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Climate change threatens on endangered relict Serbian spruce

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ABSTRACT

The increase in length and severity of drought events predicted for South-Eastern Europe are expected to engender important changes to remaining native forests. To make informed management decisions promoting their conservation, it is important to better understand their responses to climate and environmental disturbances.

In this study, we analyze growth responses over a network of 15 sites of Serbian spruce (*Picea omorika*), an endemic relict conifer species of the Balkan region — with a natural range restricted to the canyon of the Drina river at the border between Serbia and Bosnia Herzegovina — that has already shown signs of decline and dieback likely induced by increasing temperature and drought.

Tree-ring analyses spanning the common period from 1974 to 2016 have shown a strong growth reduction and highlighted an increasing negative growth response to summer drought over the last 30–40 years. The strength of the response differed among individuals and sites, where younger trees and those growing at lower altitude suffered more from drought.

Management practices oriented at reducing drought impact, such as thinning to reduce competition for water resources and enhance survival of seedlings, together with assisted natural regeneration and migration to more suitable habitats, are recommended for the conservation of this relict species. The measures are even more necessary considering that this species is more vulnerable than others due to its weak capacity to naturally regenerate and compete.

1. Introduction

The Mediterranean Basin represents one of the most important hotspots of biodiversity on Earth (Médail and Quézel, 1999; Fady-Welterlen, 2005). However, a rapid economic development, an increasing human population and climate change induced environmental disturbances are creating unprecedented pressures on the natural resources in the area. The Balkan region, hosting 7500 plant species, of which one third is endemic (Aleksić and Geburek, 2014), including some relict tree populations, does not escape this threat. The general increase in temperature together with increasing frequency and severity of drought events represent a new threat for many tree species on the Balkans. In particular, this region is expected to be one of the most affected regions in Europe, since the frequency, length and severity of droughts are maximized (Ivetić and Devetaković, 2016) in areas already experiencing water scarcity (Laušević et al., 2008). According to the IPCC (Intergovernmental Panel on Climate Change) scenario for Bosnia and Herzegovina, the mean annual temperature will increase by 2.4–4 °C by the end of this century with a decline in precipitation regimes by up to 30 % compared to the period 1961–1990 (UNDP, 2016).

These changes in climate are expected to strongly affect native forest ecosystems and first evidences of such changes already reported in the middle of the 19th century (Lindner et al., 2010). Although numerous tree-ring chronology for the broad South-Eastern Europe region are more and more available (e.g. Ważny et al., 2014), very few cover the Balkan region. These last chronologies are usually from centuries-old tree-line relict conifer with growth usually recording a summer drought signal (e.g. Panayotov et al., 2010; Seim et al., 2012). Low elevation trees are expected to be even more exposed to drought as shown in the few studies on non-endangered hardwood and softwood species (e.g. Poljanšek et al., 2012; Stojanović et al., 2015; 2018). More recently, signs of reduced growth and dieback have been mainly observed in coniferous tree species, such as spruce and pine (Ivetić and Aleksić, 2016). These diebacks are often related to insect outbreaks, such as bark beetles, which are suggested to be triggered by the ongoing climate change (e.g.; Allen et al., 2010). It is suggested that drought periods, such as the recent summer droughts in 2015 and 2018, lead to

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a tree's physiological weakening and an enhanced susceptibility to disease and pests (Ivetić and Aleksić, 2016). Yet, little is known about the long-term response to changing climate and climate extremes of relict and endangered native forest trees species of the Balkan region (Aleksić and Geburek, 2014).

Serbian spruce (*Picea omorika* (Panc.) Purk) is an endemic and endangered relict conifer species. Its natural range is restricted to the course of the Drina river, between Western Serbia and Eastern Bosnia and Herzegovina (Ballian et al., 2016; Ivetić and Aleksić, 2016). Its habitat is restricted to steep and rocky slopes primarily facing north, east and west on limestone and serpentine bedrock with an elevation of 800–1500 m a.s.l. (Wardle, 1956; Ballian et al., 2016). The area is characterized by a continental climate with cold and snowy winters and hot and dry summers. The few authors who have morphologically and ecologically described the species (Ostojić and Dinić, 2009; Nikolić et al., 2015; Ballian et al., 2016; Ivetić and Aleksić, 2016) characterized it as very heliophile and ideally requiring at least a mean annual temperature between 4 and 6 °C and a yearly precipitation around 1000 mm. Due to anthropogenic factors such as forest clearing or wildfires, together with poor competition capacity, physiological stress to global warming and a higher susceptibility to disease, have strongly contributed to fragment the habitat of the species (Mataruga et al., 2011; Aleksić and Geburek, 2014). For these reasons, Serbian spruce has been officially placed on the red list of threatened species (IUCN, 2018). In the past few years, Serbian spruce has also been the focus of several investigations, mostly genetic, oriented at clarifying the available genetic information and for promoting its conservation (Ballian et al., 2006; Nasri et al., 2008; Aleksić et al., 2009; Aleksić and Geburek, 2014). In fact, Serbian spruce can, for example, hybridize with Sitka spruce (*Picea sitchensis* x *omorika*). This hybrid displays better juvenile frost resistance and vigor at poor sites (Ivetić and Aleksić, 2016). Current conservation measures include both assisted natural regeneration by removal of competitors to enhance seedlings survival, and assisted migration.

Conservation measures would benefitted by complementary knowledge of Serbian spruce's susceptibility to future climate conditions. Since these native forests have hardly been considered for active management, there is very little information on the growth ecology of the species. In particular we expect that younger trees at lower elevation sites are more sensitive to drought since they undergo higher temperature and have lower chances to access deep soil water due to a still not fully developed root system. In this study, we use tree-ring width measurements to assess climate-growth relationships of Serbian spruce at 15 sites along its native range along the Drina river canyon with the aim of i) characterizing the long-term growth trend of populations of different age, ii) identifying the main climatic drivers limiting growth within its native range, and iii) quantifying the vulnerability to extreme (drought) events among ages and locations.

2. Materials and methods

2.1. Study area, site locations and sampling

This study has been performed in an area of naturally occurring Serbian spruce (*Picea omorika*), at the border between Serbia and Bosnia and Herzegovina (Fig. 1a). A total of 15 unmanaged stands were selected across the native area at different elevations (from 845 to 1541 m asl; Table 1). According to the CHELSA gridded climatic data from 1979 to 2013 (Karger et al., 2017), the climate of the area is characterized by mean annual temperature of 7–8 °C and precipitation well distributed over the seasons totaling ~ 950 mm (Fig. 1b). Over the last 100 years, an increase of the annual average temperature of about 1 °C has been observed while precipitation only slightly decreased (Fig. 1c).

Sampling was performed from June to August 2018 on 11 to 35 dominant and healthy trees per site. In total, 325 wood cores (one core per tree) were collected at 1.3 m stem height using an increment borer. Cores were labelled and stored in plastic straws and delivered to the Swiss Federal Institute for Forest, Snow and Landscape Research WSL for further processing which included mounting the cores on wooden holders and surface preparation with sand paper to facilitate ring-width measurements.

2.2. Tree-ring width measurements and chronology building

Tree-ring width (TRW) was measured on each collected core with a Lintab digital positioning table connected to the TSAP-Win software (both Rinntech, 2010). Time series were first visually cross-dated and its quality checked with the software Cofecha (Holmes, 1983). Tree-ring chronologies have been successively calculated by removing age and low-frequency signal using a 10-year spline function applied to each time series to extract high-frequency variations. The ring-width indices (RWI) were calculated as the ratio between the observed and fitted value and averaged into a chronology for each site using a biweight robust mean.

To assess the common variation among individual detrended time-series at each site, we calculated, i) the Gleichläufigkeit (Glk; which represents the percentage of common signs of year-to-year growth change between series, Eckstein and Bauch, 1969), ii) the inter-series correlation (calculated as the average between each series and a master chronology), and iii) the mean correlation between trees (rbar, calculated as the mean Pearson correlation coefficient of the tree-ring width time series at a site). Chronology building and quality assessment have been performed using the statistical software R (R Core Team, 2018) with the *dpl*R package (Bunn, 2008). Additionally, the mean ring width and tree age (by considering the ring curvature and pith-offsets) were also determined.

Growth rate comparisons among sites were performed by age-aligning the tree-ring width time series of each site. The age-aligned growth curves were obtained by fitting a 30-year spline to the mean age-aligned chronology at each site.

2.3. Assessing growth responses to climate

To identify the main climatic drivers of tree growth we assessed climate response analyses using the R package *Treeclim* (Biondi and Waikul, 2004; Zang and Biondi, 2015) by applying a 1000 times bootstrapped response function with a 25-year moving window (1-year step) where the RWI chronologies are used as the dependent variable and the monthly climatic data are the independent variables. The analyses only considered the period with sufficient replicates, i.e. the period 1974–2016.

As climatic variables we considered the monthly mean temperature, precipitation sum and the standardize precipitation evapotranspiration index (SPEI) with a time-scale of three months. SPEI is a multiscale drought index combining temperature and precipitation data, based on monthly water balances (Vicente-Serrano et al., 2010). Temperature and precipitation were retrieved from the high-spatially resolved (30 arc sec) data from CHELSA (Karger et al., 2017) and extended prior to 1979 (extended − CHELSA) by applying a transfer function with the lower resolved Climatic Research Unit data (CRU, 0.5 °; Harris et al., 2014) of the corresponding grid cell. Site coordinates were assessed by averaging the longitude and latitude of the trees belonging to the same population. The SPEI was calculated with the R package *SPEI* on the length of three months (SPEI3) using the previously extracted CHELSA temperature and precipitation data. The 3 months SPEI was selected since we were mostly interested in assessing growth responses to extreme climatic event due to heatwaves or seasonal lack of precipitation. For the correlations, we included only the monthly climate variables from June of the previous year to September of the current year as well as the monthly average from March to May and from June to August. The significance of the correlation coefficients was calculated by assessing the 95 % confidence levels based on 1000 random samplings

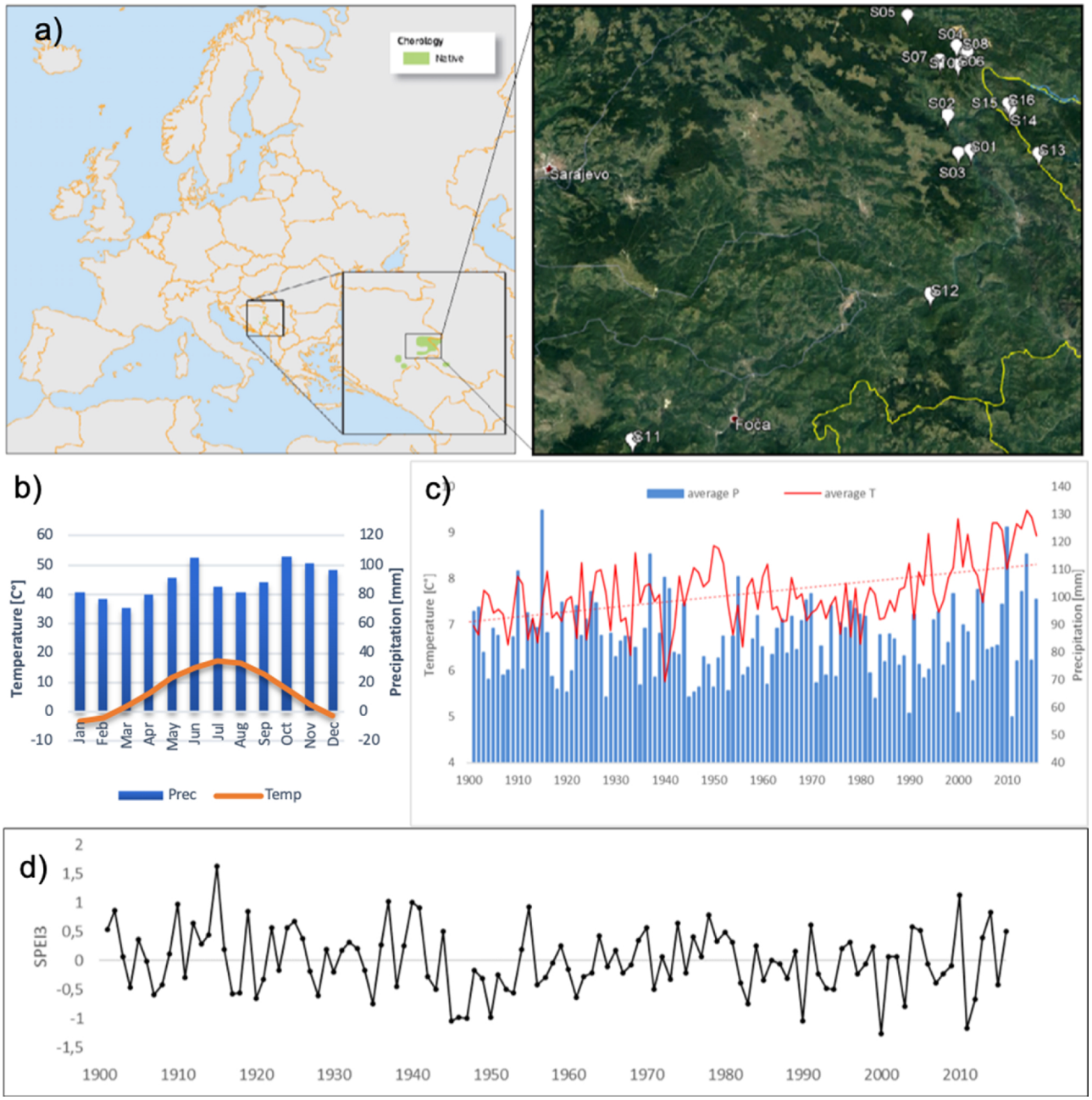

Fig. 1. Sites location and regional climate characteristics. a) Location of the study area (left panel) and sampled sites (right panel); b) Climate diagram, of c) average yearly temperature and precipitation, and d) average yearly SPEI3 (i.e. the yearly average of the monthly Standardized Precipitation Evapotranspiration Index calculated with a time scale of 3 months) of the period 1901-2017. b) and c) have been obtained from averaged CHELSA-extended gridded data (Karger et al., 2017) at all 15 sites, and d) has been calculated from c).

with replacements.

2.4. Analysis of growth responses to extreme years

Growth responses to extreme drought events were assessed by comparing the changes in growth between the year of the extreme event and the following years. The response to extreme events was assessed using the resilience parameters of Lloret et al. (2011), as:

- *Resistance* = *Dr*/*PreDr*
- *Recovery* = *PostDr*/*Dr*
- *Resilience* = *PostDr*/*PreDr*

where *PreDr* is the average ring width five years before the drought year, *Dr* the ring width in the drought year and *PostDr* the average ring width in the five years after the drought year. Extreme events were selected as negative pointer years when at least 50% of trees featured a tree-ring width index decline of at least 40% in comparison to the average previous five years using the R package *pointRes* (Van der Maaten-Theunissen et al., 2015). The analyses were performed by grouping trees into three classes according to elevation (Low = 800–1000 m a.s.l., Mid = 1000–1200 m a.s.l., and High = 1200–1500 m a.s.l.) and age (Young < 80 years, Medium = 81–160 years, and Old > 161 years).

Table 1
Site names, sampling depth, mean elevation, geographical location and age range.

Site name	Site ID	N of trees	Elevation [m]	Latitude [decimal degrees]	Longitude [decimal degrees]	Age range [years]
Vidikovac	S01	15	861	43.93219	19.27914	45-55
Karaula Štula	S02	24	915	43.92976	19.28252	43-58
Suvi Do	S03	27	935	43.85932	19.17326	35-55
Perišin Gaj	S04	29	948	43.85910	19.18797	40-57
Strugovi	S05	17	974	43.97844	19.20715	68-128
Tisovljak	S06	19	1039	44.07286	19.09082	53-243
Borov vrh	S07	14	1047	44.01689	19.20147	36-48
Šarena bukva	S08	11	1061	44.01897	19.19293	22-54
Vijogor	S09	23	1121	43.65015	19.12427	42-141
Radomišlje	S10	29	1122	43.46225	18.61265	49-180
Starogorske stijene	S11	19	1160	43.91499	19.16403	34-55
Gostilj	S12	35	1173	43.85674	19.33362	44-132
Grad	S13	23	1198	44.00212	19.22175	36-50
Veliki stolac	S14	29	1242	43.92315	19.28002	44-190
Panjak	S15	11	1290	43.99898	19.14943	59-130

Table 2
Tree-ring characteristics.

Site name	Site ID	MRW (mm)	Glk	Inter-series correlation	rbar
Vidikovac	S01	2.01	0.77	0.69	0.63
Karaula Štula	S02	2.27	0.73	0.67	0.56
Suvi Do	S03	1.67	0.67	0.54	0.42
Perišin Gaj	S04	1.95	0.70	0.63	0.53
Strugovi	S05	0.92	0.65	0.58	0.42
Tisovljak	S06	1.10	0.64	0.58	0.41
Borov vrh	S07	1.67	0.71	0.56	0.55
Šarena bukva	S08	1.86	0.66	0.47	0.36
Vijogor	S09	1.74	0.62	0.53	0.36
Radomišlje	S10	0.99	0.61	0.54	0.31
Starogorske stijene	S11	1.79	0.67	0.55	0.42
Gostilj	S13	1.45	0.63	0.58	0.37
Grad	S14	2.14	0.68	0.66	0.52
Veliki stolac	S15	1.49	0.64	0.60	0.39
Panjak	S01	1.17	0.72	0.62	0.50

MRW = Mean ring width, Glk = Gleichläufigkeit, inter-series correlation (calculated on ring width index), and rbar = mean correlation between trees (calculated on 10-year spline detrended timeseries, i.e. on the tree-ring width index).

3. Results

3.1. Growth characteristics

The 15 tree-ring width chronologies indicated large differences in age and growth rates exist between sites (Fig. 2a). The stand age ranged from 40 to 55 (S01, S02, S03, S04, S07, S08, S09, S11, S13), to 120–150 years old stands (S05 and S06). Few sites showed heterogeneity in tree age (S15, S10, S12, S14; Table 1). The average annual radial growth ranged from a minimum of 0.92 mm (S05) to a maximum of 2.27 mm (S02; Table 2) and in general it was higher for younger stands (e.g.; S01, S02, S03, S04) than older stands (e.g.; S05, S06, S10, S15). The age-aligned regional growth curves indicated that Serbian spruce generally reached a maximum ring width at around 20 years (Fig. 2b). Although few young (S01, S02, S13) and old stands (S05, S10, S15) showed higher and respectively lower maximum ring width than average, the basal area increment of the young sites is in line with the growth of older trees at similar age (Fig. 2c).

The similarity in growth patterns of trees within each site is consistently high. The Gleichläufigkeit values are > 61%, denoting strong common signs of year-to-year growth change between the series of the

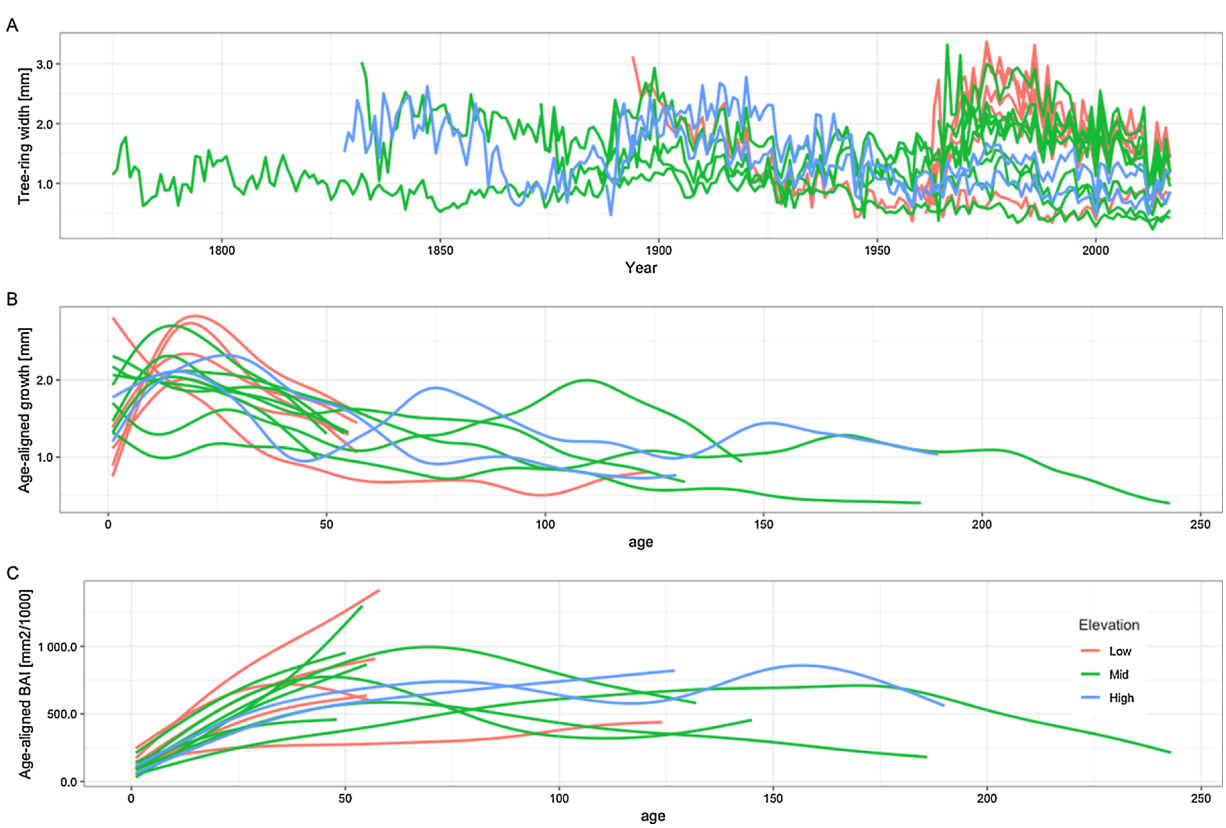

Fig. 2. Row tree-ring width chronologies (A), age-aligned regional growth curves (B), and age-aligned basal area increments (BAI0) (C) of the 15 sampled Serbian spruce sites. Color differentiate among elevation classes.

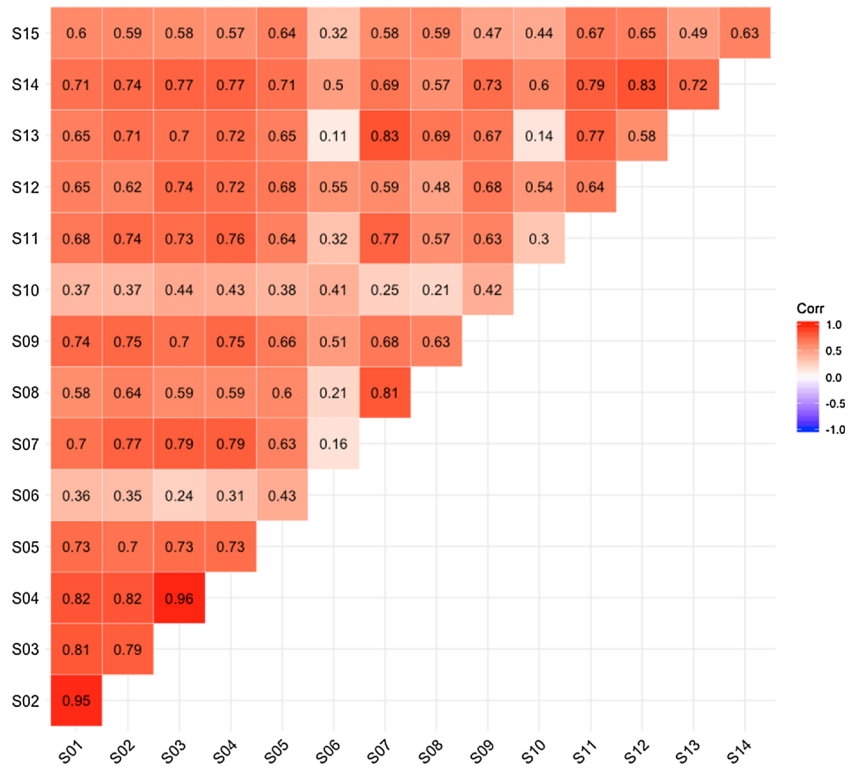

Fig. 3. Correlation matrix among the 30-yrs spline detrended ring-width site chronologies over the period.1974–2016.

same site. Moreover, both the inter-series correlation and the rbar varied little among sites and showed strong values, ranging between 0.47 and 0.69 for the inter-series correlation and between 0.36 and 0.63 for the rbar. Sites which are geographically close and/or belong to the same altitudinal band showed similar growth (see Fig. 3). The lowest correlation ($r = 0.11$) was found between a young low-elevation stand (S05) and an old high-elevation stand (S13).

3.2. Climate-growth responses

The climate-growth analysis over the common period from 1974 to 2016 indicated that Serbian spruce growth is strongly related to summer conditions (Fig. 4a). The growth responses to precipitation and SPEI were similarly strong. All the sites have a significant positive correlation with SPEI3 in August (average drought index June, July and August) and precipitation in summer, with coefficients values also above 0.6 ($p < 0.05$), meaning that smaller rings are formed during drier conditions. The composite chronology showed a positive, but non-significant relation with temperature in the early growing season and a significant negative relationship with mean summer temperature.

All study sites show a positive and significant correlation with SPEI3 in August, which represents the strongest climate signal obtained in the results, considering the sites singularly (Fig. 4b). Regarding the altitude, it is not possible to establish a clear climate-growth correlation gradient along the elevation, since the population in middle of the altitude misshape the decreasing gradient. Still, in general, sites at lower elevations (S01, S02, S03, S04) tend to show a stronger relationship with SPEI3, as well as with temperature, in comparison to those at more elevated sites (S12, S13, S14, S15). Considering the single sites, S06 and S10 show lower – though still significant - positive relationship with SPEI3. Site S06 is the northernmost one, while S10 is the most southwest one.

The climate-growth correlation on a 25-year moving window (Fig. 4c) indicated an increase of the SPEI3 correlation of September (water availability in July, August and September), which is significant from the 80ies until present. This correlation was also highly significant at the beginning of the last century, then it started to decrease around the 30ies and 40ies, to increase again in the 80ies. Also, the increase in correlation coefficient in April and May indicates the trees benefit, in terms of growth, from the higher temperature during the first part of the growing season. This means that trees seem to have a longer growing season but are simultaneously experiencing more drought during summer. The same conclusions can be drawn by looking at the temperature-growth correlation on the 25-year moving window, where an increase in the negative influence of summer months appears over the period 1976–2016, as well as an increase in the negative influence of May. Regarding the precipitation-growth correlation, positive and significant values for spring and summer months indicate that growth is higher when precipitation is high.

3.3. Resilience to extreme events

When considering all the trees, only 2012 was revealed as an extreme negative growth year, in which the majority of trees featured at least a 40 % growth decline. However, if strictly based on the criteria used to define negative pointer years, 2012 clearly emerged as a negative pointer year for the low-elevation sites. Nevertheless, the Lloret resilience components (Lloret et al., 2011) calculated for the year 2012 indicated the presence of significant differences among elevation and age classes (Kruskal-Wallis, $p < 0.05$) (Fig. 5). The resilience of low-elevation sites and young trees to the 2012 dry summer conditions were significantly lower than that of high-elevation trees (Mann-Whitney U test between both groups was $p < 0.01$). Similarly, the growth resistance to the drought 2012 was also generally smaller at low-elevation and for young trees then at high elevation and old trees, however, the difference in the median only resulted significant $p < 0.05$ between the age classes. No differences among groups were observed regarding the recovery.

4. Discussion

Serbian spruce growth — and supposedly also its establishment

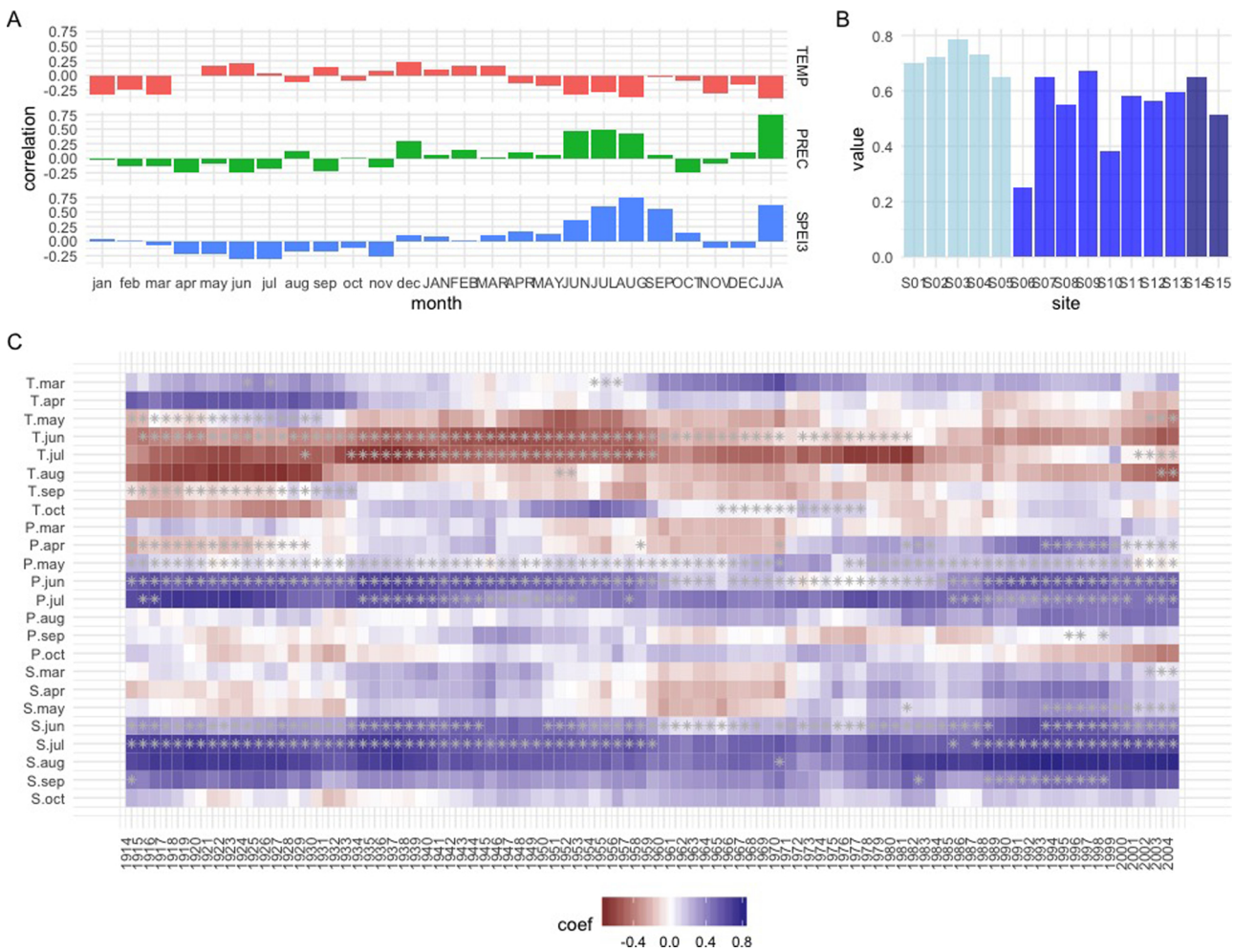

Fig. 4. Climate growth relationships. A) Bootstrapped climate correlation for the period 1974–2016 between the all-sites composite chronology (i.e. the average chronology of the 15 sites) and monthly mean temperature (red) precipitation sum (green), and drought index SPEI3 (blue) as averaged over all sites. JJA indicates the mean correlation of the summer months (June, July and August). Dashed horizontal lines represent the threshold of significance ($p < 0.05$). B) Climate-growth responses for each individual site chronologies over the period 1974–2016 for the strongest climatic signal obtained in A) (i.e.; August SPEI3). Dashed horizontal lines represent the significance level at $p < 0.05$. Site are ordered by and colored by elevation classes (Light blue: 800–1000, blue: 1000–1200 and dark blue: 1200–1500 m). C) Same correlation as A) but using a window of 25-year moving at one-year step from 1906 to 2016. Asterisk indicates significance ($p < 0.05$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

(Ballian et al., 2016) — is closely related to short-term and long-term dynamics in climate, mainly related to water availability during summer. This relationship is clearly expressed by the high correlations with summer precipitation and drought (SPEI3) that were consistently found in all sampled relict populations. Among sites however, we could still observe that Serbian spruce at lower elevation had a stronger negative growth response to summer drought in comparison to those growing at higher elevations (Fig. 4b). Although we found differences in the climate-growth correlation between the studied sites, the environmental variables used in the analysis were not sufficient to explore specific site-related reasons beyond the explained general trends related to altitude. Indeed, low elevation sites may have a generally higher growth rate, because of the warmer conditions during the early growing season, which usually anticipates the onset of growth. But at the same time higher temperature, especially during summer can cause water shortage and hence induce drought stress. Also, differences in soil depth, nutrient levels, stand density, presence of other competing species are all factors which would need to be considered in order to assess sites-specific differences. Nevertheless, this elevation trend is in line with findings for other spruce species growing in South-Eastern Europe, such as Norway spruce (*Picea abies*) in Serbia (Castagneri et al., 2014) and *Pinus peuce* and *Pinus heldreichii* in Bulgaria (Panayotov et al., 2010). Levanič et al. (2009) suggested that the increasing summer temperatures, by enhancing evapotranspiration and hence drought stress, were the main reasons for radial growth deterioration of low elevation Norway spruce in South-Eastern Europe. Our results also show that, although with minor effects, drought stress has also impacted high-elevation sites. This indicates that, despite high-elevation tree growth is often positively related to warmer conditions, although the growth conditions are still constrained by increased evapotranspiration (Jolly et al., 2005; Savva et al., 2006).

The assessment of the variation in climate-growth relationships over time (Fig. 4c) support previous statements regarding the short-term acclimation potential of Serbian spruce. Past periods characterized by summer droughts (e.g. 1945 to 1955, Fig. 1c & d) and the subsequent wetter and cooler period to the onset of recent warming around the 1980s, are well reflected by both strong and weak synchronous correlations with summer conditions. Moreover, the fact that young populations established in the relative wetter and cooler period in the 1960s and '70 s (Fig. 2) also support the drought dependency of Serbian spruce regeneration. After a period characterized by heavy droughts and forest fires between 1945 and 1955 (Fukarek, 1951) the forest has showed its potential for recovery under improved climate conditions in the 60ies (i.e.; characterized by low drought and higher rainfall).

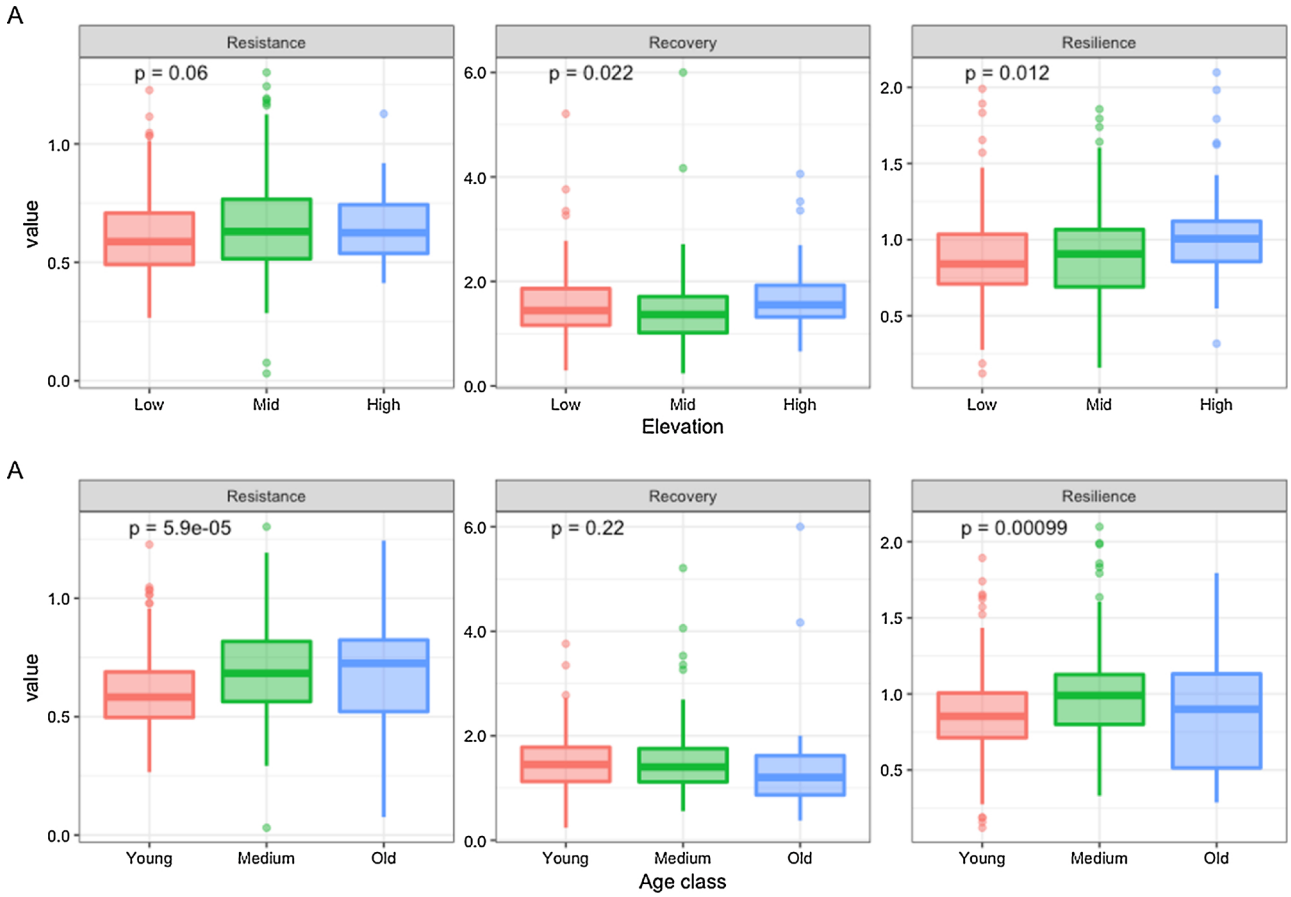

Fig. 5. Box plots representing the three resilience components of Lloret et al. (2011) **resistance, recovery, resilience of the individual trees grouped per elevation (A) and age (B) as a response to the drought year 2012.** Low = 800–1000 m a.s.l. (n = 112), Mid = 1000–1200 m a.s.l. (n = 173), and High = 1200–1500 m a.s.l. (n = 40); Young < 80 years (n = 198), Medium = 81–160 years (n = 105), and Old > 161 years (n = 22). A value of 1 indicates no changes with respect to the reference. P-values indicate differences among groups (Kruskal-Wallis test).

However, under future conditions with increasing drought this might not be any more possible. Some younger trees showed a strong growth decline in the recent period which seems stronger than the growth decline of older trees to the dry conditions in the 40ies and 50ies (Fig. 2b) and lower recovery and resilience to extreme events (Fig. 5b), which might indicate that they indeed suffered from recent climate change.

The recent period with enhanced temperature and drought frequency starting in 1980, comparably to the situation in the 40ies and 50ies, is also characterized by a stronger relationship between growth and summer conditions. The SPEI3, indicative of drought intensity in the months (JJA), reached unprecedented low values in 1990, 2000, 2003 with the lowest in 2012 (Fig. 1d). For 2012, drought caused strong growth depressions, specifically in young spruces and trees at low altitude (Fig. 5). However, the extreme drought event in 2012 does not seem to have greatly influenced the Serbian spruce populations, since almost all the trees completely recovered in the years following the event (resilience). Trees in all age (but especially young trees) and elevation categories had the ability to fast recover.

Interestingly, site S05 (Strugovi) showed an unusual growth trend in the past two and a half decades, which apparently parallels the increasing temperature trend (Fig. 3). This would suggest that this site may have better and faster adaptation to current climate change than other ones. However, a better explanation of this unusual trend can also be related to the forest fire that took place in Strugovi during 1992–1993 (Mataruga et al., 2011), which may have enhanced the growth of the surviving trees. In fact, as literature reports, Serbian spruce is a high shade-intolerant species (Tucić and Stojković, 2001; Tucić et al., 2005; Ivetić and Aleksić, 2016). In particular, Tucić and Stojković (2001) reported a low additive genetic variation for plasticity in shade-avoidance traits, leading this species to dominate open sites, although its growth may be suppressed, at a later time, by other shade-tolerant species.

Overall, these results confirm that the recent changes in climate conditions — along with fires, competition and low migration rate (Ballian et al., 2016) — form a potential threat to the survival of this endangered forest species. In addition to its small population size, the lack of regeneration, combined with the slow migration potential and speed, already constitute a broad set of threats for the conservation of the species in its natural habitat. An increased frequency of longer periods with high summer temperature in South-Eastern Europe occurring during the last few decades (Ivetić and Devetaković, 2016) add a new element reducing the growth resilience of the species. Five out of seven among the greatest heat waves in the period 1961–2010 have occurred between 2000 and 2010 and summer 2012 was recorded by most regional weather station as the hottest summer since climate measurements began (WMO, 2013; Sippel and Otto, 2014). The increased drought stress likely explains the reported increase in susceptibility to insect attack and fungal diseases (Ivetić and Aleksić, 2016) associated with warm and dry years.

This new threat is expected to further increase in the near future. According to local climate model, due to a combination of increasing temperature and decreasing precipitations (Ivetić and Devetaković, 2016), the pressure on the natural distribution of Serbian spruce is expected to increase. In addition, warmer and drier summers will have even greater repercussions, since compared to other conifer species,

Siberian spruce is often restricted to steep, sun exposed sites with shallow soils stimulating the formation of a superficial and branched roots system (Panayotov et al., 2010; Ballian et al., 2016). Changes in climate are occurring faster than the capacity for Serbian spruce to adapt or migrate. Considering other obstacles, such as habitat fragmentation, the lack of deep and nutrient rich soils, and steep topography, this species will encounter difficulties to survive in such condition (Ivetić and Devetaković, 2016; Ivetić and Aleksić, 2016). This scenario represents a substantial challenge for the conservation of this endangered relict species.

Serbian spruce has successfully and widely planted outside of its place of origin, for both ornamentals and forestry purposes. In Estonia it has been categorized as fast growing and cold resistant species for valuable timber production, while in Southern Finland its performance was assessed as "good" and considered a potential species for forestry (Sander and Meikar, 2009) and in Czech Republic its growth rate has equaled those of the domestic Norway spruce (Král, 2002). However, more active measures are required to promote in situ conservation. These includes assisted natural regeneration, removal of competitors to enhance seedlings survival, and preparation of new sites in less drought exposed conditions.

Declaration of Competing Interest

The authors don't have any conflict of interest

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