggested acclimation of plants to elevated temperatures (Shen et al., 2009), will be limited by insufficient supply of water. As a consequence, during seasons with extensive drought occurrence, such as period analyzed during 2011 in Serbia, plant water use efficiency will decrease. Since the frequency of extreme temperatures and precipitation regimes is predicted to increase (Schär et al., 2004), consequence could be a decreased amount of wood development, and tendency for reduction of mountain forest covers in such specific sites. These results are in agreement with some previous studies which state that drought appears as a main limitation factor which suppresses the acclimation role of temperate forests as a carbon sink created by elevated temperatures and increased CO_2 atmospheric level (Saxe et al., 2001; van Mantgem et al., 2009; Peñuelas et al., 2011).

CONCLUSIONS
Zaključci

The results have indicated that reduced precipitation during the second part of the vegetation season singinficantly limited CO_2 assimilation of beech (*Fagus sylvatica* L.), common spruce (*Picea abies* (L.) Karsten) and silver fir (*Abies alba* Mill). These reductions of photosynthetic and transpiration activity that resulted in reduced water use efficiency, were particularly evident at ridges and high mountain slopes, where water supply mostly depends on rainfall. Therefore, the acclimation of investigated woody species to altered climatic conditions could be limited by locality specific soil humidity conditions. Water deficiency must be considered as a determinant ecological parameter of forest population productivity and distribution.

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Sažetak

Glavni elementi globalnih klimatskih promjena su povećanje temperature, porast atmosferskih koncentracija CO_2 i redistribucija oborina, zbog čega se tijekom vegetacijskog razdoblja na nekim staništima češće javlja suša. Kao važni rezervoar ugljika, šume mogu djelomice kompenzirati rast atmosferskog CO_2, zbog čega je praćenje asimilacije CO_2 u šumama u 21. stoljeću od izuzetne važnosti. U radu su praćeni fiziološki parametri bukve (*Fagus sylvatica* L.), jele (*Abies alba* Mill) i smreke (*Picea abies* (L.) Karsten) u 4 zaštićena šumska planinska područja sa različitim osobinama staništa (Slika 1 i Tablica 1.). Mjerenja na svim lokalitetima su provedena tri puta u 2011. godini: prvo mjerenje između 29.06. i 01.07 (Termin 1)., drugo između 01.08. i 03.08. (Termin 2), a treće od 13.09. do 15.09. (Termin 3). Na odabranim stablima obavljena su mjerenja intenziteta fotosinteze i transpiracije pomoću LC Pro+ Portable Photosynthesis System-a (proizvođač ADC BioScientific Ltd), dok je učinkovitost korištenja vode (WUE) izračunata iz odnosa fotosinteze i transpiracije. Koncentracija fotosintetskih pigmenata bila je određena u 100% acetonskom ekstraktu pigmenata primjenom spektrofotometra metodom Wettsteina (1957). Podaci o količini oborina i temperaturi za ove lokalitete su dobiveni od Republičkog Hidrometerološog Zavoda Srbije.

Temeljem analize dobivenih podataka utvrđena je korelacija između niske količine oborina i smanjenje fotosintetske aktivnosti, koja je bila najizrazitija na Vidliču i na Fruškoj gori tj. na staništima smještenim na grebenskom dijelu ili uzvišenom dijelu planinske padine (Tablica 2 i slika 2). Zbog male količine oborina najmanji intenzitet fotosinteze izmjeren je u rujnu unatoč optimalnijoj temperaturi. Slična pojava je primijećena kod smreke na Tari ali ne i kod jele (Tablica 3), što se može povezati sa vlažnošću tla i smanjenom otjecanju vode. Na Kopaoniku gdje se ispitivane populacije bukve i smreke nalaze u dolini, pored potoka (Slika 1) nedostatak oborina nije izazvao značajno smanjenje intenziteta fotosinteze (Tablica 2 i 3). Vrijednost WUE je bila u pozitivnoj korelaciji sa količinom oborina i intenzitetom fotosinteze, ali u negativnoj korelaciji sa temperaturom, što ukazuje na poremećaj učinkovitosti korištenja vode zbog suše praćene povećanjem temperature (Tablica 6). Količina fotosintetskih pigmenata u rujnu se smanjila skoro kod svih promatranih populacija, ali je ovo smanjenje bilo statistički signifikantno jedino kod bukve na Vidliču i kod smreke na Tari (Tablice 4, 5). Mogući uzroci ovakvog smanjenja su kraj vegetacijske sezone ili suša. Izuzetno male količine oborina, kao posljedica poremećene klime, svakako djeluje na smanjenje asimilacije CO_2 pa samim tim i na smanjenje bioprodukcije.

Rezultati ukazuju na negativan utjecaj suše na populacije drveća koje su smještene na planinskim padinama sa izraženijim oticanjem i ocjeđivanjem vode.

Pretpostavlja se da će pojava suše imati različite učinke na šumske ekosisteme i da će najgori utjecaj imati na one šumske satojine koje obrastaju vršne dijelove planinskih masiva. Ovaj proces će rezultirati smanjivanjem bioprodukcije šumskog drveća i površine područja pod šumama. Ovakvi osobiti prirodni uvjeti, određeni povećanjem temperature na globalnoj razini, smanjuju moguću aklimatizaciju drveća na visoke koncentracije ugljičnog dioksida i otežavaju šumsko obraštanje visokih planinskih staništa s ograničenim dostupnim zalihama vode.

KLJUČNE RIJEČI: klimatske promjene, nedostatak vode, bukva, smreka, jela