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, Nataša1

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 CO2 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 CO2 concentration and upward migration to higher altitudes determined by global temperature increase.

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

INTRODUCTION

Main elements of global climate change are temperature increase, rise of atmospheric CO2 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 CO2 levels can have stimulative effect on plant productivity. However, prerequisite for such model is a sufficient water supply in the root zone (Brouder and Volenc, 2008). Forests are noted as an important terrestrial carbon sinks that partially compensate global increase of atmospheric CO2. Increased CO2 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 Boršev, 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, University of Novi Sad, Institute of Lowland Forestry and Environment, Antonia 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 stable 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 humil 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 (Northern 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-

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**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)
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 CO₂ concentration were at ambient levels.

Concentrations of acetone extracted leaf pigments were assessed 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.

## RESULTS

### The rate of photosynthesis – Intenzitet fotosinteze

At localities Vidlić and Fruška gora, beech had the highest photosynthetic rate at the end of June (Table 2). CO₂ assimilation was significantly reduced further during the vegetation season, in August on Fruška gora, and later in September also on Vidlić. Lowest photosynthetic rates were measured in September, after a drought period, also on spruce at Tara, and Kopaonik where the highest CO₂ 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 Vidlić 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.
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 Chlb, Chla+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
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 Fruska 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 padavine

<table>
<thead>
<tr>
<th>P</th>
<th>T</th>
<th>WUE</th>
<th>Temp.</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.27</td>
<td>0.64*</td>
<td>−0.22</td>
<td>0.35</td>
</tr>
<tr>
<td>0.27</td>
<td>1.00</td>
<td>−0.51*</td>
<td>0.11</td>
<td>−0.29</td>
</tr>
<tr>
<td>0.64*</td>
<td>−0.51*</td>
<td>1.00</td>
<td>−0.27</td>
<td>0.49*</td>
</tr>
<tr>
<td>−0.22</td>
<td>0.11</td>
<td>−0.27</td>
<td>1.00</td>
<td>−0.49*</td>
</tr>
<tr>
<td>0.35</td>
<td>−0.29</td>
<td>0.49*</td>
<td>−0.49*</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Correlation significant for p<0.05
*Zarina 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 Fruska 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 Fruska 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 CO₂ 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 Fruska gora). On Kopaonik, where gradual increase of photosynthesis during the season was measured on beech population and more stable 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 Frolik 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 al 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 Fruska gora, WUE remained at the same level during the observed period, in spite of signi-
significant decrease of CO₂ 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 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 flow.

Extremely reduced amount of rain fall during the vegetation season, as well elevated temperatures, provided sufficient capacity for stable transpiration flow.

The results have indicated that reduced precipitation during the second part of the vegetation season singificantly limited CO₂ 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.

ACKNOWLEDGMENT
Zahvala

This paper was realized as a part of the project “Biosensing Technologies and Global System for Long-Term Research and Integrated Management of Ecosystems” (43002) financed by the Ministry of Education and Science of the Republic of Serbia within the framework of integrated and interdisciplinary research for the period 2011–2014.

REFERENCES
Literatura


CONCLUSIONS
Zaključci

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Sazetak

Glavni elementi globalnih klimatskih promena su povećanje temperature, porast atmosferskih koncentracija CO₂ 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 CO₂, zbog čega je korisnički impaktni efekt onih šuma u pojedinim lokalitetima činjenica željna. Ispitivanje šuma, uključujući druge biljne populacije, te moguću korisnost šuma u očuvanju ekosustava i njihovim učinkovitim odgovorima na klimatske promene, bilo bi teško istraživanje. Međutim, posmatranje šuma u regionalnim kontextima i određivanje njihovih učestalih i mogućih učestalih promjena bi bilo korisno za uočavanje doprinos šuma u očuvanju bilja.

Radovi koje su ovim sazimom generalizirali i modelirali učestalost promjena šuma u različitim kontinentalnim i regionalnim kontextima su uživani. Također, radovi koje su uočavali i modelirali učestalost promjena šuma u regionalnim kontextima su uživanje. Međutim, u ovoj situaciji, ispitivanje šuma u regionalnim kontextima i određivanje njihovih učestalih i mogućih učestalih promjena bi bilo korisno za uočavanje doprinos šuma u očuvanju bilja.

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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 najgore 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 zaliham vode.

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