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Biogeochemical Modelling vs. Tree-Ring Measurements - Comparison of Growth Dynamic Estimates at Two Distinct Oak Forests in Croatia

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ABSTRACT

Background and Purpose: Biogeochemical process-based models use a mathematical representation of physical processes with the aim of simulating and predicting past or future state of ecosystems (e.g. forests). Such models, usually executed as computer programs, rely on environmental variables as drivers, hence they can be used in studies of expected changes in environmental conditions. Process-based models are continuously developed and improved with new scientific findings and newly available datasets. In the case of forests, long-term tree chronologies, either from monitoring or from tree-ring data, offer valuable means for testing modelling results. Information from different tree cores can cover a wide range of ecological and meteorological conditions and as such provide satisfactory temporal and spatial resolution to be used for model testing and improvement.

Materials and Methods: In our research, we used tree-ring data as a ground truth to test the performance of Biome-BGCMuSo (BBGCMuSo) model in two distinct pedunculate oak forest areas, Kupa River Basin (called Pokupsko Basin) and Spačva River Basin, corresponding to a wetter and a drier site, respectively. Comparison of growth estimates from two different data sources was performed by estimating the dynamics of standardized basal area increment (BAI) from tree-ring data and standardized net primary productivity of stem wood (NPP_w) from BBGCMuSo model. The estimated growth dynamics during 2000-2014 were discussed regarding the site-specific conditions and the observed meteorology.

Results: The results showed similar growth dynamic obtained from the model at both investigated locations, although growth estimates from tree-ring data revealed differences between wetter and drier environment. This indicates higher model sensitivity to meteorology (positive temperature anomalies and negative precipitation anomalies during vegetation period) than to site-specific conditions (groundwater, soil type). At both locations, Pokupsko and Spačva, BBGCMuSo showed poor predictive power in capturing the dynamics obtained from tree-ring data.

Conclusions: BBGCMuSo model, similar to other process-based models, is primarily driven by meteorology, although site-specific conditions are an important factor affecting lowland oak forests' growth dynamics. When possible, groundwater information should be included in the modelling of lowland oak forests in order to obtain better predictions. The observed discrepancies between measured and modelled data indicate that fixed carbon allocation, currently implemented in the model, fails in predicting growth dynamics of NPP. Dynamic carbon allocation routine should be implemented in the model to better capture tree stress response and growth dynamics.

Keywords: Pedunculate oak forest, basal area increment, net primary productivity, model testing

INTRODUCTION

In a changing environment, there is a growing need for estimating future forest productivity in order to forecast the impact of climate change on sustainability and adaptability of forests. Process-based modelling is a state-of-the-art technique used in predicting behaviour and future state of ecosystems with respect to environmental conditions [1, 2]. A variety of known ecophysiological and geochemical processes are implemented in these models, but continuous model development based on new knowledge is still needed [3, 4].

Process models, used for vegetation modelling, are complex and often have a high number of driving variables and parameters. This makes calibration (i.e. parameterisation) and validation of such complex vegetation models a challenging task [5]. Model calibration requires an extensive dataset of field measurements, as well as high computational skills and computing power. Most valuable source of field data, used in calibration and validation of vegetation process models, is high-frequency (i.e. half-hour) eddy-covariance (EC) data [6]. A global network of EC flux measurement sites, such as FLUXNET [7], has great potential in facilitating means for better understanding of carbon dynamics in various biomes across regional and global scales [8]. However, for a particular or specific ecosystem, such as lowland forests of pedunculate oak, this dataset has limited use due to a relatively scarce spatial distribution of flux towers. In addition, even if flux measurements for the selected forest type do exist, single site measurements cover a relatively small area (few hundred meters to few kilometres). Taller towers are capable of covering even larger areas, such as the 82 m high tower in Hegyhátsal, Hungary, but in that case, fluxes reflect a multitude of different land covers [9].

Other sources of data that might be useful in assessing the results of modelling with process-based models are long-term chronologies from monitoring or from tree-ring data. Databases of tree ring measurements usually cover a wide range of ecological and meteorological conditions. As such, these data contain information of satisfactory temporal and spatial frequency to be used for testing performance of complex process-based models. New knowledge gained through model comparison with various measurement datasets is a valuable source of information to be used for model improvements and further model developments [7, 10].

The dendrochronological approach provides a unique long-term understanding of the interplay between terrestrial ecosystems and external forcing agents [11, 12]. It is most suitable for trees of the temperate climate zone. Tree-ring width (TRW) data and its derived variables (e.g. tree basal area increment, BAI), reflect tree's radial growth due to cambial activity. Tree's stem growth at a given year often integrates the meteorological effects of the current year and several previous years, and it is further modified by site-specific conditions and management [13]. In this way, in their annual rings, trees preserve an archive of past growing conditions reflecting climate anomalies, competition, disturbance, soil characteristics or species-specific growth patterns [14, 15], as well as human-induced disturbances. Therefore, when using or interpreting tree-ring width data all these influencing factors should be kept in mind.

According to Hafner *et al.* [16], when analysing the response of lowland oak forests to climate conditions, it is important to consider the micro-environment (e.g. drier vs. wetter sites), but also to distinguish tree-ring data into early- and latewood formations. The underlying idea behind this research was to test modelling performance by using tree-ring data as ground truth, rather than to analyse the climatic influence on tree-ring formations. Therefore, we used a whole tree-ring width as a proxy for realised annual growth to test the modelled growth dynamics at different locations. Simple visual interpretation of tree growth response to the observed meteorology was performed only with the purpose of providing additional insight into differences between investigated locations which could further be used in defining potential issues in the model logic.

In our research, TRW data, combined with dendrometric data (i.e. diameter at breast height), were used to assess the inter-annual variability of productivity in lowland oak forests. The aim of this study is to test modelling performance by comparing forest growth dynamics estimates from Biome-BGCMuSo model (BBGCMuSo) against the observed growth estimated from an extensive dataset of tree-rings. The observed differences will serve for defining modelling issues and indicating potential directions for further model improvements. There is evidence of growth decrease of pedunculate oak forests in Southeast Europe as a response to a change of water regime and climate [17]. Reliable model predictions are needed for the selection of appropriate adaptation measures for the preservation of those forests.

MATERIALS AND METHODS

Study Areas

The research was conducted in two distinct areas of managed pedunculate oak forest in Croatia, Kupa River Basin (also called Pokupsko Basin) located in western part of Croatia, approximately 35 km SW of Zagreb, and Spačva Basin located in eastern part of Croatia, approximately 35 km SE of Vinkovci (Figure 1).

The dominant tree species in both forest complexes is pedunculate oak (*Quercus robur* L.) with a significant share of common hornbeam (*Carpinus betulus* L.), and narrow-leaved ash (*Fraxinus angustifolia* Vahl.). Black alder (*Alnus glutinosa* (L.) Geartn.) is also present, but more abundantly in Pokupsko Basin where it holds a significant share in stock (Table 1). Oak forests in Croatia are managed as even-aged, with 140 years long rotations that end with two or three regeneration cuts during last 10 years of the rotation.

Floodplain forests of Pokupsko Basin grow in the tectonic basin "Crna Mlaka" surrounded by hilly slopes of Samobor, Žumberak and Vukomerec hills on east, west and north side, and Kupa River on the south. The Basin lies between 15°32' and 15°50' longitude east, and 45°30' to 45°42' latitude north occupying mostly flat area, with altitude ranging from 107 to 115 m a.s.l. The climate in Pokupsko Basin is warm temperate with a mean annual air temperature of 10.6°C and

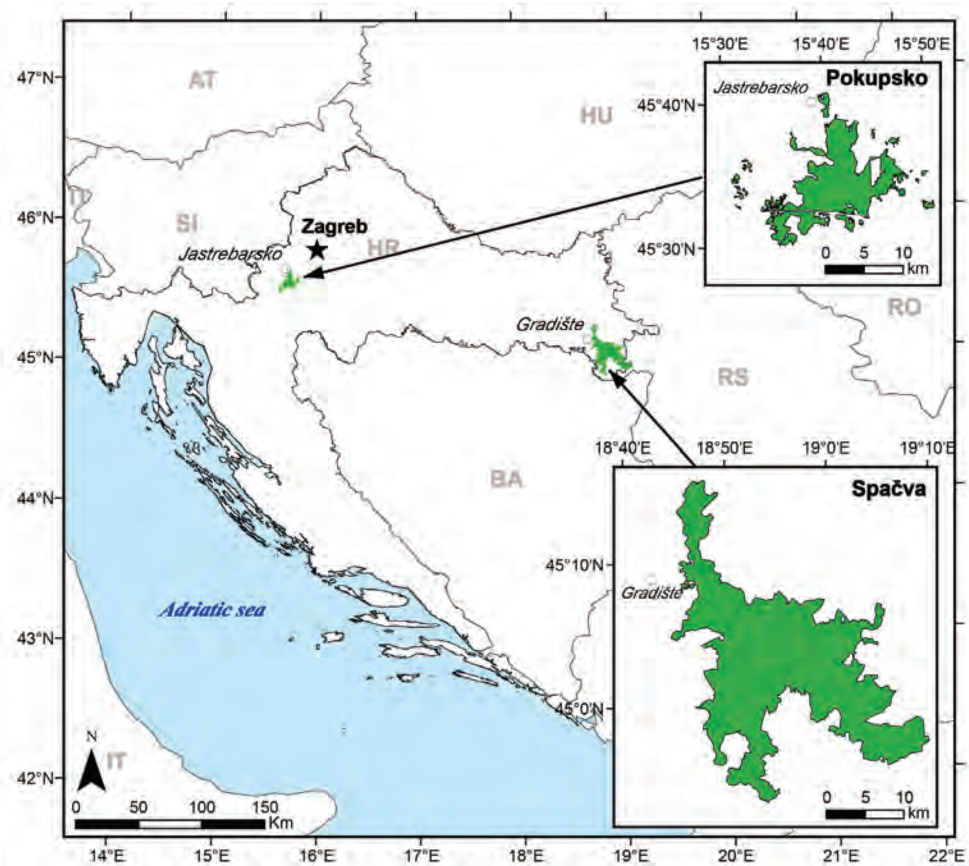

FIGURE 1. Geographical location of the research areas, Pokupsko Basin (west) and Spačva Basin (east), and the meteorological stations located in Jastrebarsko and Gradište.

precipitation of 962 mm·y^{-1} for the period 1981-2010 (data obtained from national Meteorological and Hydrological Service for nearest meteorological station in Jastrebarsko, 45°40'N, 15°39'E, 140 m a.s.l., approx. 2 km NW of the Pokupsko Basin forest). Soils are hydromorphic on clay parent material and according to the World Reference Base for Soil Resources [18], they are classified as luvic stagnosol (Table 1). Average groundwater table depth (based on the data from previous measurements until 1997 and those from 2008 onwards, made by the researchers of Croatian Forest Research Institute), is from 60 to 200 cm [19].

The forest complex of Spačva Basin lays at the most eastern part of Croatia, between Sava and Drava rivers, on the catchment area of Bosut River and its tributaries. Located between 18°45' and 19°10' longitude east and 44°51' to 45°09' latitude north, it occupies flat-curly basin of altitude ranging from 77 to 90 m a.s.l., which is intersected by numerous small rivers. According to Seletković [20], the climate in the eastern part of pedunculate oak distribution area in Croatia is warm temperate with maximum rainfall in June, without exceptionally dry months in summer, and with driest months occurring during cold period of the year. The mean annual air temperature is 11.5°C and precipitation is 686 mm·y^{-1} for the period 1981-2010 (data obtained from National Meteorological and Hydrological Service for nearest meteorological station Gradište, 45°10'N, 18°42'E, 89 m a.s.l., approx. located 4 km W of the Spačva forest). Majority of Spačva Basin forest soils are semi-terrestrial or hydromorphic soils on loamy-clay river sediments [21], and according to World Reference Base for Soil Resources [18], they are classified as chernozem. In the period from 1996 to 2012, an average observed groundwater table depth was ranging from 139 to 617 cm [22]. Differences between two forest complexes are summarized in Table 1.

Biome-BGCMuSo Model

Biome-BGCMuSo (BBGCMuSo) [23, 24] is a newer version of the original biogeochemical model Biome-BGC that simulates carbon, nitrogen, and water cycling in different terrestrial ecosystems [25]. In general, Biome-BGC is a process-based model widely used for estimating ecosystem productivity under current and changed environmental conditions [23, 26-30]. Major improvements in BBGCMuSo include introducing a

TABLE 1. Site description

Site characteristic	Pokupsko Basin	Spačva Basin
Location	western Croatia	eastern Croatia
Microclimatic conditions	wetter site	drier site
Ground water table depth (cm)	60 - 200	139 - 617
Tree species	*Q. robur* (59.4%), *F. angustifolia* (12.6%), *C.betulus* (11.5%), *A. glutinosa* (11.3%), other tree sp. (5.2%)	*Q. robur* (66.9%), *F. angustifolia* (14.7%), *C.betulus* (12.9%), other tree sp. (5.5%)
Soil type (WRB)	Stagnosol, soil depth >10 m, without stones or rocks	Chernozem, soil depth >10 m, without stones or rocks
Soil texture (sand:silt:clay)	21:29:50	24:38:37
Annual (seasonal*) temperature (°C) during the investigated period	12.2 (18.2)	12.8 (18.9)
Annual (seasonal*) precipitation (mm) during the investigated period	1140 (575)	812 (478)

* Seasonal mean time period from April to September

multilayer soil module with the possibility of using groundwater table information, management module, new plant pools, respiration acclimation, CO_2 regulation of stomatal conductance and transient run [23, 24].

There are two obligatory input datasets for running the model, namely meteorology and ecophysiological traits of the specific ecosystem, and several optional datasets, e.g. atmospheric CO_2 concentration, nitrogen deposition, management data, groundwater table etc. Model simulation has three steps: spin-up, transient run and normal run. The purpose of spin-up is to bring the ecosystem to the steady state regarding soil carbon stocks using long-term local meteorological data. Transient run enables a smooth transition from spin-up phase to the normal phase as it slowly brings the ecosystem to steady state under current (changed) environmental conditions using varying data on CO_2 concentration, nitrogen deposition and management. Finally, the normal run is done using current meteorology, CO_2 concentration, nitrogen deposition, and management for the period of interest.

In this research, we simulated the productivity of selected stands in managed oak forests in two selected areas, Pokupsko Basin (4 forest management units with 947 forest compartments covering 11.1 kha in total) and Spačva Basin (13 forest management units with a total of 2918 forest compartments covering 47.8 kha in total). Only forest compartments categorised, according to the dominant tree species, in forest management plans as management class of pedunculate oak, older than 15 years in the year 2000, and for which regeneration harvests have not occurred between 2000 and 2014 were considered for simulation and tree coring (potentially 6.4 kha in 524 compartments in Pokupsko and 33.2 kha in 2083 compartments in Spačva Basin). For the selected 2607 forest compartments in both areas, we run the simulations. However, in the comparison of modelled and measured results only those forest compartments where we actually performed measurements were considered (36 in Pokupsko and 55 in Spačva Basin). More details on the selection of forest compartments are given in the next chapter.

Model simulation was performed on a forest stand level since each forest compartment corresponds to a single forest stand. To account for different management history of stands of different age (i.e. management compartments; for age class distribution see Figure 2), we set the spin-up and transient simulations to the period 1850-1999, while the normal run was done for the period of interest, i.e. 2000-2014. From the records in forest management plans for the year and volume of thinning / regeneration harvests, and the growing stocks at the forest compartment level we calculated the intensities. Specific intensity values were used for the simulation of each forest compartment in the normal run. For the spin-up and transient run we calculated the average intensity of thinning and regeneration harvests and applied those values to all forest compartments. However, the timing (i.e. the year) of the thinning was estimated from the existing records of stand age and year of thinning in the 10-year steps (e.g. thinning in 2009 in the records implies thinning in 1999, 1989, etc., until the final harvest of the previous stand).

Meteorological data used in the simulation was obtained from FORESEE database [31]. FORESEE is a gridded database with a spatial resolution of 1/6° x 1/6° containing daily maximum/minimum temperature and precipitation fields for Central Europe. In addition, the FORESEE retrieval site (http://nimbus.elte.hu/FORESEE/map_query/index.html) offers the possibility for retrieval of core meteorological variables needed for running Biome-BGCMuSo, namely: the daily minimum, maximum and average daytime (from sunrise to sunset) temperature (°C), daily total precipitation (cm), daylight average vapour pressure deficit (Pa), shortwave radiant flux density ($W·m^{-2}$) and day length from sunrise to sunset (seconds). By overlapping FORESEE database over a spatial distribution of the selected management compartments, a specific meteorological dataset was assigned to each forest

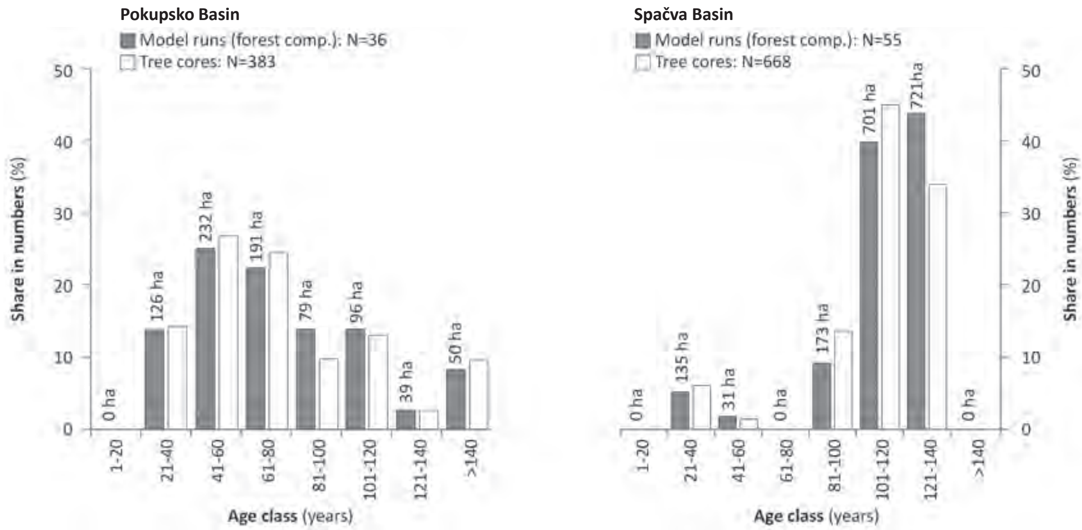

FIGURE 2. Distribution of the number of model runs (simulations) and the number of tree cores according to age classes for forests of Pokupsko and Spačva basins. Note that each simulation is made at the forest compartment level.

compartment. Considering that this dataset covers the period from 1951, also taking into account that the current minimum prescribed rotation length for pedunculate oak is 140 years, we needed to approximate to the meteorology from 1851. For the purpose of our simulations, we assumed that meteorology for 1851-1950 was the same as it was during 1951-1970. Therefore, we used multiple times data from the period 1951-1970 without randomization. For ecophysiological traits, we used a parameter list for oak forests published in Hidy *et al.* [24], slightly adjusted to site-specific conditions (Table 2). The main difference between two investigated sites is a share of black alder. Black alder is a nitrogen-fixing species, and therefore a higher nitrogen fixation rate [32], relative to the share of black alder [33]), is used at Pokupsko site. Values of other adjusted parameters are set to default [24] (Table 2). Spatially explicit data on stand elevation was obtained from Croatian Forests Ltd. database containing all information on forest stands, as prescribed by the national regulation [34], while for stand latitude, we used the latitude of the corresponding FORESEE pixel [31, 35]. Site-specific soil texture was calculated from previously collected soil data, resulting with one texture that was used in simulations at Pokupsko and the other at Spačva Basin [19, 36].

Furthermore, we used three optional input files: atmospheric CO_2, nitrogen deposition, and management file. Atmospheric CO_2 concentration data were obtained from Mauna Loa Observatory (available online at http://www.esrl.noaa.gov/gmd/obop/mlo/) and using relevant publications [37]. Nitrogen deposition data was based on Churkina *et al.* [38]. Management data (stand age, wood volume stocks by tree species, the volume of wood extracted with thinning or stand regeneration and year of the activities, soil type, etc.) was obtained from Croatian

TABLE 2. Parameter values adjusted to site-specific conditions.

Parameter	Parameter value 1) Pokupsko 2) Spačva	Reference
relative soil water content limit 1 (proportion to FC value)	1) 0.9 2) 1.0	1) [28] 2) default
relative soil water content limit 2 (proportion to SAT value)	1) 0.985 2) 1.0	1) [28] 2) default
bulk N denitrification proportion, wet case	1) 0.02 2) 0.002	1) [28] 2) default
bulk N denitrification proportion, dry case	1) 0.01 2) 0.001	1) [28] 2) default
symbiotic+asymbiotic fixation of N	1) 0.0036 2) 0.0008	1) [31, 32] 2) [24]

TABLE 3. The radius of sampling with respect to stand age and tree size.

Age class (years)	**dbh** (cm)				
	2-5	5-10	10-30	30-80	≥ 80
	Sampling radius (m)				
1-20	2	3.5	7	7	56.4
21-40	2	3.5	8	8	56.4
41-60	2	3.5	10	13	56.4
61-80	2	3.5	12	13	56.4
81-100	2	3.5	13	16	56.4
101-120	2	3.5	16	16	56.4
>120	2	3.5	16	16	56.4

Forests Ltd. database. For transient run, management was reconstructed using available information on the stand age in each management compartment. The final cut year was set as the first year of stand development, and from that year onward thinning events were set at every 10 years using average thinning rate of 15%. For the normal run, the actual thinning rates were used for each forest compartment. Thinning rates were estimated from records of standing wood stock, estimated annual wood increment, year of thinning and volume of extracted wood available from the Croatian Forests Ltd. database. In order to use groundwater table information, the user should provide daily data. Unfortunately, daily data on groundwater table was not available for both investigated sites; therefore, this model feature was not used.

Tree-Ring Data

A field survey was conducted from spring 2015 to spring 2016. This research was part of the project EFFEctivity (http://www.sumins.hr/en/projekti/effectivity/) which had, in addition to the work presented here, also the goal of testing MODIS MOD17 annual Net Primary Productivity product [39]. This determined the design for the selection of the plot locations. In short, both forest areas, Pokupsko and Spačva, were overlaid with grid corresponding to MODIS 1 km resolution pixels. Only pixels with more than 90% forest cover and with homogenous age structure (forest compartments consisting of >70% of the pixel area had to have the stand age difference of less than 40 years) were selected and in each pixel four plots were installed. The location of the plot was at the centre of the MODIS pixels with 500 m resolution (each 1 km MODIS pixel can be subdivided into four 500 m pixels). The example of the plot layout is presented in Figure 3. In total, 109 temporary circular plots were placed within two investigated forest areas (41 plots in Pokupsko and 68 in Spačva). Sampling radius varied depending on the stand age and tree size of the sampled tree with larger trees being sampled using larger radius [40] (Table 3). On each plot diameter at breast height (dbh, 1.30 m above the ground) of all sampled trees, as well as tree location on the plot (i.e. distance from the plot centre and azimuth) were recorded.

Tree cores were taken, on average, from 9.6 dominant and co-dominant trees per plot (min. 5, max. 13). In total, 1051 cores were collected, out of which 383 in Pokupsko Basin (247 *Q. robur*, 21 *C. betulus*, 34 *F. angustifolia*, 75 *A. glutinosa*, 6 other) and 668 in Spačva Basin (512 *Q. robur*, 44 *C. betulus*, 112 *F. angustifolia*).

One core per tree was taken at 1.30 m from the ground from the stem side facing the plot centre using increment borer (Haglof, Sweden) of 5.15 mm inner diameter. The collected cores were air-dried in the laboratory for several days and stored in the refrigerator at 4°C until further analysis. Following standard dendrochronological preparation methods, outlined in Stokes and Smiley [41]), the cores were glued to wooden holders and placed into a press for a day. Afterward, they were sanded with progressively finer grades of sandpaper (i.e. 120, 180, 240 and 320 grit). Finally, cores were scanned at high resolution (2400 DPI) and the scanned images were saved into the tree-core database on a local network drive for later TRW measurements.

Tree-ring widths were measured from scanned images to the nearest 0.001 mm using PC and specialized CooRecorder software v.7.8.1 (Cybis Elektronik & Data AB, Sweden). TRW measurements were corrected and underwent quality control through repeated cross-check routines for cross-dating and identification of measurement errors with COFECHA computer program [42, 43].

Data Analysis

The comparison of growth dynamics from 2000 to 2014 in two distinct locations, from two different data sources, was performed using basal area growth estimated from tree-rings and net primary productivity obtained from the BBGCMuSo model. To exclude age-related trend associated with TRW data we used basal area increment (BAI) as proposed in Biondi and Qeadan [44]. BAI was calculated using tree diameter at breast height, measured at the time of tree coring, and TRW data.

Net primary productivity (NPP) obtained from the BBGCMuSo model comprises net productivities of different tree parts. To be able to make a comparison of BAI with the model NPP data, we estimated the net primary productivity

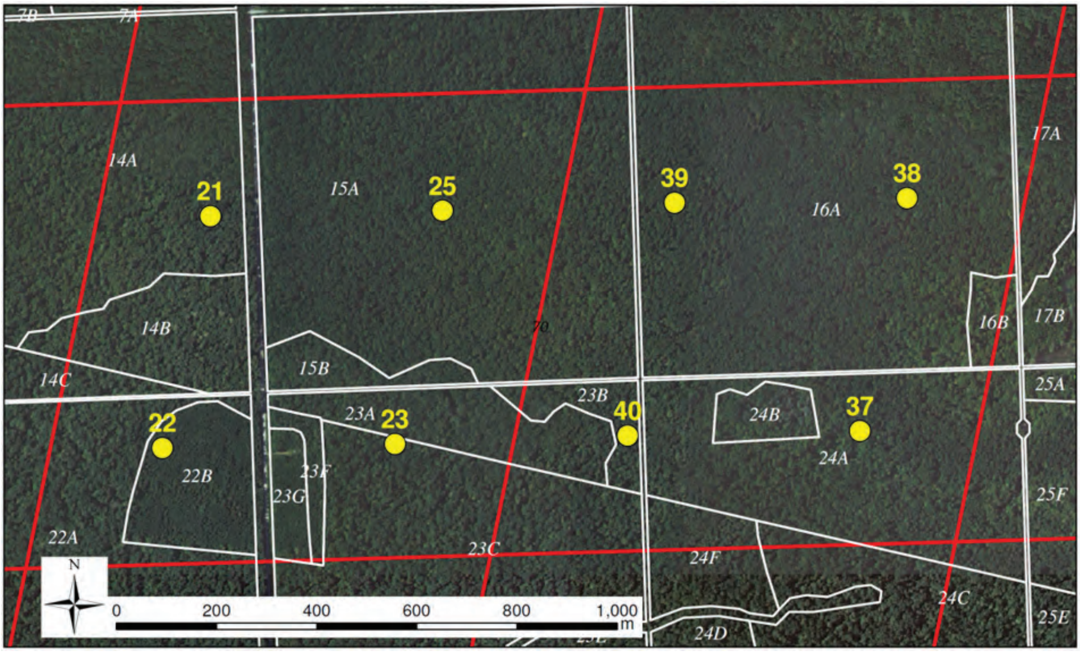

FIGURE 3. Example of the sampling plot layout (yellow circles) within MODIS 1km pixels (red parallelograms). White lines mark borders of forest compartments (labels in italic) that are part of the management unit "Slavir", part of Spačva Basin.

of stem wood (NPP_w) using carbon allocation ratios (Table 4) in the following way:

$$NPP = NPP_w + NPP_l + NPP_f + NPP_{fr} + NPP_{cr}$$
$$NPP = (1.42 + 1 + 0.14 + 0.95 + 0.26 \cdot 1.42) \cdot NPP_l$$
$$NPP = 3.88\ NPP_l$$
$$NPP_w = 1.42\ NPP_l$$
$$NPP_w = 0.366\ NPP$$

where NPP is net primary productivity, and subscripts w, l, f, fr and cr stand for wood, leaf, fruit, fine root and coarse root, respectively.

Modelling results are area-based, i.e. NPP_w is expressed in $kg \cdot C \cdot m^{-2} \cdot y^{-1}$, while tree-ring data are tree-based, i.e. BAI is expressed in $cm^2 \cdot y^{-1}$. To be able to assess the growth dynamics of the results from the modelling against the tree-ring data we calculated the average annual NPP_w and the average annual BAI from all simulation runs (36 in Pokupsko basin and 55 in Spačva basin) and all tree cores for each of the forest areas, respectively. Then we standardized both NPP_w and BAI. Standardization is introduced because a direct comparison of NPP_w and BAI is not possible without introducing additional uncertainty. To make a comparison without the standardization we would need to calculate the net primary productivity of wood based on the tree core data. This would require the use of allometric functions for estimating wood volume, as well as the use of wood density and wood carbon content values. In addition, not all trees in the plots have been cored, and NPP of the uncored trees would have to be evaluated. All this would introduce additional errors. On the other hand, using standardized values, despite being somewhat more difficult to grasp, circumvents those problems and at the same time keeps the information on growth dynamics.

Standardized values (z-values) of BAI or NPP_w, were calculated as:

$$z(x_i) = \frac{(x_i - \bar{x})}{\delta_x},$$

where is the variable of interest (the average tree BAI or the average simulated NPP_w) in the year (i = 2000 to 2014) at the given area; $\bar{x}$ is the overall average of all tree BAI, or

TABLE 4. Carbon allocation parameters and values used in BBGCMuSo model

Allocation parameter	Parameter value	Reference
new fine root C : new leaf C	0.95	[52]
new fruit C : new leaf C	0.14	[52]
new woody stem C : new leaf C	1.42	[52]
new coarse root C : new woody stem C	0.26	[54]

NPP_w of all simulated forest compartments, at a given area during the entire 15-years long period of interest; and δ_x is the standard deviation of during the period of interest (in our case years 2000 to 2014).

Before performing standardization, a Shapiro-Wilk W test for normality was conducted on a series of average annual tree BAI and average annual NPP_w estimates for each forest area using procedure swilk in STATA 14 (StataCorp, College Station, TX, USA). Average annual BAI data series were normally distributed (W=0.9791, p=0.9630 for Pokupsko; W=0.9559, p=0.6224 for Spačva). Similarly, average NPP_w data series were also normally distributed (W=0.9532, p=0.5756 for Pokupsko; W=0.9699, p=0.8563 for Spačva). Therefore, standardization of the data sets is allowed.

Meteorological data were analysed for the same period as for growth dynamics, from 2000 to 2014. For each location mean annual (October-September) and seasonal (April-September) air temperature (°C) and precipitation (mm) anomalies were calculated as follows:

$$T = T_i - T_p$$
$$P = P_i - P_p$$

where T is air temperature anomaly, Ti is mean annual (Oct-Sep) or seasonal (Apr-Sep) air temperature in year i , Tp is mean annual/seasonal air temperature of the investigated period (2000-2014), P is precipitation anomaly, Pi is annual/seasonal precipitation sum, and Pp is the mean of annual/seasonal precipitation sums during the investigated period.

RESULTS AND DISCUSSION

Measured Growth Dynamics and Observed Meteorology

Tree-ring data revealed differences in growth dynamics between two investigated oak forests (Figure 4; green circles). Interestingly, at the wetter [19, 45, 46] oak site (Pokupsko), growth decreased in colder years (e.g. 2005-2006, Figure 5), which is in contrast to the common negative response of oak trees' growth to temperature in spring and summer found in Čufar *et al.* [47], and to the positive response of oaks to rainy, humid and cloudy conditions during the current year's summer [16]. Nevertheless, according to Renninger *et al.* [48], it is highly important to account for groundwater table information when interpreting the response of oak ecosystems to dry conditions. Due to low vertical water conductivity of gleysol soil, forests at Pokupsko site are partly flooded with stagnating water during winter and early spring. During a course of a vegetation season groundwater table is relatively high (Table 1), and therefore we can consider that at this particular site growth is rarely water-limited, but can be rather sunlight-limited during colder cloudy years. For example, in Pokupsko basin in 2011 there was approx. 300 h more sun compared to 2010, or almost 17%. What is even more important, sun hours were in shortage during May and September of 2010 while the case of 2011 it was exactly the opposite (data for meteorological station Karlovac, http://klima.hr/klima_e.php?id=klima_elementi). Contrary to that, at the drier site (Spačva), growth decreased in warm and dry years (e.g. 2007), which is in line with Čufar *et al.* [47]. Forests at Spačva site can be considered to be water-limited during warm and dry years, especially after the prolonged drought from the ecological perspective, when groundwater table drops significantly (i.e. more than 1 m below the long-term average for a given month), although partial resupply of soil water reserves occurs laterally. In addition, forests in Spačva basin grow on fertile soil, with good water holding capacity, and are considered to be highly productive. Forests that grow on soil with high nutrient availability tend to have higher aboveground biomass and are found to be more susceptible to drought due to a predisposition to hydraulic

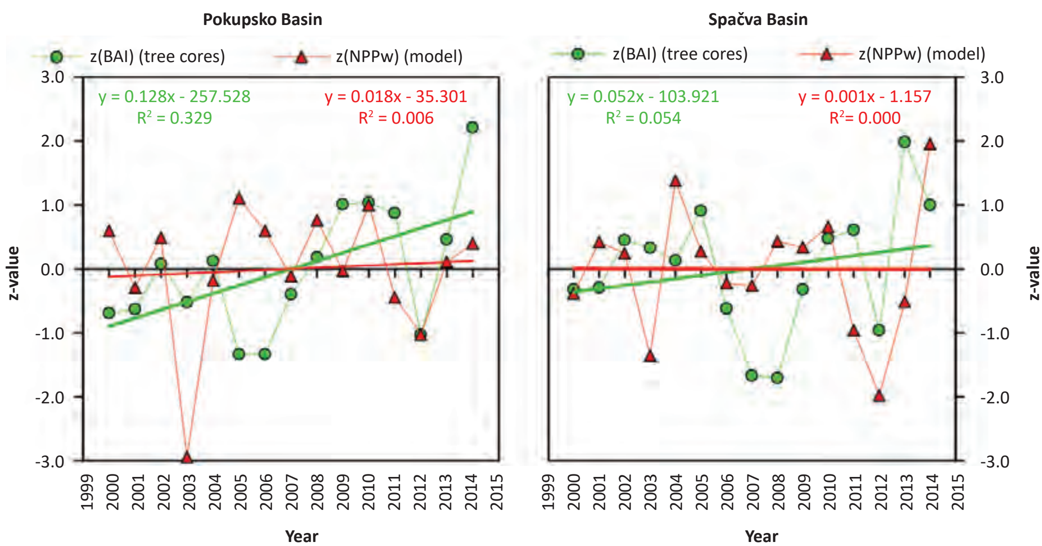

FIGURE 4. Measured and simulated growth dynamics during the period 2000-2014 in two distinct locations of pedunculate oak forests (Pokupsko and Spačva Basin) based on standardized values z(BAI) from tree cores, and z(NPPw) from BBGCMuSo model. The trends and the corresponding equations for measured and modelled z-values are also shown.

failure [49]. At both sites model falsely indicated a drop in growth (z(NPP_w)) for the dry 2011 (Figure 4). But in 2012, the growth decrease indicated by the model was evident also in tree core (z(BAI)). The observed reduction in growth was a consequence of two extremely warm and dry years in a row (i.e. 2011 and 2012) and is likely due to the carry-over effect of the drought [35, 50].

Evaluating the Predicting Power of the Model

Model results show some differences in growth dynamics between two investigated locations (Figure 4; red triangles). A strong reduction in simulated growth in years 2003 and 2012, observed at both sites, indicates high model sensitivity to dry conditions and high air temperature, i.e. negative precipitation anomalies and positive temperature anomalies during vegetation period (Figure 5). Similar modelling results at both locations indicate that the model is more sensitive to meteorology than to site-specific conditions. Although two locations have somewhat different abundances of main tree species, soil characteristics and hydrology, as well as the measured growth dynamics (Figure 4), modelled growth shows similar dynamics (Pearson's correlation coefficient between NPP_w (Pokupsko) and NPP_w (Spačva) is 0.563). Pappas *et al.* [3] obtained similar results when testing process-based LPJ-GUESS model. Authors concluded that model has a very high sensitivity to photosynthetic parameters (i.e. light correlated parameters) and minor sensitivity to hydrological and soil texture parameters.

Quantitative comparison of the growth dynamics from the two different data sources (the measured tree rings and BBGCMuSo model) reveals a poor agreement (i.e. correlation) for both sites (Figure 6). Table 5 shows the results of statistical evaluation for the model-measurement agreement. The extremely dry year 2003 acted as an outlier, according to Tukey's definition [51], for NPP_w at wetter (Pokupsko) sites (Figure 6, left panel). It seems that a single extremely dry year, such as the year 2003, when strongly negative effects on vegetation productivity at European scale were recorded [52], has not significantly affected tree growth at the investigated sites (Figure 4). The ability of oak trees to overcome a single dry event could be explained by the presence of significant soil water reserves (e. g. records from groundwater monitoring in Spačva show that depth to groundwater in Spačva Basin can fluctuate from 0 to ~5 m, while the average water holding capacity of soils is ≳150 mm·m^{-1} [46]) and/or large carbohydrate reservoirs (i.e. carbon storage pools in trees). The analysis of remote sensing data also indicates a different response of forests and other vegetation to drought [35], where the results suggest that drought in a given year might negatively affect growth in the consecutive years in case of forests, but not for other vegetation types. This is in line with the logic that due to stress carbohydrate reserves might be depleted because of decreased photosynthesis (due to stomatal closure) and/or increased respiration demand due to excess heat, which then has a legacy effect on the growth in the next year [53].

Significantly decreased growth in 2003 obtained from the model indicates that model routines, describing a biological response to the single drought event, have difficulties with predicting growth dynamics under such conditions. In stress conditions carbon allocation ratios (i.e. proportions of assimilates allocated to different plant pools/organs, as well as mobilization of reserves) change in order for the plant to successfully overcome stress [54]. The shortcoming of fixed carbon allocation ratios, currently implemented in the BBGCMuSo model, might become increasingly pronounced in the case of extreme events. Additionally, BBGCMuSo is a "source-driven" model, meaning that the current photosynthates are immediately allocated to tissues with fixed allocation ratios. According to new findings (e.g. [54]), this logic might not be completely applicable to forests, which can partly explain why the extreme event in a given year might have pronounced effect on plant growth in the forthcoming year(s). These issues are limiting the model to properly predict plant's response to drought stress. The improvement of modelling results for both sites might be achieved if groundwater table information is used [24].

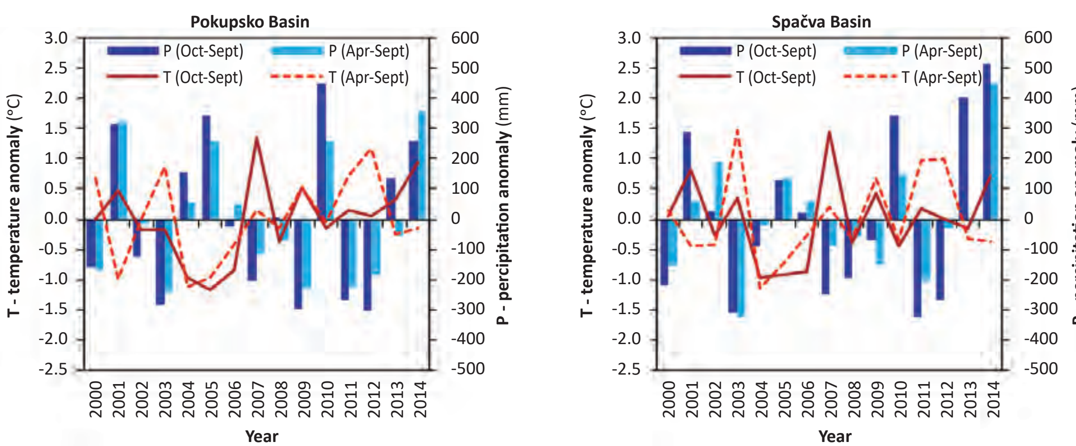

FIGURE 5. Mean annual (October from the previous year – September of the current year) and growing season (April-September from the current year) air temperature (°C) and precipitation (mm) anomalies during the period 2000-2014 in two distinct locations of pedunculate oak forests (Pokupsko and Spačva Basin).

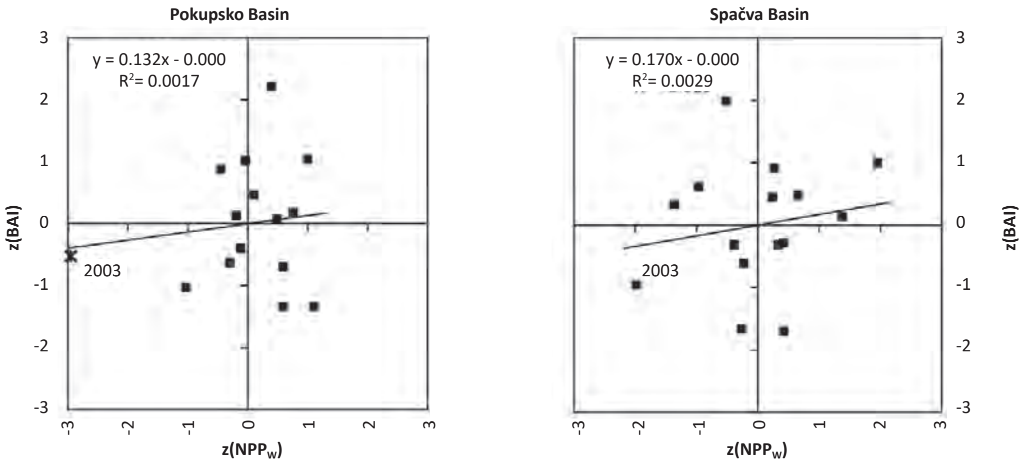

FIGURE 6. Assessing the predictive power of the model for two distinct locations of pedunculate oak forests at Pokupsko and Spačva Basin with standardized values (z-values) of BAI and NPP_w.

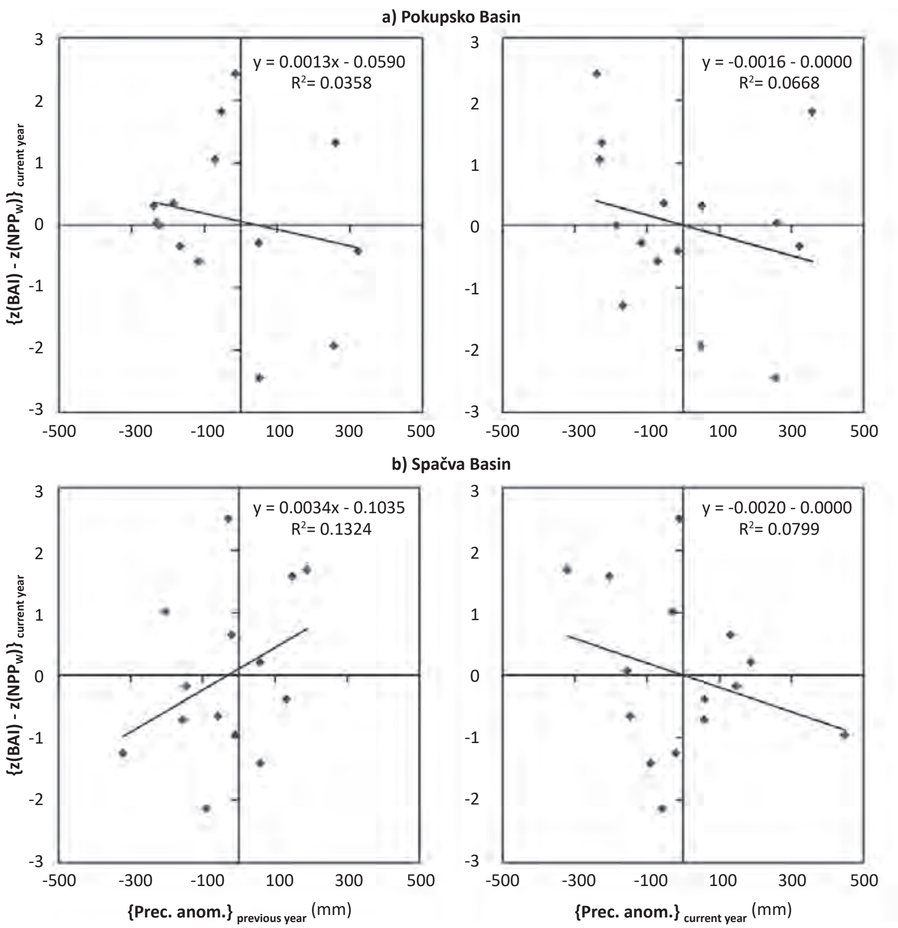

FIGURE 7. The correlation of residuals with seasonal (April-September) precipitation anomaly during the previous and the current year for Pokupsko (a) and Spačva Basin (b).

TABLE 5. Performance statistics (based on z-values) of Biome-BGCMuSo compared with the observed tree ring data.

Statistic	Pokupsko Basin	Spačva Basin
R^2	0.022	0.034
RMSE	1.26	1.23
MAE	0.96	1.02
NSE*	-0.70	-0.63

R^2 - Coefficient of determination; RMSE - Root Mean Square Error; MAE - Mean Absolute Error; NSE – Nash–Sutcliffe model efficiency coefficient)
* Acceptable levels of model performance when 0 < NSE ≤ 1 [56].

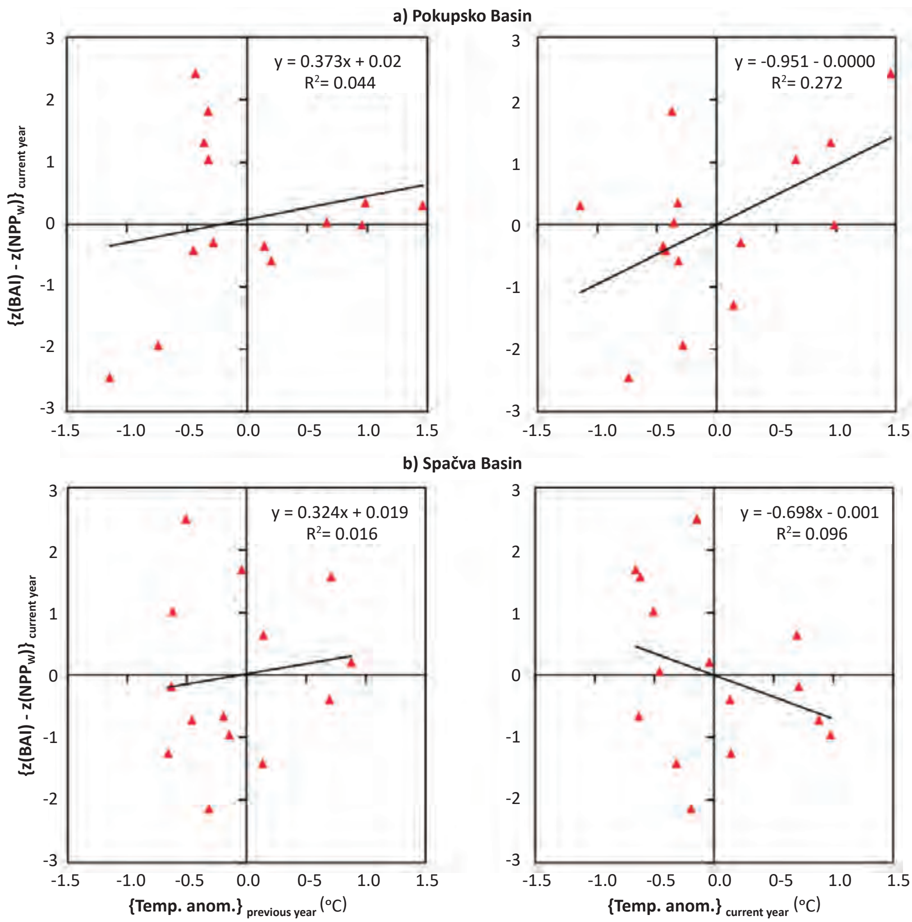

FIGURE 8. The correlation of residuals with seasonal (April-September) temperature anomaly during the previous and the current year for Pokupsko (a) and Spačva Basin (b).

Residual analysis was performed to find possible sources of model-data discrepancy. According to Figures 7 and 8, the relationship between the studied meteorological variables (data from the previous year and the current year) and the model residuals was not significant for the two study sites. However, the trends, although not statistically significant, might be indicative. Positive/negative precipitation (Figure 7) anomaly in the current year seems to cause over/underestimation of NPP_w at both sites, although data variability is high. This means that the role of water availability is more emphasized in the model than in reality. On the other hand, there is a difference between locations in the model performance for the current year with respect to the precipitation anomaly in the previous year (Figure 7). At the wetter (Pokupsko) location negative precipitation anomaly still seems to cause the underestimation of the NPP_w by the model, but at the drier site (Spačva) the effect is reversed (negative precipitation anomaly seems to cause overestimation of NPPw by the model). Opposite to the effects of precipitation, positive/negative air temperature (Figure 8) anomaly in the current year seems to have different effects at each location. At the wetter (Pokupsko) location, positive temperature anomaly seems to cause underestimation of NPP_w, while at the drier (Spačva) site it causes overestimation. Interestingly, positive air temperature anomaly in the previous year seems to cause underestimation of NPP_w at both locations. The observed relations are not statistically significant, as we already emphasized, but are in accordance with the logic of buffered growth response against single drought events due to a large rooting depth of trees.

In a previous study [24] statistical evaluation of the observed Biome-BGCMuSo simulated carbon fluxes against measured eddy covariance data from Pokupsko Basin (Jastrebarsko site) showed much better agreement (see Table 5 in [24]) than in the current study. The explained variance of the observed gross primary production (GPP) and total ecosystem respiration (TER) reached 84% and 83%, respectively. This is in striking contrast to the negligible amount of explained variance (~2%) for the BAI dataset. It is important to note that biogeochemical models like Biome-BGCMuSo are typically calibrated/validated with data-rich eddy covariance based measurements. The application of BAI as validation data in the case of processed based models is rare in the literature. The use of BAI data or NPP estimated from BAI measurements, in Biome-BGCMuSo calibration might help to improve the allocation parameters and thus improve the predictive power of the model. This would be even more important when dynamic allocation will be implemented in the next version of Biome-BGCMuSo (Barcza, personal communication). Multi-objective calibration using both eddy covariance and BAI data (probably with additional variables such as leaf mass, leaf C:N ratio) might provide additional constraints to improve model performance in such cases. The calibration will be a challenging task where sophisticated calibration (e.g. Bayesian [55]) techniques will have to be used.

CONCLUSIONS

The comparison of modelling results with the observed tree-ring data revealed two important model issues related to its predictive power. The first one is the importance of including site-specific conditions (i.e. groundwater table information) with the purpose of enabling the model to be more case-sensitive. At both oak forest locations, Pokupsko and Spačva basins, BBGCMuSo showed poor predictive power in capturing the dynamics obtained from tree-ring data. Using groundwater table information for modelling in lowland oak forests might improve model results.

The second issue is related to carbon allocation. Fixed carbon allocation ratios, currently used in BBGCMuSo model, do not enable the model to successfully predict plant response to stress conditions (e.g. drought). A dynamic carbon allocation routine might better capture tree stress response and growths dynamics. There is an urgent need to investigate and implement more sophisticated carbon allocation routines in the BBGCMuSo model.

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Spatial and Temporal Growth Variation of *Pinus heldreichii* Christ. Growing along a Latitudinal Gradient in Kosovo and Albania

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ABSTRACT

Background and Purpose: Trees growing at high elevations are particularly sensitive to climate variability. In this study, tree-ring chronologies of *Pinus heldreichii* Christ. have been developed to examine their dynamism along a 350 km latitudinal gradient.

Materials and Methods: Sampling was conducted in 6 high elevation sites along a latitudinal gradient from Kosovo and Albania. Two opposite cores from 148 healthy and dominant *P. heldreichii* trees were taken using an increment borer. The cores were mounted and sanded, and after a rigorous cross-dating, the ring widths were measured to a resolution of 0.01 mm using the LINTAB 6 measuring device. The ARSTAN program was used for tree-ring series detrending and site chronologies' development. The relationship between radial growth and climate, as well as between temporal patterns of *P. heldreichii* growth were investigated using simple correlation analysis and principal component analysis (PCA) over the common period 1951-2013.

Results: Radial growth variability of Bosnian pine increased with latitude and elevation. Significant correlations among our chronologies and others from neighbouring countries indicated that our chronologies possess a good regional climatic signal. *P. heldreichii* growth at all sampling sites was significantly influenced by seasonal and mean annual temperatures, as well as by the July drought. Thus, temperature was the main driving force of species growth, showing a larger control at spatial scale than precipitation. The difference in species growth patterns along the latitudinal gradient is implicated by the common action of climatic and non-climatic factors (age and human activity). With continued warming and precipitation decrease during the second half of the 20th century, *P. heldreichii* growth from these high elevation sites resulted in being more sensitive to drought. This climatic signal is assumed to be stronger in the future due to climate change.

Conclusions: *P. heldreichii* chronologies developed in our study possess a good local and regional climatic signal. Temperature was the main driving force of *P. heldreichii* growing in these high elevations sites. The reduction of *P. heldreichii* growth during the second half of the 20th century due to temperature rise and rainfall decrease imposes the necessity to continue investigations on potential impacts of climate warming on species growing near the tree-line.

Keywords: high-elevation, latitudinal gradient, tree-ring growth, spatial analysis, principal component

INTRODUCTION

Tree-ring records provide valuable information for understanding the spatial and temporal patterns of tree-growth variability induced by environmental factors. Tree-ring data from high elevation sites are considered to be highly sensitive to climate variations, providing evidences about the impact of climate in the past [1]. In addition, these sites have a great potential to build long tree-ring chronologies for exploring the environmental changes at a variety time-scales [2, 3]. Bosnian pine (*Pinus heldreichii* Christ.) is a long-living, high elevation species situated in the Balkan (including Kosovo and Albania) and southern Italy [4]. The overall area covered by Bosnian pine in Kosovo is accounted 2150 ha, mostly mixed with silver fir (*Abies alba* Mill.). Some of the natural forest stands of this species in Kosovo are situated in Prevalla, Koritnik and Decani mountanious regions. In Albania, coniferous species occupy an area of 245 thousands hectares, but there is a lack of information regarding forest area covered by *P. heldreichii*. Several studies have been conducted using *P. heldreichii* tree- ring variables for temperature reconstruction and for exploring climate-growth relationship in neighbouring countries. In Bulgaria, maximum latewood density of *P. heldreichii* trees from a high-elevation stand in the Pirin Mountains is used for reconstruction of summer temperatures for the period 1768-2008 [3]. Other studies conducted in Bulgaria [5, 6], Greece [7], Kosovo [8] and Albania [9], have addressed the dynamism of climate–growth relationship of this high elevation species at various scales. In Albania, a 1391-year tree-ring width (TRW) chronology (617–2008) was developed and maximum density measurements were acquired on living and dead *P. heldreichii* trees [9]. Such dendroclimatological studies on *P. heldreichii* growth at high elevation sites are based on the fundamental axiom that tree growth represents a reaction to climate conditions [10]. Therefore, a comprehensive analysis of the spatial and temporal patterns of *P. heldreichii* radial growth along a latitudinal gradient and its response to monthly and seasonal climate by means of dendroclimatological techniques is needed. The aim of this paper is: (i) to identify the dominant spatial and temporal patterns of *P. heldreichii* radial growth over a 350 km latitudinal gradient in Kosovo and Albania; (ii) to compare the newly developed chronologies with other *P. heldreichii* chronologies from neighbouring countries; (iii) to analyse the spatial and temporal patterns of temperature and precipitation variability in all sampled sites, as well as to study the spatial and temporal climate-growth relationship.

MATERIALS AND METHODS

Research Locations

During 2014 and 2015 we sampled 148 healthy living *P. heldreichii* trees growing in six high elevation sites along a 350 km latitudinal gradient with a northeast to southwest direction from Kosovo and Albania (Figure 1). The sampling

FIGURE 1. Research sites along latitudinal gradient. Red circles show locations where *P. heldreichii* samples were collected (Decani - DE; Prevalla - PRE; Koritinik - KOR; Theth - THE: Korab - KO: Llogara - LLO).

sites represent the boundary area between forest vegetation and alpine pastures. Cold temperate coniferous forests in the research area are dominated by Bosnian pine (*P. heldreichii* Christ.) mixed with Silver fir (*A. alba* Mill.). Due to landscape patterns these forest stands are situated between 1450 and 1945 m (m a.s.l.) (Table 1). All natural forest stands from Kosovo are growing under the influence of continental climate with some influences of Mediterranean climate in the Koritnik (KOR) site. The Decani (DE) sampling site is located on a relatively steep rocky slope with south-west exposure in the Strelca area. Elevation of the site is 1830 m a.s.l and soil type is carbonate brown soil on limestone bedrocks. The mean annual temperature of the site is 8.1°C and the annual rainfall 792 mm. The Prevalla (PRE) and Koritinik (KOR) sampling sites represent natural forest stands

TABLE 1. Location and altitude of the sampled sites.

Code	Name	Latitude (N)	Longitude (E)	Elevation (m a.s.l)	Slope aspect
PRE	Prevalle	42°11'01.3"	20°57'42.0"	1945	SW
DE	Decan	42°36'19.8"	20°14'52.5"	1830	SW
KOR	Koritnik	42°04'46.5"	20°31'58.6"	1815	NE
THE	Theth	42°23'05.0"	19°43'02.6"	1640	SW
KO	Korab	41°47'38.8"	20°28'56.0"	1670	NW
LLO	Llogara	40°12'57.7"	19°35'34.4"	1450	W

of Bosnian pine located in the south of Kosovo inside the Sharri National Park. The sampled forest stands are located on ultrabasic bedrocks growing on deep carbonate brown soils. The research site in PRE is a pure Bosnian pine stand, while the KOR site represents a mixed Bosnian pine - Silver fir stand situated at an altitudes of 1945 and 1815 m a.s.l respectively. The forest stands are situated on SW (PRE) and NE (KOR) slope exposure. The mean annual temperature range is between 8°C (PRE) and 8.3°C (KOR), while annual rainfall varies from 874 mm to 1024 mm repectively. The Thethi (THE) research site is located in the north of Albania inside the area of Thethi National Park. The sampling site elevation is 1640 m a.s.l located on a relatively steep, rocky area with SW (south-west) exposure. Bosnian pine trees on that site grow on typical brown soils developed on limestone bedrocks. The Korabi (KO) sampling site is situated in eastern Albania, while Llogara (LLO) is the southernmost site, located in the SW of Albania inside the Llogara National Park. Most of the Bosnian pine trees grow on slopes with moderate to relatively steep inclination with NW (KO) to W exposure. The soils in THE and LLO sites are relatively shallow, while soils in KO site are moderately deep. Bosnian pine forest stands in Albania are growing under the influence of mountainous Mediterranean climate with annual mean temperature between 10°C (KO) and 15.5°C (LLO). Llogara site is the driest (870 mm) and warmest site compared to other sites from Albania, while THE site is the wettest with 1447 mm rainfall per year. Increment cores were taken from trees with a diameter at breast height (dbh) from 33 cm to 98 cm and height between 20 and 35 m. The average diameter of the sampled trees varies between sites and ranges from 46.6 cm (KO) to 63 cm (LLO) (Table 3). Ground vegetation in all sampled sites comprises (mostly) of the following species: *Sesleria autumnalis* Ard., *Brachypodium sylvaticum* Huds., *Carex humilis* Leyess., *Thymus balcanus* L., *Fragaria vesca* L., *Festuca heterophylla* Lam., *Dactylus glomerata* L. etc. Annual temperatures along the latitudinal gradient increase from NE to SW, while precipitation decreases and becomes more irregular throughout the year. The climate data in Figure 2 shows the lack of drought period in each sampled site during the summer season. Mean annual temperature decreases along rising elevation at any given latitude, while the rainfall is less influenced.

Data Collection, Chronology Development, and Statistics

Two opposite cores from dominant trees were taken at dbh using increment borers, where the number of sampled trees varied from 11 to 38. The cores were extracted along the slope contour to avoid reaction wood. The cores were then mounted and sanded following the standard dendrochronological procedures [11].

After rigorous cross-dating of the tree-ring cores, the ring widths were measured to a resolution of 0.01 mm using the LINTAB 6 (RINNTECH, Heidelberg) measuring device and the TSAP-Win Scientific software [12]. The quality of the time series measurement and cross-dating was examined and confirmed statistically using the COFECHA program [13]. The tree-ring width (TRW) measurements were standardized to remove the age-related growth trends. The TRW measurement series were converted into dimensionless indices [14]. For that, the ARSTAN,41b program was used [15].

Firstly, a negative exponential curve was fitted to each measured tree-ring series and ratios between the observed values and fitted growth curves were calculated. Secondly, a more flexible detrending was applied using a cubic smoothing spline with a 50% frequency response of 32 years to reduce non-climatic variation [16]. The persistence of the detrended series was removed by autoregressive modelling and the resulting residual series were averaged to a mean site chronology by computing the bi-weight robust mean [16]. In order to assess the temporal variability in the strength of the common variation in each site chronology, which reflects common responses to climatic influences, we used the running series of average correlations (R_{bar}) and expressed population signal (EPS) statistics [17]. R_{bar} is the mean correlation coefficient for all possible pairings among tree-ring series from individual cores, computed for a specific common time interval. The running EPS statistics computed from R_{bar} indicates to what extent the sample size is representative of a theoretical infinite population. Running EPS values were calculated over a 50-year window with a 25-year overlap. A threshold value for EPS≥0.85 for any given site chronology was considered adequate to reflect a common growth signal [17]. Several statistical parameters, such as the mean sensitivity (MS), the standard deviation (SD), first-order autocorrelation (AC1), the average correlation among all series (R_{bar}) and the expressed population signal (EPS) were calculated to assess the qualities of the six site chronologies.

In order to assess the similarity between the chronologies (tele-connection) from distant sites [18], regional chronologies were compared by t_{BP}-values and Gleichlauigkeit values (GLK) with the nearest existing tree-ring data available via the NOAA International Tree-Ring Data Bank (www.ncdc.noaa.gov/paleo/treering.html). The available Bosnian pine chronologies from the International Tree-Ring Data Bank were: Katara Pass (Greece, elevation 1750 m a.s.l, 1673-1981), Olympos Oros (Greece, elevation 2250 m a.s.l, 1583-1981), Sierra da Crispo (Italy, elevation 2000 m a.s.l, 1441-1980), Vihren (Bulgaria, elevation 1920 m a.s.l, 1721-1981), Pirin Mountain (Bulgaria, 2150 m a.s.l, 1288-2005). Additionally, we used the tree-ring chronology for Mount Smolikas (Greece, 575-2012) site provided by Paul Krusic (personal communication, 2017).

To assess the spatio-temporal patterns among six residual site chronologies the principal components analysis (PCA) [19] was applied over the common period 1840-2014. All principal components (PCs) with eigenvalues greater than 1 were retained for correlation analysis using the Minitab 17 program [20].

Spatial and Temporal Patterns of Temperature and Precipitation Variation

Instrumental climate records are spatially and temporally limited in these high mountain areas, and therefore the updated CRU TS 3.22 0.5°×0.5°- gridded monthly temperature and precipitation data sets were used [21] (www.climexp.knmi.nl). The climate data were extracted from the database for the region encompassed by the coordinates 40°25’-42°25’N and 19°25’-20°75’E (Table 2).

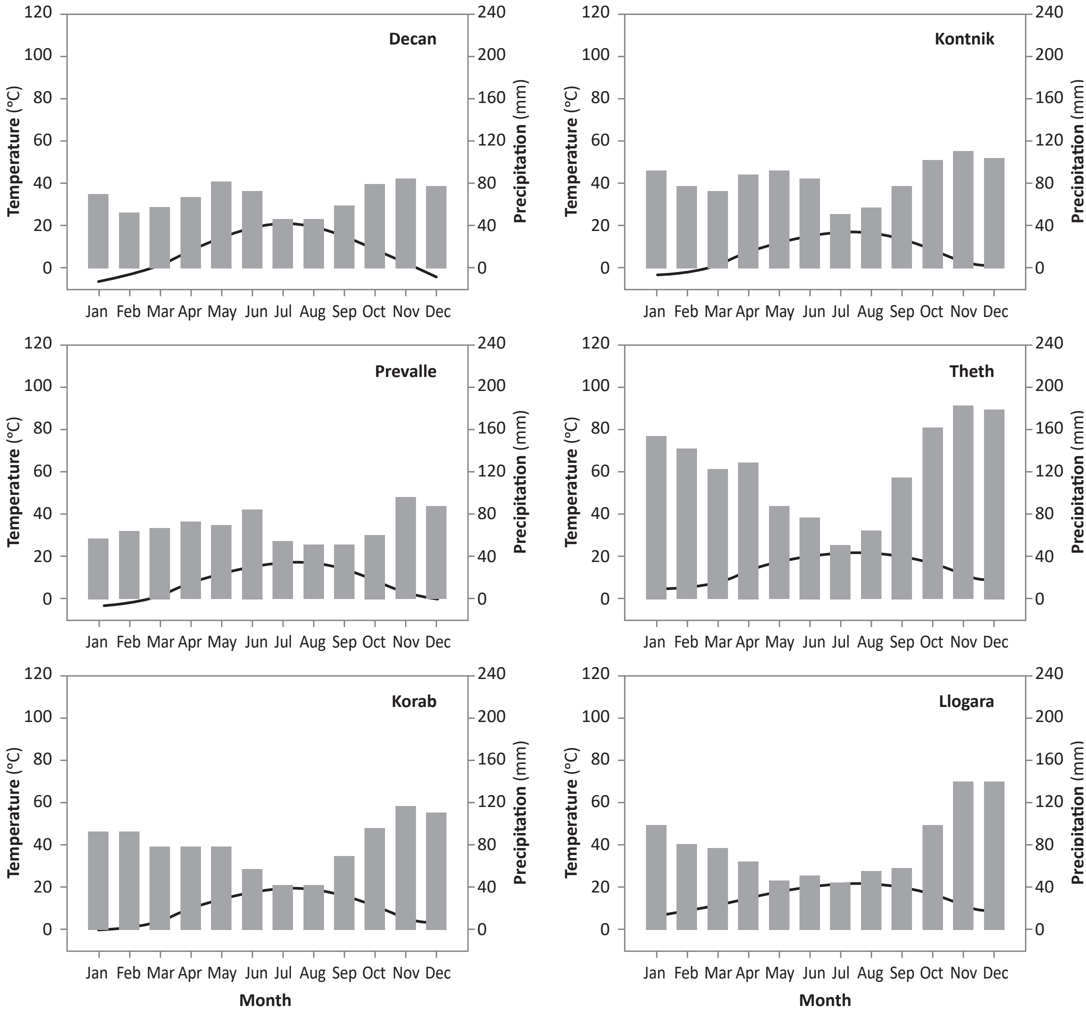

FIGURE 2. Climatic diagrams of the studied sites based on the CRU TS 3.22 data for the 1951-2013 period. Solid lines show temperature, while histograms show precipitation values.

Growth–Climate Spatial and Temporal Relationship

Climate sensitivity of *P. heldreichii* at spatial and temporal scale was assessed over the common period 1951-2013 using correlation analysis. The Pearson correlation analysis was performed between the principal components (PCs) of tree-ring residual chronologies and monthly, seasonal and annual climate variables to determine which climatic variables had the strongest influence on the radial growth of species growing in different sites along the latitudinal gradient. The *P. heldreichii* radial growth may be influenced by the current year's climatic conditions and that of the previous years. Thus, a period of 18 months, from previous May to current October, was involved in the following analysis [22]. The growth-climate relationship was quantified using the PCA. First a correlation matrix among each site chronology was estimated. In addition, three main principal components (PCs) were extracted from PCA, using the Kaiser criterion (eigenvalue>1). We applied the Varimax method for components rotation in order to minimize the number of variables that have high loadings and that have the main contribution in the final explained variance [23]. To detect which climatic factors affect the growth patterns as well as the spatial variation of this influence along the latitudinal gradient, correlation analysis was used between the first three PCs loadings and climate data [22]. To test the relationship at spatial and temporal scale we calculated the correlation coefficients among principal components of *P. heldreichii* residual chronologies and climate variables for the common period 1951-2013. Additionally, we selected the PCs which showed the strongest relationship with climate variables and plotted them graphically against each other to examine their coherence in temporal scale over the common period 1951-2013.

RESULTS

Sampling Site Characteristics

Sampling sites have a considerable difference in altitude (c.a. 495 m a.s.l.) along the latitudinal gradient. Elevation decreased southward along the latitudinal gradient and the correlation between elevation and latitude was 0.77 ($p<0.05$). The difference in elevation among sampling sites was associated with a northward decrease of mean annual temperature (c.a 1.6°C per 100 m elevation increase). Furthermore, a significant correlation ($R<0.85$, $p<0.05$) was found between mean annual temperatures and elevation at all research sites, while a weaker correlation was reached with precipitation. Based on climate data it was noticeable that aridity is increased with decreasing latitude (Figure 2).

Descriptive Statistics of the Tree-Ring Width Chronologies

Table 3 shows the descriptive statistics of each ring-width chronology. The longest chronology is from DE site spanning through the period from 1474 to 2014 with a replication of 35 trees, while the shortest chronology belongs to KOR site with 175 years (Figure 3). The mean ring-width values of built chronologies decreased with age indicating the presence of a biological trend in *P. heldreichii* radial growth. Mean sensitivity, characterizing the year-to-year variability in tree-ring records, ranges between 0.17 and 0.25, whereas the standard deviation varies from 0.50 to 1.32. Mean sensitivity is significantly affected by latitudinal and elevation gradients indicating that intra-annual variability in TRW increases with latitude and altitude. General patterns show that *P. heldreichii* chronologies located in the northern portion of the latitudinal range have higher sensitivity as compared to the southern ones. Tree-growth patterns through time vary among the site chronologies. The EPS values above the threshold (EPS>0.85) for all chronologies were reached after 1933, indicating a strong climate signal and a good temporal stability for all chronologies during the 1951-2013 common period.

Comparison among Chronologies

Correlations between site chronologies in the study area resulted depending on site characteristics and distance among sites. Correlation matrix displayed a greater similarity among site chronologies that are geographically situated in the central-northern and southern part of the latitudinal gradient, while a low correlation was found between the two most distant sites (Table 4). LLO chronology displayed significant correlations with most of the site chronologies except with DE-site. The highest correlations were found between LLO and THE, as well as between KOR and KO site chronologies. The correlation between KOR and PRE chronologies was statistically significant but not very high

TABLE 2. Climatic variables used for comparison with radial growth at a spatial and temporal scale.

Site	Latitude (N)	Longitude (E)	Record period	Parameter	Source
PRE	42° 25'	20° 75'	1951-2013	T ; P	https://climexp.knmi.nl/select.cgi?id
DE	42° 25'	20° 25'	1951-2013	T ; P	https://climexp.knmi.nl/select.cgi?id
KOR	42° 25'	20° 25'	1951-2013	T ; P	https://climexp.knmi.nl/select.cgi?id
THE	42° 25'	19° 25'	1951-2013	T ; P	https://climexp.knmi.nl/select.cgi?id
KO	41°25'	20° 25'	1951-2013	T ; P	https://climexp.knmi.nl/select.cgi?id
LLO	40° 25'	19° 25'	1951-2013	T ; P	https://climexp.knmi.nl/select.cgi?id

T - temperature; P - precipitation

TABLE 3. Descriptive statistics of the six ring-width chronologies.

Code	Name	Sampled trees	Period	Mean dbh (cm)	Mean ring-width (mm)	SD	MS[a]	AC1[a]	R_{bar}	EPS>0.85
PRE	Prevalle	30	1776-2014	52.0	2.13	0.91	0.21	0.78	0.55	1920
DE	Decan	38	1474-2014	62.6	1.06	0.50	0.22	0.77	0.56	1770
KOR	Koritnik	30	1840-2014	60.4	1.81	0.87	0.25	0.75	0.61	1876
THE	Theth	11	1575-2014	54.5	1.08	0.50	0.23	0.79	0.36	1726
KO	Korab	22	1833-2014	46.6	2.16	1.32	0.20	0.75	0.47	1933
LLO	Llogara	17	1597-2014	63.0	1.65	0.76	0.17	0.77	0.41	1765

SD - standard deviation; MS - mean sensitivity; AC1- first-order autocorrelation; R_{bar} - mean inter-series correlation; EPS - expressed population signal
[a] - Calculated for the standardized chronologies prior to autoregressive modelling

(R=0.22, p<0.01) due to the difference in tree age (c.a. 64 yr) and the influence of slope aspect on solar radiation budget.

PCA revealed that the first three rotated PCs have eigenvalues >1 and account for 35%, 20% and 15% of the total variance respectively, or cumulatively 70% of the total variance (Figure 4). The remaining components explain only 30% of the total variance. According to the loadings of the first three PCs, the site chronologies can be divided into three groups. This division is consistent with the results of the correlation analyses. The loadings of PC1 describe the environmental signals that are common between the *P. heldreichii* chronologies for KOR and DE with a clear pattern of decreasing towards the KO site.

PC2 represents the common variances of three high-elevation sites (LLO, KO and PRE) with a clear decreasing northwards (the PRE site). THE chronology showed the highest loadings of PC3-growth (>0.6). Temporal patterns of *P. heldreichii* radial growth are shown in Figure 5. The PC1 growth pattern shows a considerable variability of intra-annual values during the common period 1951-2013. The most negative factor scores were noted in several years: 1840, 1861, 1874, 1907, 1908, 1929, 1942 and 1947. This pattern is related to the northern chronologies (DE and KOR), which have the highest loadings. The PC2 growth pattern indicates a double decrease of negative values at KO site chronology where most of the negative values in factor scores were recorded after the year 1905. The negative score values of PC3 growth indicate the existence of lower variability. The most negative values were reached in 1853, 1869, 1993 and 1996 and this growth pattern is related to THE chronology.

The comparison of our chronologies with others from neighbour countries showed a strong dependence on the distance between sampled sites. Thus, the correlations of our *P. heldreichii* chronologies from DE, THE and KO sites with the Mount Smolikas (Greece) and Lure (Albania) were statistically significant (Table 5). Moreover, Bosnian pine chronology from KOR site showed a good agreement with Bulgarian chronologies from Pirin and Vihren sites. Tables 5 indicates that agreement was stronger between chronologies from the closest sites (Table 6). Thus, LLO chronology showed a good connection with chronology from Sierra del Crispo in Italy, while our *P. heldreichii* chronologies from THE site and KO site displayed good agreement with chronologies from Thethi and Lure built earlier by Seim et al. [9]. These results show that our *P. heldreichii* chronologies

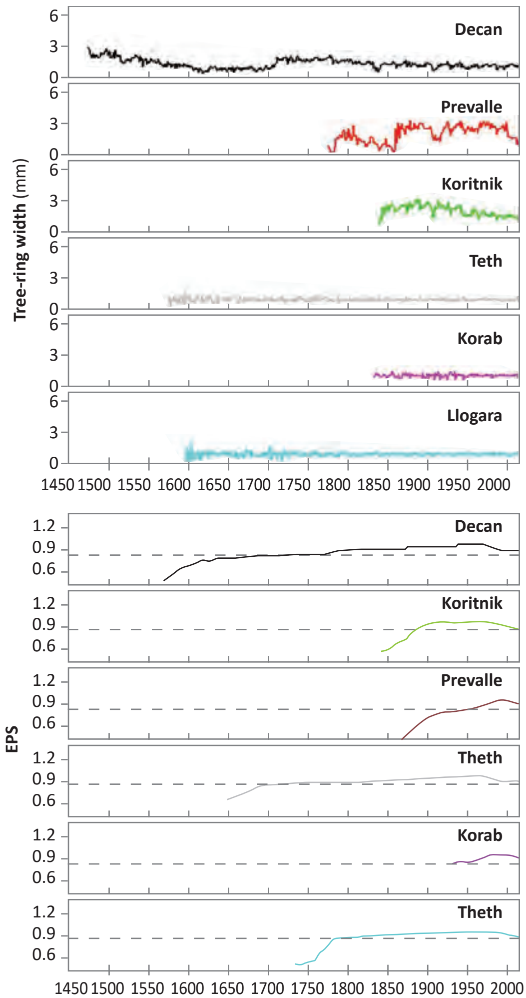

FIGURE 3. Raw tree-ring width chronologies of Bosnian pine (*P. heldreichii* Christ.) from research sites along latitudinal gradient. The upper part in the graph shows the raw ring width chronologies, while the lower part shows EPS value for each site chronology (dashed line shows EPS threshhold >0.85).

TABLE 4. Correlation between 6 site ring-width chronologies along the latitudinal gradient over the 1840–2014 common period.

Sampled sites	Pearson's correlation coefficients among site tree-ring chronologies					
	Decan	Prevalle	Koritnik	Theth	Korab	Llogara
Decan	1.00	0.08	0.48**	-0.18	-0.13	- 0.14
Prevalle		1.00	0.22**	0.11	-0.07	0.25**
Koritnik			1.00	-0.56**	-0.61**	-0.23**
Theth				1.00	0.58**	0.67**
Korab					1.00	0.19*
Llogara						1.00

** - correlation is significant at the 0.01 level (2- tailed)
* - correlation is significant at the 0.05 level (2 tailed)

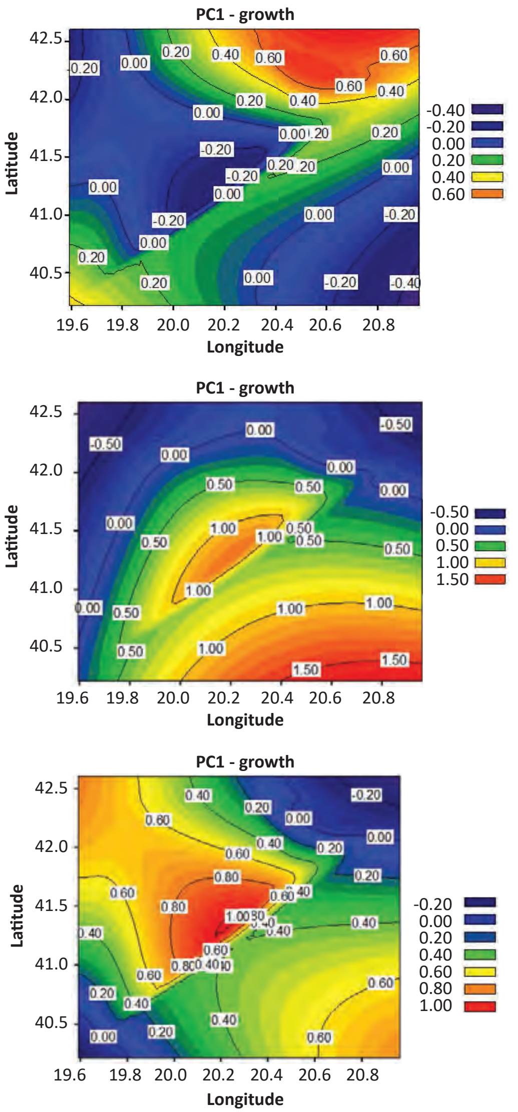

FIGURE 4. Spatial patterns of *P. heldreichii* tree growth along their latitudinall range. Site chronologies are plotted along longitudinal (X) and latitudinal (Y) location of respective sampling sites (DE 42.60 N - 20.26E; PRE 42.18 N - 20.96; KOR 42.08 N - 20.54 E; THE 42.38 N - 19.07 E; KO 41.79 N - 20.48 E; LLO 40.21 N- 19.59 E) . Isolines represent factor scores for the first three principal components for radial growth.

posses a good regional signal and may be included into a Bosnian pine dendrochronological network covering the whole geographical distribution of the species.

Spatial and Temporal Patterns of Temperature and Precipitation

Spatial and temporal patterns of temperature and precipitation were analysed for the period 1951-2013 which

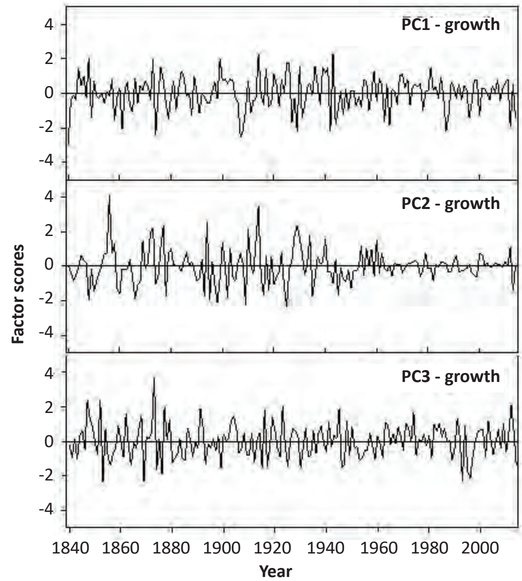

FIGURE 5. Temporal variations in factor scores of the first three principal components of *P.* heldreichii growth (from top to bottom: PC1-growth, PC2-growth and PC3-growth) extracted from the 6 site chronologies over the 1840–2014 common period.

is considered reliable from the climate data point of view. The first two PCs for mean annual temperature (PC1-temp and PC2-temp) explain 81% and 16% of the variance respectively (cumulative value 97%). The two stations (DE and KO) had the highest loadings for PC1-temp (>0.45) with a decreasing trend toward southern Kosovo. PC2-temp shows the opposite trend with the highest loadings (>0.9) in the KOR-site, and decreasing values northward Albania with negative loadings for THE-site (Figure 6). Regarding precipitation the first two PCs (PC1-prec and PC2-prec) explain 87% and 8% of the total variance respectively (cumulative value 95%). PC1-prec loadings reached high values (>0.41) for the sampled sites located in the north and central part of the latitudinal transect, whereas PC2-prec showed the highest loadings (>0.8) for LLO, which is the southernmost site along latitudinal gradient. The temporal patterns of temperature and precipitation in Figure 7 display the variability of PC1 and PC2 loadings. PC1-temp shows a temporal fluctuation of mean annual temperatures associated with a sustained positive trend in specific years (1984-1987; 1995-1998; 2000-2002 and 2010-2013) attributed to DE and KOR climate data. On the other hand, the PC2-temp shows a sustained decrease over the 1967-1997 period, associated with an increase of PC loadings during the 1998-2004 and 2006-2013 periods. Such trends reflect temperature variations at KOR site, which is located in southern Kosovo. The temporal patterns for both principal components of precipitation show a typical intra-annual variability over the 1951-2013 period. The long-term annual pattern for PC1-prec shows a distinct fluctuation in certain periods and a sustained decrease in precipitation during the period 1966-1979. The

TABLE 5. The comparison of all six *P. heldreichii* chronologies from Albania and Kosovo with others from neighbour countries.

Site	Mt. Smolikas, Greece		Lure, Albania		Olympos-Oros, Greece		Sierra da Crispo, Italy		Pirin, Bulgaria		Vihren Park, Bulgaria		Tomorr, Albania		Katara Pass, Greece		Theth, Albania (Seim)	
	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%	t_{BP}	GLK%
Decan, Kosovo	6.29*	65*	6.29*	65*	8.29	60	2.33	52	3.59	54	14.11	62	4.52*	66*	2.19	59	1.67	45
Koritink, Kosovo	6.59	59	6.59*	65*	2.67	62	3.71	57	9.60*	66*	6.28*	69*	2.64	60	1.31	54	1.95	46
Prevalle, Kosovo	4.13	59	4.13	51	1.29	53	6.79	57	2.29	60	5.32	62	1.07	52	2.92	49	0.91	57
Theth, Albania	24.42*	69*	4.42	48	2.00	47	12.24	49	3.36	47	12.05	58	2.73	49	2.3	52	6.94*	68*
Llogara, Albania	9.69	53	9.69	51	1.77	53	6.60*	65*	0.61	54	3.62	53	0.81	51	3.58	54	2.24	52
Kala Dodes, Albania	10.01*	68*	10.01*	70*	4.98	53	6.26	46	3.23	51	5.59	57	7.41	45	3.13	48	1.72	55

* - significant correlations ($p<0.05$)

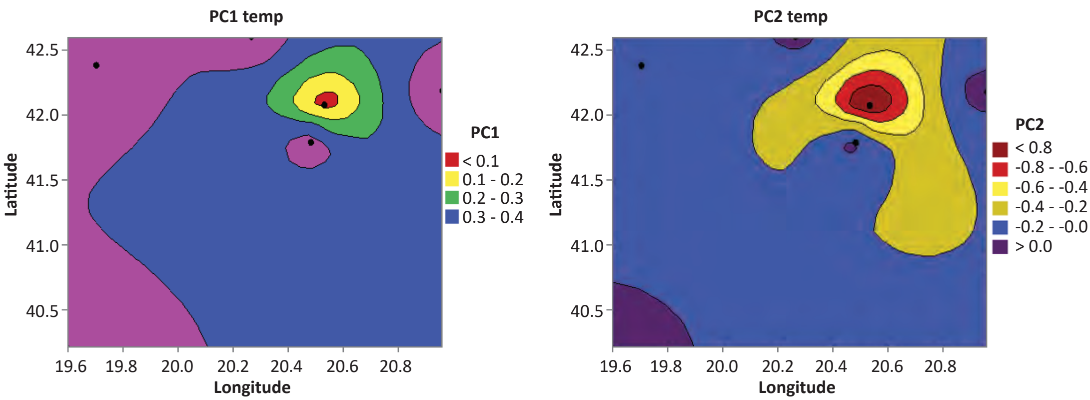

FIGURE 6. Spatial patterns of mean annual temperature variability for all research sites along their longitudinal (X) and latitudinal (Y) geographic range over the 1951–2013 period. Isolines represent factor scores of the first two principal components for mean annual temperature (left: PC1-temp and right: PC2-temp).

opposite patterns were observed from 1986 to 1992, as well as from 2007 to 2010. The long-term pattern for PC2-prec shows a higher variability than the first component associated with only two periods of precipitation decrease after the 1960s (1960-1964 and 1994-1998).

Growth-Climate Spatial Relationship

According to the available climatic data, all *P. heldreichii* chronologies were truncated over the common period 1951–2003, and then used for the growth-climate analysis. Correlation analysis indicated that our Bosnian pine chronologies were negatively correlated with temperatures in the summer and autumn prior to growth and in the spring, summer and autumn of the growing season (Figure 8). The growth-climate response for DE chronology (PC1) shows significant negative correlation to monthly temperatures from May prior to growth to current October, as well as to seasonal and annual temperatures. The climatic response of KOR chronology resulted as being weaker than the response showed by DE chronology. The KOR chronology was negatively correlated with previous July and August temperatures, as well as with current spring (MAM), summer (JJA) and early-mid autumn (September and October) temperatures of the growing year. The same response was also noted with seasonal and annual temperatures. The distinct drought signal in these two chronologies is supported by positive correlations with current July and August precipitation and with current summer precipitation ($r=0.24$, $p<0.05$) and negative correlation with summer (JJA) temperatures ($r=0.46$, $p<0.05$). The DE chronology was the only which showed significant positive correlation to annual sum precipitation. Similar correlation patterns with previous July, August, September and October temperatures were also noted for the second PCs, which represents the growth variability at KO, PRE and LLO sites. Our chronology from LLO site showed a stronger response against temperature than the previous ones. Thus, *P. heldreichii* trees responded negatively against to the previous June, July, October as

TABLE 6. Distance between our sampling sites and others from neighbouring countries

Site	Mt. Smolikas, Greece	Lure, Albania	Olympos-Oros, Greece	Sierra da Crispo, Italy	Pirin, Bulgaria	Vihren Park, Bulgaria	Tomorr, Albania	Katara Pass, Greece	Theth, Albania (Seim)
Decan, Kosovo (DE)	n.a	91.96	334.98	449.19	294.25	274.23	213.78	330.58	46.48
Koritink, Kosovo (KOR)	n.a	39.05	270.92	433.10	241.23	238.80	152.03	259.60	73.22
Prevalle, Kosovo (PRE)	n.a	75.64	265.16	469.44	224.80	205.86	175.99	268.30	101.75
Theth, Albania (THE)	n.a	77.89	341.96	399.26	330.77	312.14	188.07	317.30	6.40
Llogara, Albania (LLO)	n.a	183.03	240.63	289.01	366.82	362.96	69.07	148.00	249.00
Kala Dodes, Albania (KO)	n.a	22.58	248.30	413.63	257.20	241.61	126.80	233.21	90.49

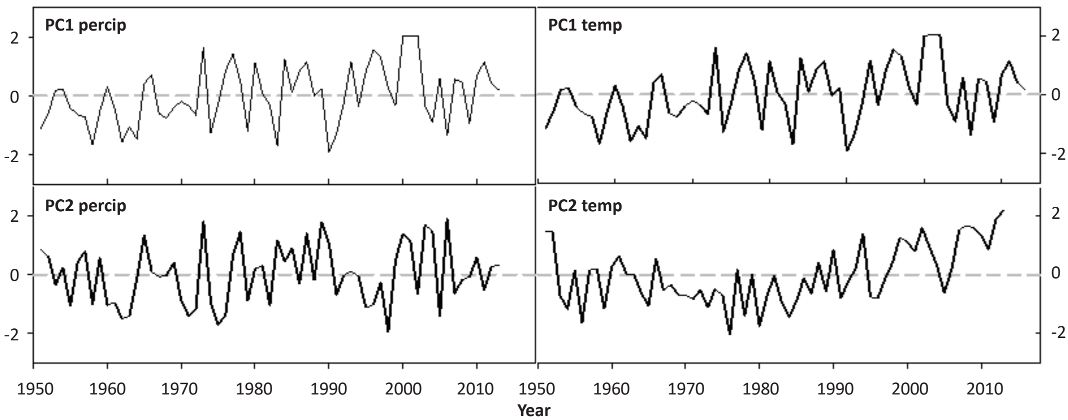

FIGURE 7. Temporal variations in factor scores of the first two principal components of annual precipitation (left) and mean annual temperature (right) extracted from CRU climate data for respective research sites.

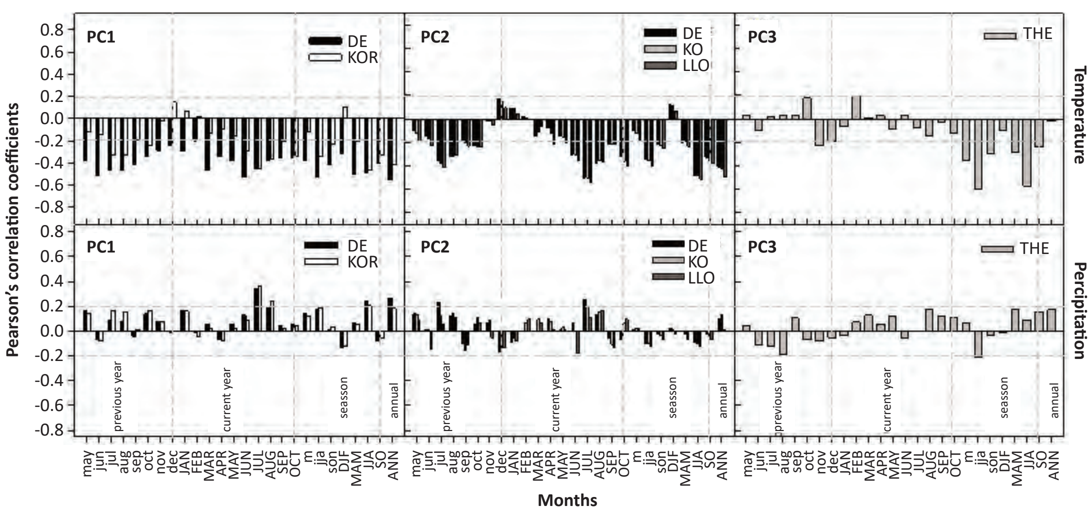

FIGURE 8. The correlation between monthly, seasonal and annual values of temperature and precipitation with first three principal components of *P. heldreichii* radial growth. The correlation coefficients were calculated from previous year May to current year October over the common period 1951–2013. The horizontal dash lines in each graph indicate the significance level of Pearson's correlation coefficients ($p<0.05$).

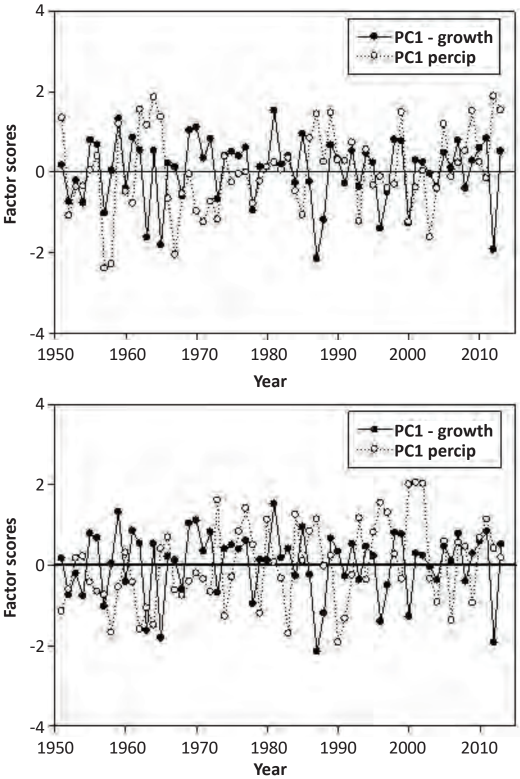

FIGURE 9. Temporal patterns of tree growth variability for the selected principal components extracted from 6 research sites for the 1951-2013 period compared with PCs of temperature and precipitation. The graphs show factor scores between PC1-growth and PC1-temp (left graph) and PC1-growth and PC1-precip (right graph).

well as current JJA and SO temperature at those three sites. The PRE chronology was positively correlated with previous and current July precipitation, while KO chronology showed positive correlation only with current July precipitation. The growth of *P. heldreichii* trees from THE site (PC3) has been negatively influenced by November temperatures of the previous year, as well as by seasonal temperatures except in winter. This is the only chronology which showed inverse correlation with summer (JJA) precipitation of the previous growing season ($r<-0.21$, $p<0.05$).

Growth–Climate Temporal Relationships

The correlation analysis revealed a significant correlation ($r=-0.24$, $p<0.05$) between *P. heldreichii* growth (PC1-growth) and mean annual temperatures, while the relationship with annual precipitation was weaker (Figure 9). Long-term gridded mean annual temperature data showed an increasing trend, whereas species growth has decreased ($p<0.05$) since 1951. The annual air temperature calculated from gridded data set showed a decreasing trend during the 1951-1985 period and a steady increasing trend from 1986 to 2013 for both countries. The air temperature has risen during May-August period. Furthermore, long-term annual precipitation data showed a decreasing trend for the 1951-2013 period characterized by a year-to-year variation and an uneven monthly distribution for both countries. The precipitation decline (c.a. 50 mm) in Kosovo was especially accounted for July, November, and May, whereas in Albania the annual sum of precipitation decline was two times higher than in Kosovo and the largest decline in rainfall was recorded during January, February, March, May, October, and November. Over the past 30 years, both countries experienced several extreme drought events (e.g. 1990; 2000; 2003; 2008 and 2011) which might have affected the Bosnian pine's radial growth [24].

DISCUSSION

Our study aims to reveal a comprehensive understanding of spatial and temporal patterns of *P. heldreichii* radial growth related to climate along the latitudinal gradient. We present a dataset of 148 living sample trees from six high elevation sites across Kosovo and Albania that used to build *P. heldreichii* radial growth chronologies. Such chronologies will contribute to a denser tree-ring network of Bosnian pine, providing a better understanding of the impact of climate on species growth along its geographic range. In comparison, the nearby *P. heldreichii* chronologies documented for the Balkan Peninsula and southern Italy, span periods of 1392 years (617 to 2008) in Albania [9], 762 years (1243 to 2004) in Greece [25], 758 years (1250 to 2008) in Bulgaria [6] and 827 years (1148 to 1974) in south Italy [26]. The comparison of our chronologies with others from neighbour countries showed a strong dependence on the distance between sampling sites. These results showed that our chronologies posses a good regional signal and that they could be integrated into a Bosnian pine dendrochronological network. Our *P. heldreichii* ring-width chronologies have different length, ranging from 174 to 541 years and a mean sensitivity ranging from 0.17 to 0.25. Mean sensitivity showed the suitability of *P. heldreichii* for dendroclimatic analyses. The presence of young trees in PRE, KO and KOR chronologies implies that such forest stands have been intensively managed and used by humans in the past. We analysed *P. heldreichii* growth patterns along a 350 km latitudinal gradient oriented toward northest-southwest direction. The sampling sites ranged in elevation from 1450 m to 1945 m a.s.l along latitudinal and longitudinal gradient associated with a northward decrease in mean annual temperature (c.a. 1.6°C per 100 m elevation). Although sampling was performed at the highest forested elevations, our research sites do not represent the typical tree - line conditions. Körner [27] stated that high elevation sites in Mediterranean region do not show a clear temperature control in radial growth pattern as compared to the Alpine sites, but our study found that temperature was the main climate driver of *P. heldreichii* growth. Climatic sensitivity of Bosnian pine chronologies increased with latitude and elevation. Thus, those *P. heldreichii* chronologies located in the northern portion of the latitudinal range had a higher year-to-year variation as compared to the southern ones. The difference in climate-growth relationship might be due to the combined effect of local site conditions, tree age and human activity. Thus, *P. heldreichii* radial growth showed stronger significant negative correlation with temperature at the northernmost site (DE) of the latitudinal gradient and an opposite relationship with precipitation. The significance of the growth-climate relationship is diminished towards the southern limit of the latitudinal gradient. The intra annual variability in radial growth from these sites has increased, not only by local climate conditions, but also by non-climatic factors. The diversity noted in Bosnian pine growth patterns (especially for PRE and KOR sites) and the relationship with climate variables might be caused by the presence of in-situ natural processes (e.g. rockfall, landslide, thunderclap) and anthropogenic activity (slash-and-burn for grazing, wood cutting for heating). It is known that shepherds and goatherds have been using the pastures close to the sampling sites in summer for grazing for many centuries and that the wood of Bosnian pine is traditionally used for cottage building and heating. *P. heldreichii* response versus climate seems to be age dependent because the oldest trees growing in DE, THE and LLO sites, resulted more sensitively against temperature than the youngest trees. Previous studies have shown that in old conifer trees the duration of wood formation is shorter than in younger ones [28]. It is well-known that tree ageing affects carbon allocation to different parts of the plant, reduces the foliar efficiency and gas attributes [29, 30]. Thus, decline of photosynthetic rate in old conifer species induce the increasing of climatic sensitivity, especially towards temperatures [31]. Although our sampling sites represent high elevation ecotones, the climate diagrams show the presence of a moderate water stress during the summer season. The inverse relationship noted at most of the sites between temperature and precipitation of the current July displays the presence of a distinct drought signal in Bosnian pine growth. Young trees are able to face with water stress which directly reduces their stomatal conductance, showing a higher sensitivity to drought. These moderate water deficits have a direct impact by reducing the foliar efficiency due to earlier stomatal closure, as well as the potential assimilation [32, 33]. Furthermore, young Bosnian pine trees do not have a deep root system, which makes them unable to utilize water sources in the deepest and wettest soil layers and meet their demands during the summer season [34].

Considering the latitudinal gradient we found that temperatures have greater control on Bosnian pine growth than precipitation, as indicated by negative correlations with PCs of species growth. This finding is supported by other authors' works on high elevation showing that radial growth of *P. heldreichii* correlates well with mean or seasonal temperatures [35, 36]. We found that all correlations between principal components and climate variables over the 1951-2013 period were relatively strong, exceeding the 95% significance level. Similar patterns of temperature and precipitation change over the 1951-2013 period have been observed at both countries. The climate data used here showed an overall decrease of annual temperature during the 1951-1985 period, followed by a prominent increase over the 1986-2013 period. Precipitation declined throughout the 1951-2013 period, which is associated with inter-annual variation and uneven monthly distribution for both countries. These important evidence of climate variables in both countries has been reported earlier by other authors. Thus, [37] stated a mean temperature increase by 1°C in Albania during the 20th century. They reported in their study a temperature decrease by 0.6°C during the 1900-1975 period associated with a warming by 2°C up to the present. The warming period in Albania during the 20th century is accompanied with changes of the rainfall regime, wind speed and wetness. They reported a decrease by 200-400 mm in the annual rainfall quantity [37]. Within the study area, spatial variability in *P. heldreichii* response to climate noted during the 20th century supports the conclusion that global warming possibly lead to differences among sites in sensitivity and climate variation [38]. Recently, other studies conducted in the European Alps have shown that global warming has potentially increased radial growth of conifer species growing in high elevations [39]. The decrease of *P. heldreichii* growth noted in our study during the second half of the 20th century implies that species growth is limited by humidity. The adequate explanation might be that hot dry summers recorded in the 1990s (1990; 2000; 2003; 2008 and 2011) caused drought stress where water storage capacity is limited because of shallow soil depth. Earlier studies have shown that *P. heldreichii* trees displayed higher sensitivity to summer drought, which was probably a result of increased summer temperatures and decreased winter precipitation [6].

It is assumed that there will not be any competition for the Bosnian pine by other tree species of the upper mountain level zone during the course of shifting of vegetation zones due to climate warming, which means that *P. heldreichii* would be the winner of climatic changes [40, 41]. However, ongoing and future research focused on *P. heldreichii* behavior to current and predicted climate change along its geographic range is required to improve the current level of knowledge of dendroclimatological studies.

CONCLUSIONS

P. heldreichii chronologies developed in our study possess a good local and regional climatic signal. Growth-climate relationship indicated that temperature is the main driving force of *P. heldreichii* growing in these high elevations sites. The difference in Bosnian pine growth patterns along the latitudinal gradient is implicated by common action of climatic and non climatic factors (age and human activity). The reduction of *P. heldreichii* growth during the second half of the 20th century due to the temperature rise and precipitation/rainfall decrease impose the necessity to continue investigations on potential impacts of climate warming on species growing near the tree-line.

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Disaster Risk Reduction Based on a GIS Case Study of the Čađavica River Watershed

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ABSTRACT

Background and Purpose: Although natural hazards cannot be prevented, a better understanding of the processes and scientific methodologies for their prediction can help mitigate their impact. Torrential floods, as one of the consequential forms of the existing erosion processes in synergy with extremely high precipitation, are the most frequent natural hazard at the regional level, which was confirmed by the catastrophic events in May 2014 when huge territories of Serbia, Bosnia and Herzegovina and Croatia were flood-struck. The basic input data for the design of protective structures in torrential beds and watershed slopes are the values of the maximal discharge, area sediment yields, and sediment transport. The calculation of these values requires a careful approach in accordance with the characteristics of torrential watersheds, such as the steepness of slopes and beds in torrential watersheds, intensive erosion processes, favorable conditions for fast runoff formation and the transport of huge quantities of sediment.
Materials and Methods: The calculations of maximal discharges, area sediment yields, and sediment transport in the experimental watershed of the Čađavica River were based on using two different spatial resolutions of digital elevations models (DEMs) – 20 m resolution DEM, with land use determined from aerial photo images, and the 90 m resolution DEM, with land use determined on the basis of the CORINE database. The computation of maximal discharges was performed by applying a method that combined synthetic unit hydrograph (maximum ordinate of unit runoff q_{max}) and Soil Conservation Service methodologies (deriving effective rainfall Pe from total precipitation Pb). The computation was performed for AMC III (Antecedent Moisture Conditions III – high content of water in the soil and significantly reduced infiltration capacity). The computations of maximal discharges were done taking into account the regional analysis of lag time, internal daily distribution of precipitation and classification of soil hydrologic groups (for CN – runoff curve number determination). Area sediment yields and the intensity of erosion processes were estimated on the basis of the "Erosion Potential Method".
Results and Conclusions: The selected methodology was performed using different input data related to the DEM resolution. The results were illustrated using cartographic and numerical data. Information on relief conditions is a vital parameter for calculating the elements of the environmental conditions through the elements of maximal discharge, area sediment yields and sediment transport. The higher precision of input data of DEM provides a more precise spatial identification and a quantitative estimation of the endangered sites.

Keywords: torrential floods, erosion, DEM resolution, land use, maximal discharge, area sediment yield, sediment transport

INTRODUCTION

Natural catastrophes lead to the loss of human lives and inflict huge material damage [1], leaving strong environmental and social impacts [2-4]. Torrential (flash) floods are the most common hazard in Serbia, having caused a loss of more than 130 human lives and material damage exceeding 10 billion euros in both urban and rural areas [5] in the period from 1950 to 2014 [6]. This was confirmed when huge parts of Serbia, Bosnia and Herzegovina and Croatia were struck by torrential floods in May 2014.

The torrential (flash) flood represents a sudden appearance of maximal discharge in a torrent bed with a high concentration of sediment. The torrential watershed is a hydrographic entity which involves the bed of the mainstream and its tributaries, and the gravitating surfaces with erosion processes of a certain intensity. The attribute "torrential" refers to any watershed with a sudden appearance of maximal discharge with a high concentration of sediment, regardless of the size and category of the stream [7]. Climate, specific relief characteristics, distinctions of the soil and vegetation cover and social and economic conditions cause the occurrence of torrential floods as one of the consequences of the existing erosion processes.

It is very important to raise public awareness of the threats of flooding and promote a wise use of watersheds [8], combining environmental protection and flood management as factors of similar importance [9]. Destructive erosion processes [10-12] and torrential floods cannot be prevented. However, a better understanding of the processes and scientific methodologies for their prediction can help mitigate their impact [13]. In most cases, torrential floods are caused by natural incidents (such as climatic and morpho-hydrographic particularities of watersheds), but the human factor contributes significantly to the effects of disasters (the mismanagement of forest and agricultural surfaces, uncontrolled urbanization and the absence of erosion control and flood protection structures). Inadequate dimensions of protective structures are commonly the initial cause of their damage or destruction, which significantly increases the intensity of torrential floods. Therefore, hydraulic and hydrological computations should be based on reliable input data (precipitation, land use, hydrographic characteristics and runoff curve number).

Representative examples are the torrential floods in Western Serbia, particularly in the Municipality of Krupanj, covering a territory of 342 km². Local watersheds received a three-day rainfall ranging from 180 to 420 mm, while the absolute daily maximal precipitation amounted to 218 mm. A few settlements were struck by floods on local torrents on May 15th 2014, causing the deaths of two people, almost 900 hectares of flooded arable land or damage by landslides, 333 flooded buildings (of which 40 severely damaged or destroyed), 120 km of destroyed or damaged roads, 14 destroyed and 8 damaged bridges, 5 km of destroyed river regulations and 300 evacuated inhabitants. In addition, 269 landslides were activated during the propagation of heavy precipitation and flood waves. The estimated material damage amounted to over 30 million €. A total of four protected surfaces with areas ranging from 0.03 to 6.73 ha were endangered (three monuments of nature and one nature reserve).

The values of the maximal discharge, area sediment yields and sediment transport, are the basic input data for the design and dimensioning of ETCS (Erosion and Torrent Control Structures) such as check-dams, overflows, regulations, contour ditches and channels, silt-filtering stripes and wattle works. In May 2014, during the torrential floods, numerous river regulations, check-dams, cascades, and culverts did not have a sufficient capacity for maximal discharge and sediment, which caused their obturation, damaging and destruction. A GIS-based flood reconstruction was carried out, with a recalculation of maximal discharges (using data on the maximal daily precipitation in May 2014), area sediment yields and sediment transport. The corrected results of the calculations will be used as the basic input data for ETCS dimensioning, both for the reconstructed structures and the new ones.

This paper presents the results of calculations of the maximal discharge, area sediment yields and sediment transport in the experimental watershed of the Čađavica River, using GIS processing of two digital elevation models (DEMs) with different spatial resolution.

STUDY AREA

The experimental watershed of the Čađavica River is located in Western Serbia, in the Municipality of Krupanj, with the outlet profile in the center of the city (Figure 1). The watershed is built from schists and sandstones, with layers of phyllite and argillaceous schist [14]. The dominant soil is Dystric Cambisol with a light mechanical composition, medium porosity and good aeration [15]. The soil profile is shallow, with good infiltration and poor retention capacity, due to the high percentage of sand.

METHODOLOGY

Spatial analysis was carried out by processing of the DEM of 20 m (hereinafter referred to as DEM_{20}) and 90 m (hereinafter referred to as DEM_{90}) resolutions using software ArcMap 10.3 and its extension 3D Analyst. In addition, analyses concerning watershed and stream network delineation were performed using ArcHydro Tools in Arc Map. DEM_{20} was generated using scanned topographic maps (scale 1:25000) and vectorized isolines as primary spatial elements for the triangulated irregular network (TIN) database creation and later conversion to a 20 m raster resolution. DEM_{90} was derived from Shuttle Radar Topography Mission (SRTM). The land use analysis for DEM_{20} was performed using 2014 orthophoto with a 1 m resolution. The land use analysis for DEM_{90} resolution was performed using the CORINE database [16]. The determination of hydrographic characteristics was performed with the ArcHydro® model [17], which is often used for creating hydrological information systems on the basis of geospatial and temporal information about water resources [18]. ArcHydro® was developed as an extension of ArcGIS software, which is suitable for the delineation of watershed boundaries [17]. DEM is a necessary input data for spatial analysis and could be generated using different techniques such as photogrammetry [19, 20], interferometry [21], laser scanning [22] and topographic surveys [23].

The factors dominating the formation of torrential floods were analyzed, such as natural characteristics (hydrographic characteristics, soil and geological conditions) and human impact (land use structure, the relation between surfaces with low and high water infiltration-retention capacity). Land use analysis was based on the field investigations, orthophoto, the CORINE (COoRdination of INformation on the Environment) database, topographic, geological and soil maps. Land use

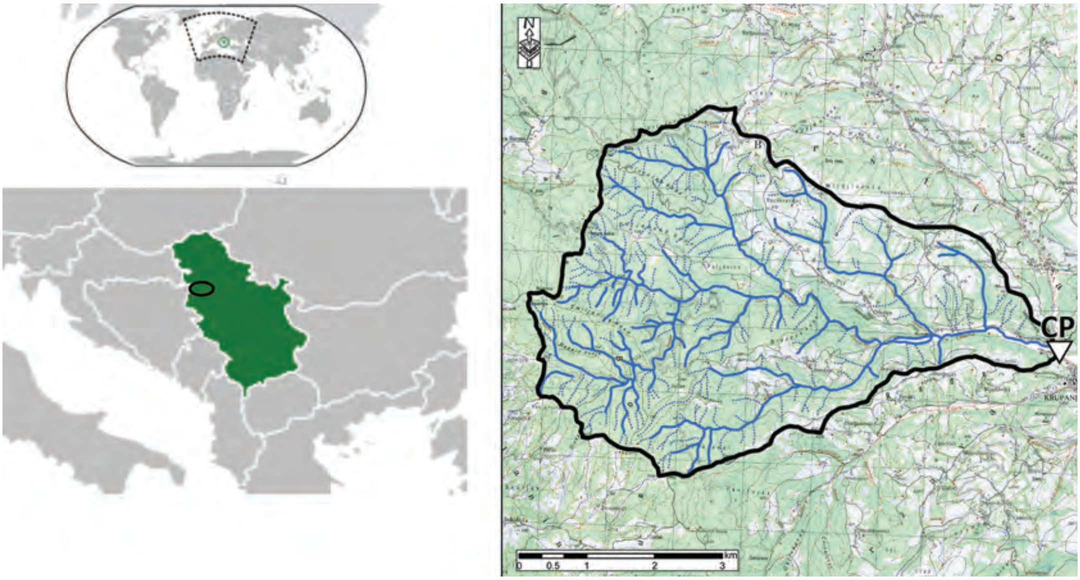

FIGURE 1. Location of the experimental watershed of the Čađavica River.

classification was based of the CORINE methodology [16]. Area sediment yields and the intensity of erosion processes were calculated using the "Erosion Potential Method" (EPM). This method was created, developed and calibrated at the Faculty of Forestry of the University of Belgrade and at The Jaroslav Černi Institute for the Development of Water Resources in Belgrade [24, 25]. The method is still in use in all countries that originate from former Yugoslavia. The application of this method is based on the calculation of the basic parameters: the coefficient of erosion Z, sediment yields and sediment transport:

$$W_a = T \cdot H_{year} \cdot \pi \cdot \sqrt{Z^3} \cdot A \;\; (\mathrm{m^3})$$

T - temperature coefficient,

$$T = \sqrt{\frac{t_{mean}}{10} + 0.1}$$

t_{mean} - average yearly temperature of air (°C)
H_{year} - average yearly precipitation [mm]
π - 3.14159
Z - coefficient of erosion
A - magnitude [km²]

$$W_{asp} = \frac{W_a}{A} \;\; (\mathrm{m^3 \cdot km^{-2} \cdot year^{-1}})$$

$$W_{abls} = W_{at} \cdot \delta \;\; (\mathrm{m^3})$$

R_u - sediment delivery ratio,

$$R_u = \frac{(P \cdot A_{md})^{0.5}}{0.25 \cdot (L + 10)}$$

P - perimeter of the watershed (km)
L - the length of the watershed (km)
A_{md} - medium altitude difference of the watershed (km)

$$W_{atsp} = \frac{W_{at}}{A} \;(\mathrm{m^3 \cdot km^{-2} \cdot year^{-1}})$$

$$W_{abls} = W_{at} \cdot \delta \;\; (\mathrm{m^3 \cdot year^{-1}})$$

δ - content of bed load sediment

$$\delta = \frac{z \cdot (\rho_1 - 1)}{\pi \cdot \rho_2}$$

ρ_1 - mean volume mass of bed load sediment (t·m⁻³)
ρ_2 - mean volume mass of suspended sediment (t·m⁻³)

$$W_{ass} = W_{at} - W_{abls} \;(\mathrm{m^3 \cdot year^{-1}})$$

The method is based on the analytical processing of data on factors affecting erosion. The erosion spatial phenomenon appears on the map according to the classification based on the analytically calculated erosion coefficient (Z), which does not depend on climate, but on soil characteristics, vegetation cover, relief and visible representation of erosion. The coefficient of erosion (Z) is obtained from the following expression [24]:

$$Z = Y \cdot X \cdot a \cdot (\phi + \sqrt{I_m})$$

Y - coefficient of soil resistance to erosion
X·a - the land use coefficient,
ϕ - coefficient of the observed erosion process (takes into consideration clearly visible erosion processes),
I_m - mean slope of terrain

The computations of maximal discharges (for control profile CP, Figure 1) were performed using a method combining the synthetic unit hydrograph (maximum ordinate of unit runoff q_{max}) and Soil Conservation Service

[26] methodologies (deriving effective rainfall Pe from total precipitation Pb). This combined method is the most frequently used procedure for the computation of maximal discharges in unstudied watersheds in Serbia. The computations were performed for AMC III (Antecedent Moisture Conditions III- high content of water in the soil and significantly reduced infiltration capacity). Synthetic triangular unit hydrographs were transformed to synthetic (computed) curvilinear hydrographs using the SCS basic dimensionless hydrograph [27]. The computations of maximal discharges were performed using the regional analysis of lag time [28], the internal daily distribution of precipitation [29] and the classification of soil hydrologic groups for CN-runoff curve number determination [30].

RESULTS

The main hydrographic characteristics of the experimental watershed are presented in Table 1.

Land Use

Land use was determined using DEM_{20} and DEM_{90} with a structure presented in Table 2 and Figure 2.

Erosion and Sediment Transport

The result of the area sediment yields and sediment transport calculations based on using different DEMs resolutions (DEM_{20}, DEM_{90}) are presented in Table 3, as well as the representative values of the coefficient of erosion Z.

W_a – annual yields of erosive material; W_{asp} – specific annual yields of erosive material; W_{at} – annual transport of sediment through the hydrographic network; W_{atsp} – specific annual transport of sediment through the hydrographic network; W_{abls} – annual amount of bed load sediment; W_{ass} – annual amount of suspended sediment.

The spatial distribution of the erosion coefficient Z is presented in Figure 3 (DEM_{20}; DEM_{90}), while the structure of erosion categories is presented in Table 4.

TABLE 1. Main hydrographic characteristics of the Čađavica River watershed.

Parameter	Mark	Unit	DEM_{20}	DEM_{90}
Magnitude	A	km^2	24.10	24.23
Perimeter	P	km	29.92	27.90
Peak point	Pp	m a.s.l.	863.967	869.46
Confluence point	Cp	m a.s.l.	290	288.54
Mean altitude	Am	m a.s.l.	586.32	594.16
Length of the main stream	L	km	10.97	9.84
The distance from the centroid of the watershed to the outlet profile	Lc	km	5.47	5.11
Absolute slope of the river bed	Sa	%	5.23	5.90
Mean slope of the river bed	Sm	%	3.78	4.31
Mean slope of the terrain	Smt	%	33.24	21.14
Density of hydrographic network	D	km·km^{-2}	4.64	4.62

TABLE 2. Land use in the Čađavica River watershed.

Land use	DEM_{20}		DEM_{90}	
	km^2	%	km^2	%
Land principally occupied by agriculture, with significant areas of natural vegetation	2.30	9.53	2.71	11.19
Degraded area	0.01	0.04	/	/
Degraded forests	0.04	0.19	/	/
Complex cultivation patterns	1.50	6.22	1.28	5.30
Broadleaved forest	19.49	80.87	19.82	81.80
Pastures	0.44	1.81	0.28	1.16
Discontinuous urban fabric	0.32	1.35	0.13	0.55
Total	**24.10**	**100.00**	**24.23**	**100.00**

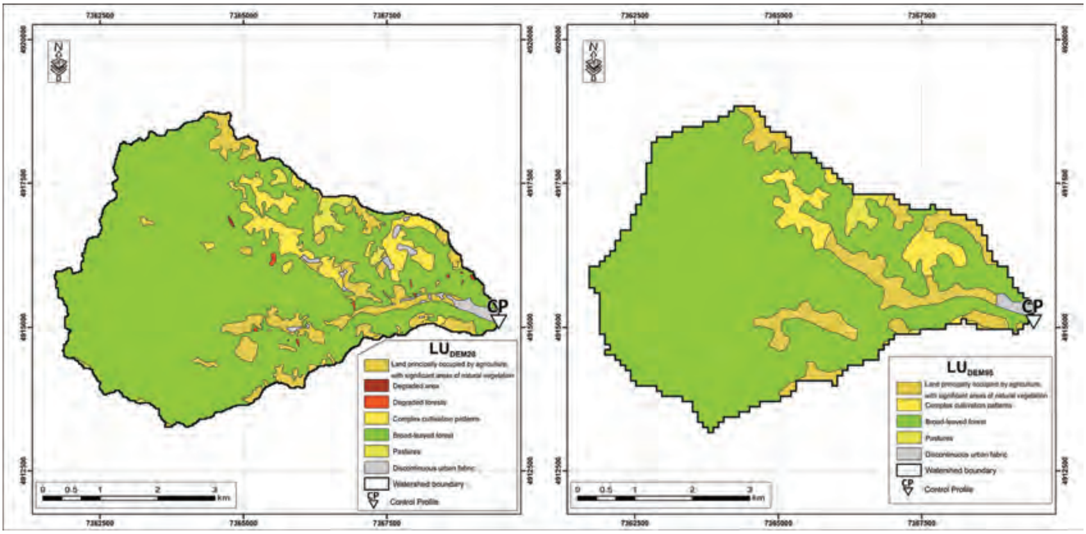

FIGURE 2. Land use (DEM_{20} and DEM_{90})

TABLE 3. Characteristic outputs of computations of sediment yields and transport.

Parameter	DEM_{20}	DEM_{90}
W_a (m^3)	12367.51	9005.05
W_{asp} ($m^3 \cdot km^{-2} \cdot year^{-1}$)	513.17	371.65
W_{at} (m^3)	7049.48	5312.98
W_{atsp} ($m^3 \cdot km^{-2} \cdot year^{-1}$)	292.51	219.27
W_{abls} ($m^3 \cdot year^{-1}$)	695.78	422.91
W_{ass} ($m^3 \cdot year^{-1}$)	6353.7	4890.07
Z	0.31	0.25

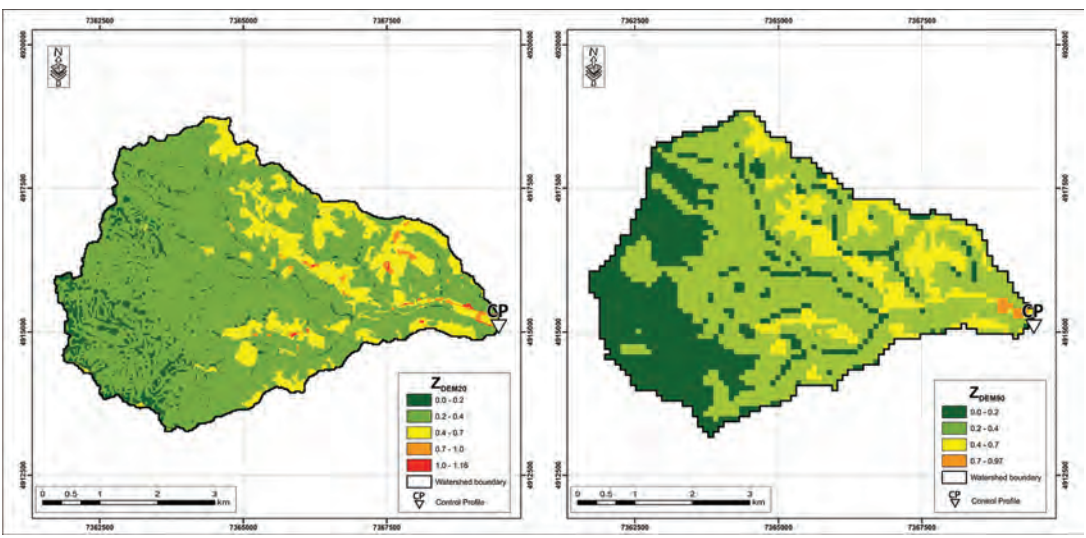

FIGURE 3. Spatial distribution of erosion coefficient Z (DEM_{20} and DEM_{90})

TABLE 4. Structure of erosion categories.

Category	Erosion process intensity	DEM_{20}		DEM_{90}	
		km²	%	km²	%
V	Very weak erosion	1.81	7.50	7.55	31.16
IV	Weak erosion	18.00	74.67	13.17	54.36
III	Medium erosion	4.05	16.79	3.42	14.11
II	Intensive erosion	0.21	0.86	0.09	0.37
I	Excessive erosion	0.04	0.17	/	/
Total		**24.1**	**100.00**	**24.23**	**100.00**

Hydrological Conditions

Maximal discharges ($Q_{max1\%}$) were computed using a combined method based on designed precipitation $Pbr_{24h(1\%)}$=113.8 mm. The hydrographs of maximal discharges ($Q_{maxDEM20\_1\%}$; $Q_{maxDEM90\_1\%}$) are presented in Figure 4. Some characteristic outputs of hydrologic computations are presented in Table 5 (unit runoff q_{max}; CN – runoff curve number; Pbr – total precipitation; Pe – effective rain).

TABLE 5. Structure of erosion categories.

Parameter	DEM_{20}	DEM_{90}
q_{max} ($m^3 \cdot s^{-1} \cdot mm^{-1}$)	1.617	1.672
$Q_{max1\%}$ ($m^3 \cdot s^{-1}$)	75.06	63.84
CN_{sr}III	84	79
$P_{br(24h1\%)}$ (mm)	113.8	113.8
P_e (mm)	46.41	39.07

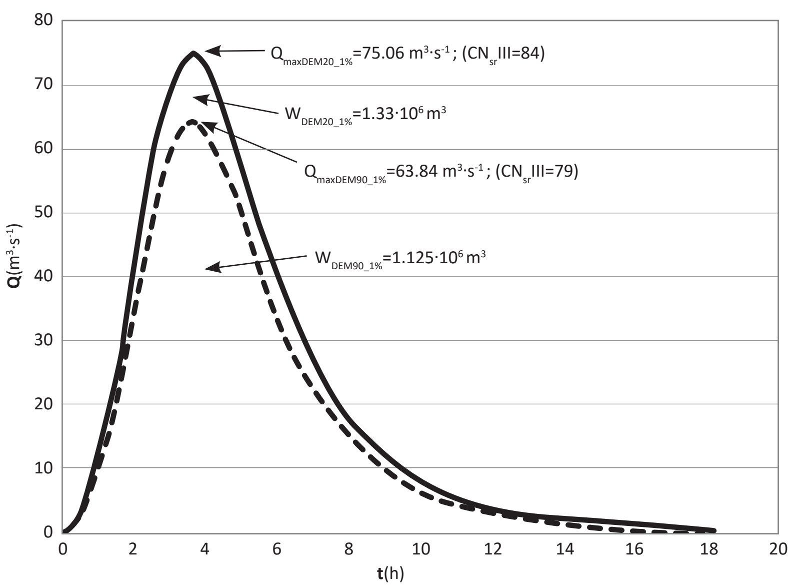

FIGURE 4. Hydrographs of maximal discharge for AMC III (Antecedent Moisture Conditions III - high content of water in the soil and significantly reduced infiltration capacity).

DISCUSSION

Destructive erosion processes and torrential floods endanger the life security of the population and material goods, while they also have environmental and social impacts. Current climate fluctuations (precipitation, air temperature extremes, droughts) associated with anthropogenic impacts (urbanization, forest fires, land degradation) provoke intensive erosion processes and a frequent occurrence of torrential floods.

The experimental watershed of the Čađavica River was analyzed using GIS processing of two DEMs with different spatial resolution (20 m (DEM_{20}) and 90 m (DEM_{90}) resolution), which produced differences in hydrographic characteristics, land use, and the runoff curve number. It also affected the values of maximal discharges, area sediment yields, and sediment transport. Among the hydrographic characteristics, the most expressive one is the difference in Smt (mean slope of terrain): $S_{mtDEM20}$=33.24% and $S_{mtDEM90}$=21.14%. Unlike DEM_{90}, DEM_{20} m recognized some specific land uses such as degraded areas and degraded forests.

The actual state of erosion processes is marked with the representative Z values of Z_{DEM20}=0.31 (dominant weak erosion - deep processes) and Z_{DEM90}=0.25 (dominant weak erosion - mixed surface and deep processes). Consequently, the annual yields of the erosive material amount to W_{aDEM20}=12367.5 m^3 and W_{aDEM90}=9005.1 m^3, with a specific annual transport of sediment through the hydrographic network of $W_{atspDEM20}$=292.5 $m^3 \cdot km^{-2} \cdot year^{-1}$ and $W_{atspDEM90}$=219.3 $m^3 \cdot km^{-2} \cdot year^{-1}$. DEM_{20} registered excessive erosion and larger surfaces under medium and strong erosion than DEM_{90}.

The runoff curve number values CN_{DEM20}=84 and CN_{DEM90}=79 have an impact on the computed maximal discharges $Q_{maxDEM20\_1\%}$=75.06 $m^3 \cdot s^{-1}$ and $Q_{maxDEM90\_1\%}$=63.84 $m^3 \cdot s^{-1}$. In addition to that, the volume of the computed hydrograph of direct runoff $W_{DEM90\_1\%}$=1.125·10^6 m^3 is significantly reduced in comparison to the volume of direct runoff $W_{DEM20\_1\%}$=1.33·10^6 m^3.

A decrease in the DEM resolution (DEM_{90} in comparison to DEM_{20}) leads to a loss of detailed topographic characteristics such as mean altitude, slope steepness and area [31, 32].

Field work was carried out to determine the accuracy of the spatial analysis using different DEMs resolutions (DEM_{20} and DEM_{90}), especially for land use and the erosion map. DEM_{20} m recognized degraded areas and degraded forests, as well as surfaces under excessive erosion processes, which was not possible when DEM_{90} was used. The higher accuracy of DEM_{20} enabled a more precise identification of the zones which were the sources of erosive material production and generation of surface runoff. Consequently, the results of the computations of area sediment yields and transport and maximal discharge on the basis of DEM_{20} were significantly higher. Since they are the basic input data for the dimensioning of ETCS in the torrent bed and on watershed slopes, these higher results caused the design of structures with larger dimensions and higher construction costs, but also an elevated level of security. In addition, DEM_{20} recognized small protected areas (0.03-6.73 ha), which were almost "invisible" when DEM_{90} was used.

CONCLUSION

The values of the maximal discharge, area sediment yields, and sediment transport are the basic input data for the design and dimensioning of protective structures in torrential beds and on watershed slopes. GIS applications and their tools offer an effective spatial analysis of the watershed with a precise determination of hydrographic characteristics, land use, land use changes and runoff curve number, as parameters of great importance for the final values of the maximal discharge, area sediment yields, and sediment transport. This requires a careful approach in accordance with some specific conditions at torrential watersheds, including the steepness of slopes of the terrain and the torrent bed, intensive erosion processes, favorable conditions for fast surface runoff formation and transport of huge quantities of sediment. The usage of nonrepresentative input data produces inadequate results of computations and poor subsequent dimensioning of protective structures. As a result, the insufficient capacity for maximal discharge and sediment leads to obturation, damage, and destruction of these structures. The higher accuracy of DEM enables a more precise identification of the "source" zones of erosive material production and generation of surface runoff. That was confirmed by this investigation, where the usage of DEM_{20} resolution produced a more "realistic" picture of the experimental watershed than the usage of DEM_{90}. The results of computations of area sediment yields and transport and maximal discharge on the basis of DEM_{20} m are significantly higher, which affects the dimensions of ETCS in the torrent bed and on watershed slopes, the costs of their construction and the achieved level of security. In addition to other measures, the reduction of flood risk is based on the construction of effective and well-dimensioned structures, with a capacity that is sufficient for maximal discharge and sediment. An adequate GIS approach can help in the precise evaluation of the factors affecting the generation of destructive erosion processes and torrential floods in order to provide effective erosion control and torrential flood protection in endangered watersheds.

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Surface Accessibility with Spatial Analysis During Fire Extinguishing Procedures: Example on the Island of Vis

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ABSTRACT

Background and Purpose: The existing public and forest transport infrastructure (truck forest roads) are permanent objects used when passing through forests. They also serve as a firefighter belt and provide direct access to firefighting vehicles, or are used as the starting point where firefighting teams extinguish fires or move toward remote fires. The paper identifies the existing fire road network (including public roads, forest roads, non-classified roads and fire roads) for access of firefighting vehicles during fire extinguishing interventions.

Material and Methods: An analysis of the intervention rate was conducted on a dispersive sample (35 positions) from two volunteer fire associations (VFA) on the island of Vis. Also, an analysis of the surface availability to fire vehicles concerning the time of departure from the fire station was conducted, as well as the comparison with the Standard time of intervention defined by the regulations on fire department organization in the Republic of Croatia.

Results: For each simulated fire location for intervention of two existing volunteer fire associations: VFA Komiža and VFA Vis, results show that for a few fire locations, despite a smaller distance from the VFA Komiža, a quicker intervention is possible from the VFA Vis (locations 4, 5 and 14), and vice versa (locations 21, 22 and 25). With the use of a New Service Area, tool intervention times regarding different areas were calculated. Intervention times were divided into intervals: <5 min, 5–10 min, 10–15 min, 15–25 min and >25 min. The last two categories of area are beyond reach for firefighters within the Standard time of intervention (15 min) and together they comprise to 27.88% of the total research area.

Conclusions: The results of Closest Facility tool indicate that for the simulated fire position the best/fastest route is not always the shortest one, because of a significant effect of the structural elements of each road, the state of the road and the longitudinal slope of the road itself. One of the possible approaches to gain access to the area for fire-fighting, as well as to prioritize fire roads regarding maintenance/reconstruction is to improve road conditions, and thus increase the average driving speed.

Keywords: fire road infrastructure, fires, access time, GIS analysis

INTRODUCTION

A forest fire is uncontrollable, destructive movement of fire on the forest surface. It is categorized as a natural disaster and distinguished by type, origin and resulting damage. There are specific needs regarding temperature, pressure and oxygen required for fire, and if one of them is removed, the fire will stop [1]. Forest fires represent a great danger to the forests and forest land in the Republic of Croatia, and are common to the climate in which we live, especially in Dalmatia, Istria, on islands and in Dalmatian Hinterland.

Recently, the danger of forest fires has become extremely high, mostly due to the extensive climate change (long hot summers, warm autumns, strong winds, and long periods with very high temperatures). In Istria and the Croatian Littoral, about 70% of fires emerge in February, March and April, while in Dalmatia most fires occur in July and August. In Croatia, the monitoring and processing of data related to forest fires began in 1955. According to these data, a total of 10,369 fires, or an average of 370 forest fires per year [2] occurred in the period from 1955 to 1984. In the period from 1995 to 2014 in the Republic of Croatia, there were a total of 5,377 fires in forests and other land, and a total of 259,003.17 ha were under fire. In the mentioned twenty-year period, the annual average was 269 fires, with an average annual fire area of 12,950.16 ha [3]. The year 2007 was a record year when 706 forest fires were registered, causing damage to 68,171.00 hectares.

The number of fires in the first half of the year 2017 (or until 15 July) was three times higher than in the year 2016. In the seven coastal counties, there were a total of 642 fires, while in the whole 2016 there were 214 [4]. This area covers 67,397.00 ha.

When we talk about the causes of fires, only about 10% of fires have a known cause, a thunder stroke, while 90% of all fires are a result of accidental or deliberate human action (neglect, burning of agricultural waste, intentional fire, traffic, electricity lines, mines and other) [3]. The emergence of fires in the Dalmatian area is high due to the vegetation cover which consists of coniferous and broadleaved forests, pastures and agricultural land, and due to the neglect of people during agricultural work, soil cleansing and weeding of weeds [5]. A research by Netolicki *et al.* [6] has shown that the anthropogenic influence is considered to be the major factor in the outbreak of fires. High influence also lies in terrain morphology, geological substrate and soil. As Rosavec [7] points out, the higher probability of fires and the amount of burned surface can be determined by the condition of the vegetation and the climate. Martinović [8] points out that in the USA the most considerable damage is caused by forest fires, similar to those in our karst forest ecosystems, and points to the fact that attention should be paid to the pedological conditions of forest fires.

There are two groups of fire protection measures, both preventive and curative. Preventive measures are used to prevent or reduce the possibility of fires, while curative include the process of extinguishing and repairing the burnt area. Exceptional measures of both preventive and curative protection are fire roads. During fires, fire roads serve as a firefighting belt, provide access to firefighting vehicles, emergency vehicles and vehicles for the transportation of personnel and equipment, and can also serve as a place for firefighters to wait for the future fires, as well as places for pre-fire and anti-fire ignitions [9].

In this paper, the analyses are based on the use of firefighting vehicles for firefighting interventions, and the term “intervention” is considered as a movement of a fully qualified vehicle and equipment until the vehicle reaches the endpoint of the fire road. Of course, the intervention can be considered to consist of unified operations from the call itself up to access and shutdown or localisation of the fire.

Since time is the most important factor for reaching a fire, every efficient firefighting system, due to its rapid localisation, requires well-planned intervention, an appropriate risk assessment and management system, comprehensive training, and quick implementation of the above-mentioned steps through an application. Technology with a growing frequency of use in optimising this system is the Geographic Information System (GIS) [10-12]. Every day firefighters are faced with ever-increasing demands for work, so they have been forced to implement state-of-the-art tools, techniques and methods [13]. The imperative of all firefighting interventions is the speed and accuracy of the reaction. In this context, using GIS technologies enables us, thanks to implemented algorithms, to eliminate possible human errors when selecting a route, thus significantly shortening the time of intervention [13]. The most common data layers used by fire departments are streets, parcels, hydrants, public networks, rivers and lakes, business buildings, police and fire stations, schools and hospitals, satellite imagery and previous fire locations [11, 14].

MATERIAL AND METHODS

The main tool for conducting the analysis is the Network Analyst. It is a powerful ArcGIS extension and enables analysis based on topologically accurate traffic data [13]. It is useful in firefighting because it enables: to define the fire department closest to the fire area, estimate the travel time, select a new potential location, find the fastest route, nearest fire station, or define the optimal deployment of the existing fire departments. Three components are important when selecting a faster firefighting intervention: the location of the fire, the location of the fire department and the distance from the unit to the fire location.

The establishing of the database relies on the existing digitalized network of roads and on adding newly established traffic infrastructure (Figure 1), in which all “controversial” road segments are corrected directly on the field and recorded using GPSMAP 62S GPS, brand Garmin. In this paper cartographic background was used which was made in the transverse Mercator projection and by the reference coordinate system HTRS96 (Croatian Terrestrial Coordinate System at epoch 1995.55).

The control time of vehicle arrival at the test sites, i.e. the average travel time of the fire truck on particular road segments, and the trace recording were done by a GPS device mounted on the Mercedes Atego 1528 fire truck. This resulted in average speeds of the vehicle in all the routes used in the analyses, shown in different colours for a certain average driving speed (Figure 2). By calculating the length of each road segment and the required transition time, all the parameters necessary for calculating the fastest possible path to simulated fire positions can be obtained.

Based on such structured data layer, an analysis in Network Analyst can begin. With the aid of this tool, the fastest/closest firefighter unit to the fire position (on a dispersive sample) is defined. The tool also finds the fastest route and estimates the travel time to the site of intervention. Within Network

1 - Dijkstra’s algorithm was designed by Dutch computer scientist Edsger Dijkstra, born in Rotterdam in 1930. In addition to the algorithm for searching the shortest route, Dijsktra was entrusted with computer science and with various algorithms for resource allocation, as well as the implementation of multiple task-based operating systems. The algorithm works on weighted graphs that have only the positive weights on lines. Dijkstra’s algorithm is defined as a group of algorithms having one initial node, which means that the algorithm for each node in the graph will find the shortest path relative to the parent node [16].

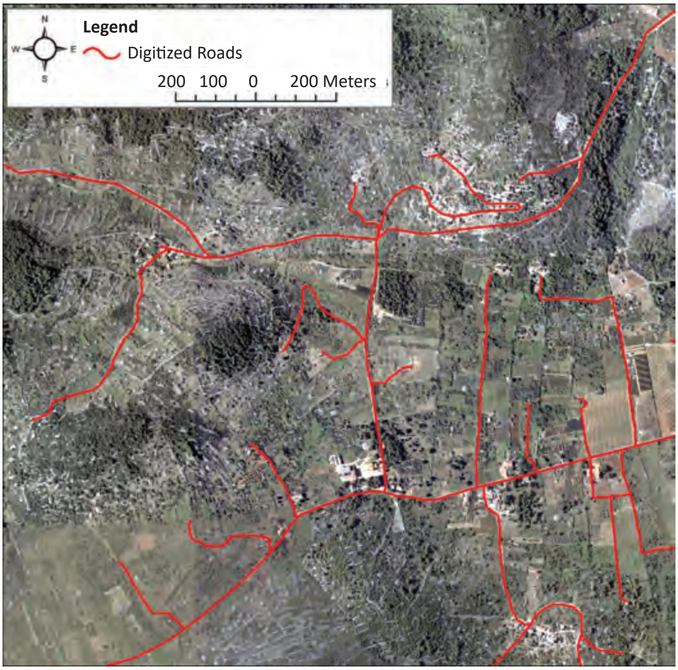

FIGURE 1. The method of digitizing a network of trafficable roads on digital orthophoto (DOP).

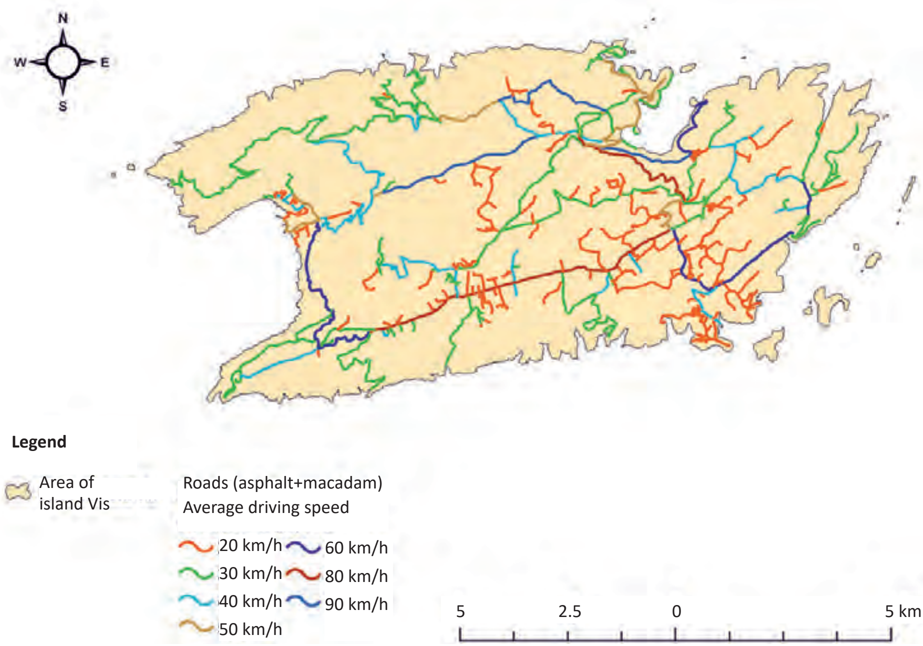

FIGURE 2. Transport infrastructure network with average driving speed.

Analyst tools, Closest Facility tool is used, which is based on Dijkstra's algorithm[1] or shortest path algorithm. The algorithm breaks the network into nodes, and the routes that link them are visualised by the vector line data with the attribute values. Additionally, each line between two nodes has a related value (cost or distance) that needs to be overcome in order to reach the destination node or point [15]. An important factor when choosing a route is not only speed but also traffic conditions on the road network, which in this case are the average driving speeds on certain road segments.

The model created for this research within Network Analyst tools, a tool entitled New Service Area was used. This tool gives us an output polygon that shows the area of a given firefighting station's intervention period through time aspect and distance. Also, tools such as Select, Clip, Merge, and Erase have also been used to calculate the availability of different surface areas at a certain time.

The aim of the analysis is to identify the location that covers the largest area and that makes responding to fires in standard intervention time possible. Standard intervention time is defined as the standard time set by the regulations on fire department organization in the Republic of Croatia, in which Article 19 states: "The distribution of fire brigade units on the territory of the Republic of Croatia should be such that the arrival of the fire brigade to intervene to the furthest place of the protected area is set to a fifteen-minute limit.".

Research Area

Forest administration (FA) office Split is one of the 16 administrations included within the Croatian Forests Ltd company. This FA manages forests between the Pag Bridge and Prevlaka, on the territory of four counties: Zadar, Šibenik-Knin, Split-Dalmatia and Dubrovnik-Neretva. The total area covered by the FA is 563,804.38 ha, which is also the largest area covered by one administration office. Out of the total forest areas covered by this management, 444,175.16 ha are covered forest areas, 105,825.20 ha are uncovered forest areas and 13,804.02 ha are barren forest areas [17].

FA Split includes 986 islands, five nature parks and four national parks. In the coastal area, FA Split manages species

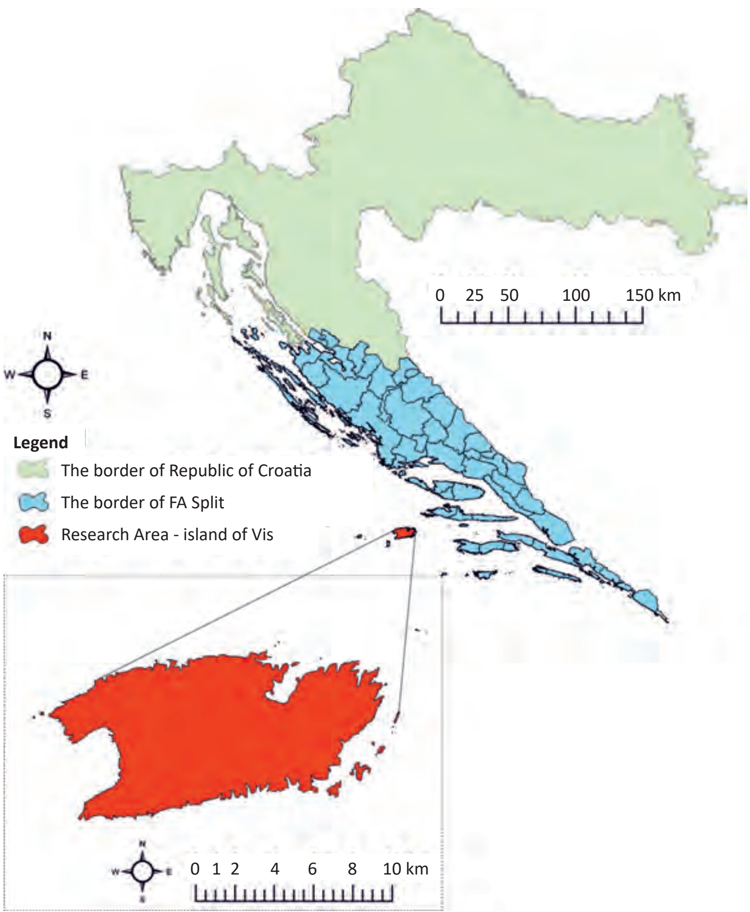

FIGURE 3. Research area – the island of Vis.

preservation, forest protection, planting and other activities. With the rise of summer heat, the fear of possible upcoming fires grows, since fires are the greatest enemies of forest land. In the karst area, the greatest threat to forests are forests fires, so a lot of money is invested in the preventive protection of forests. Anti-fire prevention measures include the organisation of observatory firefighting service, the construction and maintenance of observation posts, the construction and maintenance of forest fire roads, the placing of warning signs and the preservation of forests. A big problem is that volunteer fire associations on the Adriatic islands and coastal areas have lately been in great trouble, quite often at the border of existence. The reason for this is primarily that a small number of young people are included in the associations, and that there is a growing lack of interest, insufficient equipment, obsolete equipment, and inability to acquire new equipment [5].

The island of Vis has been selected for research for a number of reasons, primarily due to the existence of two active voluntary firefighter associations, the existence of a large number of different road categories and their conditions (level of damage) with a total of 208.50 km in length, great distance of the island from the mainland (about 45 km), and the fact that it is wholly unavailable for quick firefighting interventions from the air, so all fire protection and intervention depend on the existing roads.

The surface of the island is 90.3 km^2, the total length of the indented and quite inaccessible coast is 77 km. The island of Vis, according to the WGS84 geographic projection, is located between 16°02’22’’E 43°00’13’’N and 16°16’13’E 43°04’53’’N.

RESULTS

The tools used in this research enabled us to create a supplemented road cadastre that was the input for all the necessary analysis foreseen in this research. The total length of roads that can be used in firefighting interventions is 208.50 kilometres, and the existing roads are divided into 552 segments of the researched road network with assigned average vehicle driving speeds. The road network designated for firefighting interventions is divided into segments defined by nodes (intersection points), i.e. intersections and road endings that according to the tool use and represent a mandatory intercept.

By simulation/random selection, 35 points have been set in the entire research area that represents areas of eventual fire (Figure 4). The points were determined by order of 1 to 35, and a dispersed pattern was set. This analysis would point out that the closest route is not always the shortest one during the intervention due to different conditions of the roadway. The tool has proved to be efficient for making sensible objective decisions in the logistics of the fire extinguishing system.

To confirm a dispersive pattern of the simulated fires, a statistical analysis was carried out using the Average Network Neighbor tool. Given the value of Nearest Neighbor Ratio of 1.532692, a p-value of 0.000000 and a z-score of 6.028936, there is a less than 1% likelihood that this dispersed pattern could be the result of random chance, proving the dispersed layout of the locations (Figure 5).

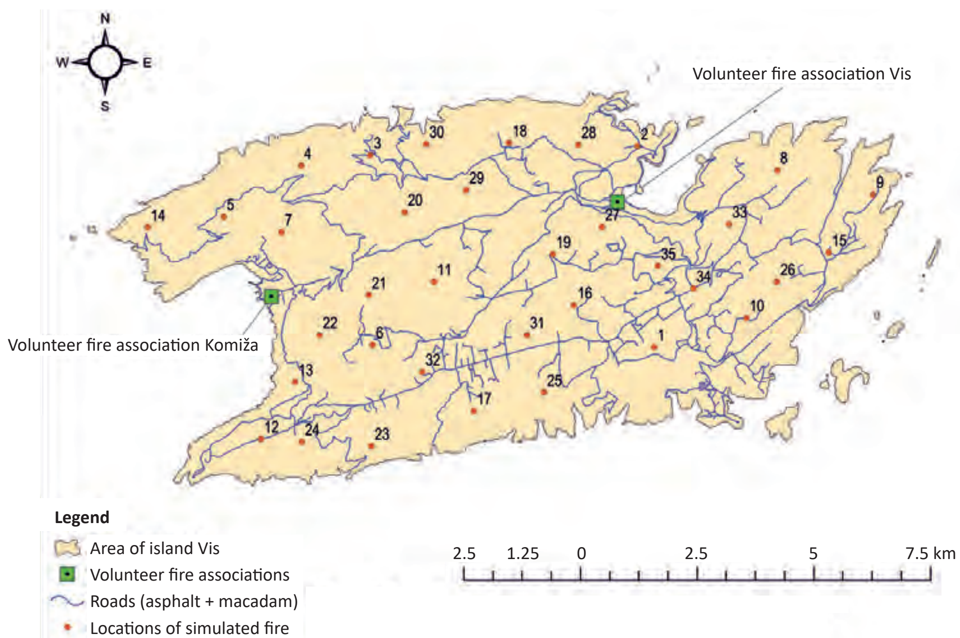

FIGURE 4. Spatial positions of simulated fires.

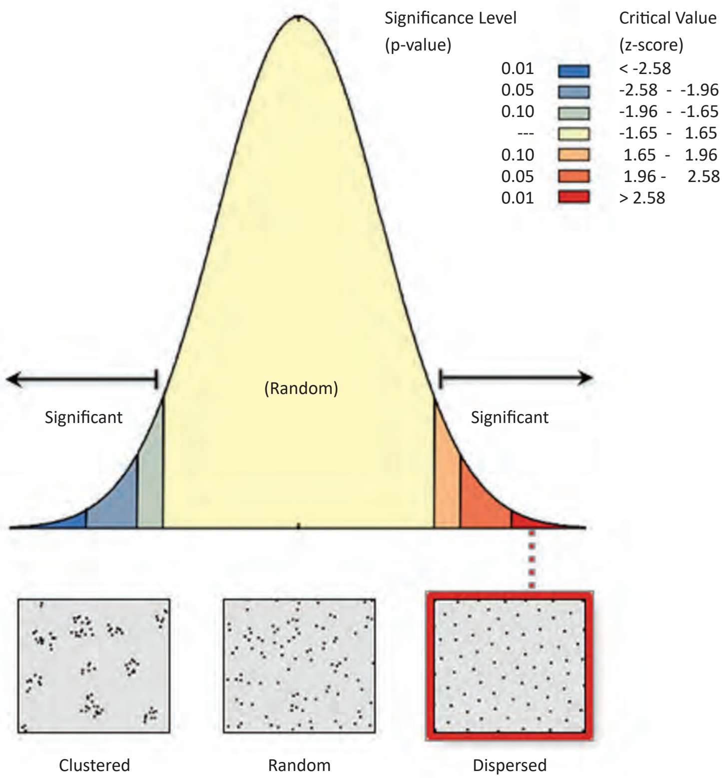

FIGURE 5. The results of testing the selected locations using the Average Network Neighbor tool.

For each simulated fire location, an analysis was conducted regarding the required time and length of the access route for intervention along with the two locations of existing volunteer fire associations: VFA Komiža and VFA Vis (Table 1). Time was displayed in minutes and distance in kilometres. The results show that for a few fire locations, despite a smaller distance from the VFA Komiža, a quicker intervention is possible from the VFA Vis (locations 4, 5 and 14), and vice versa (locations 21, 22 and 25). The reason for this is terrain configuration and the degree of road damages, which cause a decrease in the average driving speed of firefighter trucks on certain road segments, and therefore it takes longer for the firefighters to arrive at the intervention site.

With the use of a New Service Area, tool intervention times regarding different areas were calculated. Intervention times were divided into intervals: <5 min, 5–10 min, 10–15 min, 15–25 min and >25 min, so that it is possible to differentiate areas accessible within the standard time of 15 minutes. The last two categories (15–25 min and >25 min) shown in Figure 6 are beyond reach for firefighters within the standard time and together they comprise to 2,530.62 ha which is 27.88% of the total research area.

Areas accessible at different time intervals were calculated for each of the volunteer fire associations separately to determine the area coverage of a particular firefighter unit. The results show that areas accessible to firefighters within 5 minutes significantly differ between these two volunteer fire associations. The area accessible within 5 minutes to VFA Vis is twice the size of the area accessible to VFA Komiža in the given period.

This difference increases in favor of VFA Vis by increasing the time of intervention and within the standard time where almost ¾ of the areas' coverage/accessibility is in favor of VFA Vis, as opposed to the ¼ surface accessibility of VFA Komiža (Figure 7). It is also noticeable that after a time interval of 15 minutes, area coverage of VFA Vis enlarges, while of VFA Komiža it slightly decreases. Namely, during a time of intervention of more than 15 minutes, more rapid interventions are those of VFA Vis, regardless of the greater geometric distance in the case of VFA Komiža, all due to better linkage and driving speed from the direction of VFA Vis.

DISCUSSION AND CONCLUSIONS

The only efficient way to minimize damages caused by forest fires is the early detection of forest fires and fast and appropriate reaction, apart from applying preventive measures. Considerable efforts are therefore made to achieve early forest fire detection, which is traditionally

TABLE 1. Intervention time and route distance for the simulated fire positions.

Number of fire intervention	Position of the location in WGS84 projection (decimal degrees)		Volunteer fire association Vis		Volunteer fire association Komiža	
	X coordinate	Y coordinate	Total time (min)	Total length (km)	Total time (min)	Total length (km)
1	16.19263726140	43.03225211140	12.55	10.67	14.15	13.14
2	16.18816226600	43.07100964020	3.59	2.83	14.45	12.37
3	16.11783006590	43.06902742350	9.75	8.05	16.12	12.89
4	16.09959125940	43.06689427460	12.20	10.19	12.25	8.01
5	16.07923187950	43.05708273680	16.89	12.53	16.93	10.35
6	16.11864021660	43.03245320820	14.76	8.42	12.24	11.15
7	16.09449014900	43.05408142500	13.01	11.04	2.74	1.98
8	16.22491325090	43.06647735340	9.72	7.58	18.79	15.93
9	16.25015627980	43.06177388930	15.46	11.04	23.94	22.75
10	16.21694230240	43.03798073610	11.78	9.40	19.18	18.30
11	16.13465577380	43.04468646290	9.86	5.62	13.66	8.57
12	16.08933359600	43.01415857270	16.02	17.57	5.75	5.23
13	16.09826107950	43.02517752550	13.61	12.26	3.14	3.04
14	16.05923093460	43.05484236750	23.88	16.03	23.92	13.85
15	16.23849347470	43.05062981980	12.06	9.34	20.53	21.04
16	16.17159291420	43.04031236580	12.33	10.52	13.90	12.94
17	16.14529954660	43.01985695470	13.36	13.68	9.88	9.37
18	16.15433494290	43.07153270000	4.74	4.54	11.60	10.11
19	16.16593334520	43.05008805760	10.99	8.03	15.77	12.32
20	16.12691215820	43.05805362280	8.04	7.23	14.41	12.07
21	16.11754499210	43.04201914320	17.12	9.74	14.61	12.47
22	16.10457296290	43.03430003040	17.19	9.52	14.67	12.25
23	16.11842325340	43.01285691380	19.64	18.40	12.45	9.15
24	16.10005706530	43.01364699300	15.41	16.97	5.14	4.63
25	16.16368732350	43.02340283510	12.38	11.44	12.31	11.69
26	16.22496042720	43.04488603610	12.64	9.95	20.64	21.17
27	16.17886306120	43.05534043610	1.89	1.71	10.95	10.06
28	16.17249910410	43.07118406270	2.86	2.36	12.38	11.92
29	16.14300495990	43.06239753250	5.24	5.39	11.61	10.24
30	16.13248492740	43.07123310960	9.65	7.99	16.02	12.84
31	16.15920936090	43.03447576190	10.16	11.09	9.13	10.06
32	16.13171257660	43.02723197390	12.69	13.60	8.33	8.12
33	16.21235163320	43.05594117490	7.72	6.45	16.79	14.80
34	16.20291042160	43.04355160250	6.07	5.26	14.15	15.45
35	16.19355270360	43.04787625460	7.30	6.04	16.37	14.39

based on human surveillance [18]. Therefore, it is crucial to determine the optimum route that minimizes the travel time of the initial response team from fire headquarters to fire areas using firefighting trucks [19]. It is essential to pay close attention to a well-developed road network that allows access to fires on islands that are far off the mainland and where rapid air intervention is not possible, especially in the summer months when these areas have a high risk of fire due to long dry periods without rainfall and highly flammable plant species.

To maximize the existing traffic infrastructure for firefighting, it is important to determine the state of the road, its trafficability and the possible driving speed of firefighting vehicles. With the knowledge of all these details and GIS, it is possible to find the best and the fastest solution for individual firefighting interventions. Firefighting units have several GIS tools available for the analysis of intervention speed, which, as shown in this paper, can be categorised within the Network Analyst tools. It is also possible to conduct other analysis such as complex modelling of various hazard indexes, the

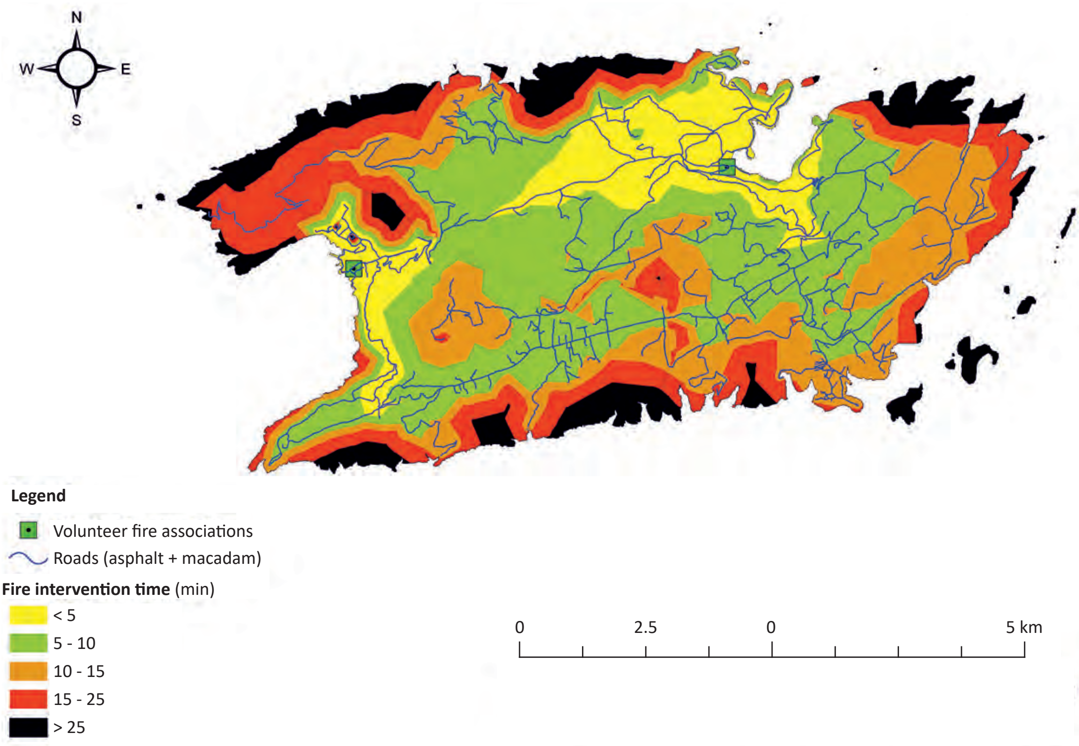

FIGURE 6. Firefighters' access within different time intervals.

degree of fire risk, fire susceptibility, topography and weather conditions, simpler visibility analysis, selection of optimal location of fire lookout towers and fire stations, determination of intervention location, etc. [13].

The results obtained with the Closest Facility tool indicate that for the simulated fire position the best/fastest route is not always the shortest one, because of a significant effect of the structural elements of each road, the state of the road and the longitudinal slope of the road itself. In addition to the variables used in this paper (average driving speed and road length), it is possible to define obstacles and constraints that block or hinder traffic on certain road segments [20]. For analysis of obstacles and changes in road conditions, it is necessary to carry out real-time analysis whereby the previously formed databases would obtain current road conditions, which would result in a change of intervention route [21, 22].

The New Service Area tool showed that approximately ¼ of the island's surface is unavailable to firefighters within a 15-minute standard time. The cartographic presentation gives us guidelines for reconstruction or maintenance of the existing roads, and thus a total increase in the average driving speed of firefighting vehicles would be possible. The areas shown in Figure 5 are a good indicator of areas where new roads need to be built to shorten the drive, all for comprehensive protection and possible interventions in the entire research area.

An important indicator of the conducted analysis is that much larger surface area is available to the VFA Vis within the standard time (Figure 7), because there are higher road categories in the vicinity of the city of Vis where the VFA is located, which then allows faster movement of firefighters due to improved traffic conditions and two traffic lanes.

The density of roads suitable for firefighting interventions is 23 m·ha^{-1}. The established road density was shown to be insufficient, which prevents timely intervention on all the areas covered by this research. This is also contributed by the poor state of the upper rod layer on a large number of roads, which decreases the driving speed on both asphalt and macadam roads. One of the important problems identified is the position of volunteer fire associations located in the coastal part of the island in the centre of the cities of Vis and Komiža.

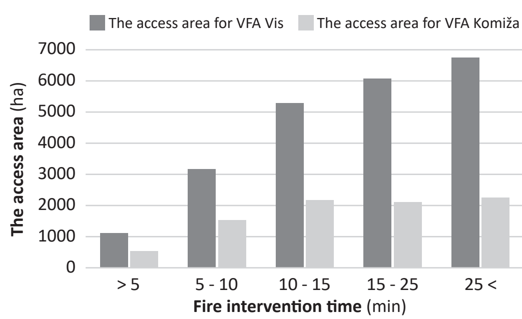

FIGURE 7. Firefighters' access within different time intervals for a particular volunteer fire association.

They are not placed in ideal positions regarding road layout, terrain configuration and island indentation. This case shows the need to set up new firefighting stations or to seasonally displace them for better efficiency and better protection [23].

Taking into account all the given results in this paper, the time of intervention can be reduced by appropriate planning and realization of the proposed measures. The existing network of roads needs to be improved in qualitative and quantitative terms, and the available VFAs should be brought closer to possible interventions. This research has also shown the need to redefine the existing knowledge of the optimal density of roads in the island karst area because in the case of a fire the time of approach determines the success of the entire intervention system. It is not possible to propose a final solution by this research, but many questions arise that open the way for new research, oriented towards conscious and rational surface management where there is an obvious high risk of fire.

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The Evaluation of Photogrammetry-Based DSM from Low-Cost UAV by LiDAR-Based DSM

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ABSTRACT

Background and Purpose: Unmanned aerial vehicles (UAVs) are flexible to solve various surveying tasks which make them useful in many disciplines, including forestry. The main goal of this research is to evaluate the quality of photogrammetry-based digital surface model (DSM) from low-cost UAV's images collected in non-optimal weather (windy and cloudy weather) and environmental (inaccessibility for regular spatial distribution of ground control points - GCPs) conditions.
Materials and Methods: The UAV-based DSMs without (DSM_P) and with using GCPs (DSM_{P-GCP}) were generated. The vertical agreement assessment of the UAV-based DSMs was conducted by comparing elevations of 60 checkpoints of a regular 100 m sampling grid obtained from LiDAR-based DSM (DSM_L) with the elevations of planimetrically corresponding points obtained from DSM_P and DSM_{P-GCP}. Due to the non-normal distribution of residuals (vertical differences between UAV- and LiDAR-based DSMs), a vertical agreement was assessed by using robust measures: median, normalised median absolute deviation (NMAD), 68.3% quantile and 95% quantile.
Results: As expected, DSM_{P-GCP} shows higher accuracy, i.e. higher vertical agreement with DSM_L than DSM_P. The median, NMAD, 68.3% quantile, 95% quantile and RMSE* (without outliers) values for DSM_P are 2.23 m, 3.22 m, 4.34 m, 15.04 m and 5.10 m, respectively, whereas for DSM_{P-GCP} amount to -1.33 m, 2.77 m, 0.11 m, 8.15 m and 3.54 m, respectively.
Conclusions: The obtained results confirmed great potential of images obtained by low-cost UAV for forestry applications, even if they are surveyed in non-optimal weather and environmental conditions. This could be of importance for cases when urgent UAV surveys are needed (e.g. detection and estimation of forest damage) which do not allow careful and longer survey planning. The vertical agreement assessment of UAV-based DSMs with LiDAR-based DSM confirmed the importance of GCPs for image orientation and DSM generation. Namely, a considerable improvement in vertical accuracy of UAV-based DSMs was observed when GCPs were used.

Keywords: stereo photogrammetry, unmanned aerial vehicle (UAV), digital surface model (DSM), Structure from Motion (SfM), light detection and ranging (LiDAR), vertical agreement assessment, forest inventory

INTRODUCTION

Today we are witnessing the growing use of unmanned aerial vehicles (UAVs) for monitoring purposes. Potential applications of UAVs can be found in agricultural, forestry, and environmental sciences; surveillance, and reconnaissance; aerial monitoring in engineering; cultural heritage; and traditional surveying, conventional mapping and photogrammetry, and cadastral applications [1]. Due to various construction solutions UAVs are flexibile to solve various surveying tasks. Compared to the classical terrestrial survey, UAVs are capable to cover considerably larger areas in short time period, as well as to survey distant or inaccessible areas (e.g. distant forest and mined areas) and objects (e.g. high buildings). The flexibility of photogrammetric surveying methods along with the selection of the adequate cameras and lenses results in adaption of the measuring platform (UAV) to the needs of the tasks. Furthermore, UAVs have a capability of an autonomous recording, and hence they are becoming independent devices for gathering a large number of high-quality data of the field or object with appropriate accuracy.

Recently, comprehensive reviews on applications of UAVs in forestry have been provided by Tang and Shao [2] and Torresan *et al.* [3]. In general, the common UAVs applications in forestry are related to monitoring of forest health and disturbances [4-6], forest inventory [7, 8], forest cover mapping [9], etc. Digital surface model (DSM), which is one of the main photogrammetric products of UAV surveys, has great application in forest inventory. By subtracting available digital terrain model (DTM), which presents terrain surface, from DSM, which presents forest surface, a canopy height model (CHM) is generated. DTMs are nowadays commonly generated using airborne laser scanning (ALS) technology based on light detection and ranging (LiDAR) or airborne digital photogrammetry [10]. From CHMs various metrics can be derived which are then used for estimation of various tree [11] and stand variables [7, 12]. The Structure from Motion (SfM) algorithm has been suggested for DSM generation by many authors [13-15]. Camera calibration and image phototriangulation process are initially performed to generate accurate DSM or digital terrain model (DTM) [16]. Camera calibration method and the algorithm for the precise elimination of lens distortion on digital cameras was developed by Gašparović and Gajski [17]. Continuing the research Gašparović and Gajski [18] presented a new method of two-step camera calibration for micro UAVs.

Methods for producing photogrammetric DSMs without using ground control points (GCPs) were presented in several studies [19-21]. To obtain external orientation parameters, Chikhradze [19] used single-frequency Global Navigation Satellite Systems (GNSS) receivers, while Vander *et al.* [20] and Fazeli *et al.* [21] used dual-frequency differential GNSS. Furthermore, Gimbal influence on the stability of exterior orientation parameters of UAV images was examined in study by Gašparović and Jurjević [22].

The DSMs generated from airborne digital stereo images were evaluated in many studies [e.g. 23-25] which revealed that many factors may influence on their quality, especially in complex forest structure. The research on DSM quality obtained from UAV images are still lacking (especially in South-east European region), but it can be assumed that apart from technical characteristics related to UAV (e.g. camera quality, GNSS precision) similar factors (e.g. image quality, algorithm for image processing, weather conditions, forest structure, etc.) are present.

The main goal of this research is to evaluate the quality of photogrammetry-based DSM from low-cost UAV's images collected in non-optimal weather (windy and cloudy weather) and environmental (inaccessibility for regular spatial distribution of GCPs) conditions. Namely, urgent cases (e.g. detection and estimation of forest damage) sometimes require rapid and immediate reaction when data acquisitions have to be done in non-optimal weather conditions during the survey. Furthermore, in dense forests it is very difficult to find a place for GCPs, especially to obtain the regular spatial distribution of GCPs which will provide the most accurate orientation of images. Therefore, vertical agreement assessment of UAV-based DSMs generated without and with using GCPs was evaluated with LiDAR-based DSM in this study.

MATERIALS AND METHODS

Study Area

The research was conducted in the lowland forest complex of Pokupsko Basin located 35 km southwest of Zagreb, Central Croatia (Figure 1). The study area (77.39 ha) encompasses two 45-year-old mixed forest stands (subcompartments 36a and 37a, management unit "Jastrebarski lugovi") dominated by pedunculate oak (*Quercus robur* L.) accompanied by black alder (*Alnus glutinosa* (L.) Geartn.), common hornbeam (*Carpinus betulus* L.), and narrow-leaved ash (*Fraxinus angustifolia*

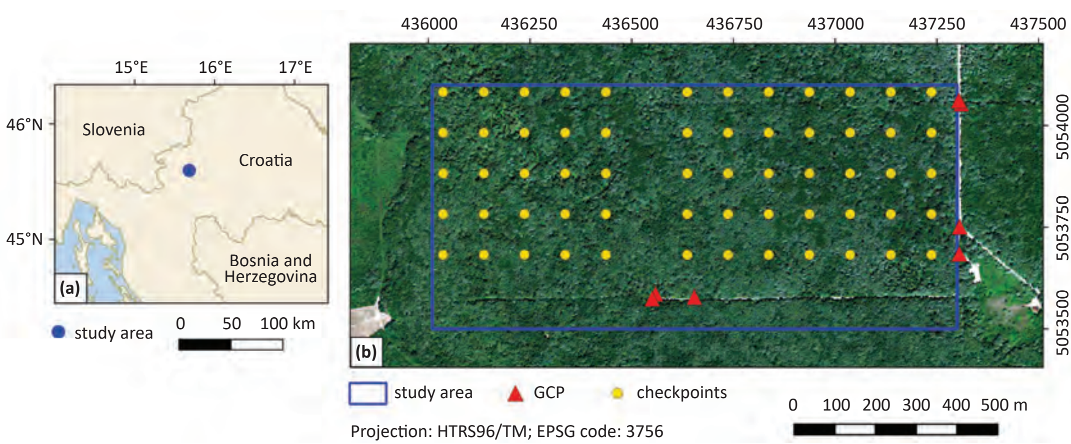

FIGURE 1. (a) Location of the study area; **(b)** Study area with 7 GCPs and 60 checkpoints of the regular 100 m sampling grid (background: satellite image WorldView-3, "true colour" composite (5-3-2), sensing date: 12 June 2017).

Vahl.), and with the *Corylus avellana* L. and *Crataegus monogyna* Jacq. in the understorey. The study area is flat, with ground elevations ranging from 108 to 113 m a.s.l.

UAV-Based Canopy Digital Surface Models

The UAV images were acquired using the DJI Phantom 4 Pro UAV with FC6310 camera (Table 1) on 14 September 2017. The average flying height was 200 m above ground level. The study area was covered by 488 RGB images with the ground sampling distance (GSD) of approximately 5 cm. The images were collected in 11 flight lines with endlap of 90% and sidelap of 80%. Weather conditions during UAV survey were not suitable (non-optimal) due to windy and cloudy weather.

TABLE 1. Characteristics of FC6310 camera.

Digital camera	FC6310
Sensor type	CMOS
Sensor size (mm)	13.2 × 8.8
Pixels size on the sensor (µm)	2.4
Number of pixels (million)	20
Sensor sensitivity	ISO 100 – 12800
Max. aperture	F2.8
Field of view (°)	84
Image size (pixels)	5472 × 3078
Focal length (mm)	8.8

Before the UAV survey, seven ground control points (GCPs) were placed and measured in the study area (Figure 1). The GCPs' positions (x, y, z coordinates) were measured using the Trimble GNSS receiver connected with the Croatian Positioning System (CROPOS) which enables to obtain both horizontal and vertical positional accuracy from 2 to 5 cm (CROPOS - Users' Manual). Due to dense forest and mostly invisible ground from the air, it was not possible to provide (set up) the regular spatial distribution of GCPs over the entire study area which enables the most accurate orientation of images [26]. Therefore, GCPs were set up and measured on the forest roads from where they can be easily detected on UAV images (Figure 1).

From the collected UAV images, two DSMs were generated. First DSM was generated without using GCPs. This means that DSM was generated from UAV images whose orientation was based on *a priori* exterior orientation parameters (EOPs) only. *A priori* EOPs were measured during flight in metadata files of each image by GNSS. Firstly, tie-points on all images were automatically determined using the Structure from Motion (SfM) algorithm. Image coordinates of tie-points and *a priori* EOPs were then used for photo-triangulation with self-calibration. By automatic correlation of oriented images, the point cloud was obtained and then used to generate raster DSM (hereinafter referred to as DSM_P) with a spatial resolution of 0.5 m.

To generate the second DSM, the classic image photo-triangulation method based on tie-points and GCPs was used. Tie-points on all images, as in the previous case, were automatically determined using SfM algorithm. Photo-triangulation with self-calibration was based on image coordinates of tie-points and GCPs, and GCPs' coordinates in the terrestrial coordinate system. *A priori* EOPs were not used in this case. A raster DSM (hereinafter referred to as $DSM_{P\text{-}GCP}$) with a spatial resolution of 0.5 m was generated from the point cloud obtained by automatic correlation of oriented images.

The whole procedure of image orientation and DSMs generation was performed using Agisoft PhotoScan software (version 1.2.6, 64 bit).

LiDAR-Based Canopy Digital Surface Model

A raster LiDAR-based DSM (hereinafter referred to as DSM_L) with a spatial resolution of 0.5 m was provided by Hrvatske vode Ltd. (Zagreb, Croatia). Table 2 provides an overview of LiDAR sensor and data characteristics used for DSM_L generation. The resulting point densities (11.59 points·m^{-2}) and the stated horizontal (0.15 m) and vertical (0.08 m) accuracies were based on a considerably larger area (which included and non-forested areas as well) than the one considered in this study. DSM_L was generated from returns classified as "first return" and "only return". DSM_L was used as reference data for vertical agreement assessment of UAV-based DSMs (DSM_P and $DSM_{P\text{-}GCP}$). Due to its high accuracy, the LiDAR data were often used as reference data for evaluation of UAV data [27-29].

TABLE 2. LiDAR sensor and data characteristics.

Parameter	Technical specification
Platform	Pilatus P6 aircraft
Sensor	Optech ALTM Gemini 167
Flying period	29 June - 25 August 2016
Flying height above ground level (m)	720
Flying speed (m·s^{-1})	51
Pulse repetition frequency (kHz)	125
Scan frequency (Hz)	40
Field of view (°)	±25
Swath width (m)	671
Max No. of returns per pulse	4
Point density (points·m^{-2})	11.59
Horizontal accuracy (m)	0.15
Vertical accuracy (m)	0.08

Vertical Agreement Assessment

The vertical agreement assessment of the UAV-based DSMs was conducted by comparing elevations of 60 checkpoints of a regular 100 m grid obtained from DSM_L with the elevations of planimetrically corresponding points obtained from DSM_P and $DSM_{P\text{-}GCP}$. Prior to defining measures for agreement assessment, the normality of residuals (vertical errors between UAV- and LiDAR-based DSMs) distribution was analyzed using: (a) histograms with a superimposed curve indicating normal distribution, (b) Shapiro-Wilk test [30, 31], and (c) normal Q-Q plots (Figure 2). All performed tests revealed non-normal distribution of vertical errors for both UAV-based DSMs. Consequently, the following robust measures suggested by Höhle and Höhle [10] were used for vertical agreement assessment: median, normalised median absolute deviation (NMAD), 68.3% quantile and 95% quantile. Additionally, root mean square errors before (RMSE) and after removing outliers (RMSE*) were calculated. The equations for all measures, as well as for the threshold for outliers can be found in Höhle and Höhle [10]. The statistical analyses were performed using the STATISTICA software (version 11) [32] and R programming language (version 3.3.3) [33].

To support statistical analyses, the visual assessment of UAV- and LiDAR-based DSMs, as well as the visual assessment of difference raster models was performed. Difference raster models were generated by subtracting LiDAR-based from UAV-based DSMs. Both, difference raster model generation and its visualization were conducted using Global Mapper (version 19) [34] and QGIS (version 2.18) [35] software.

RESULTS AND DISCUSSION

According to the described methods, DSM_P (Figure 3a) and $DSM_{P\text{-}GCP}$ (Figure 3b) were generated. Detailed information on DSMs processing is presented in Table 3. It can be seen that computer processing time for both DSMs is almost the same, whereas the time spent on manual work is considerably greater for $DSM_{P\text{-}GCP}$ generation (30 min) than for DSM_P generation (10 min). Namely, during the $DSM_{P\text{-}GCP}$ generation, most of the time (≈20 min) was spent on the manual detection of the GCPs on images, while for the DSM_P generation the UAV images were orientated without using GCPs.

The results of the vertical agreement assessment of the UAV-based DSMs (DSM_P and $DSM_{P\text{-}GCP}$) with DSM_L conducted on 60 checkpoints of the regular 100 m sample grid are shown in Table 4. When comparing UAV-based DSMs with DSM_L, it is necessary to have in mind that between the acquisition of LiDAR and UAV data is a time gap of one year which corresponds with one vegetation and subsequently with annual height increment. According to the internal database (unpublished material) of Croatian Forest Research Institute, annual height increment for the forest of the study area ranges from 0.2 m to 0.45 m depending on tree species. As expected, $DSM_{P\text{-}GCP}$ shows higher accuracy, i.e. higher vertical agreement with DSM_L than DSM_P. Namely, the horizontal accuracy ($RMSE_{XY}$) of DSM_P assessed with 7 GCPs (which were not used in its generation) is 5.67 m (Table 3). Since such horizontal errors may produce greater vertical errors [36], especially for surfaces with great variations in height on a small area (e.g. forest) [25, 37], the lower vertical agreement of DSM_P with

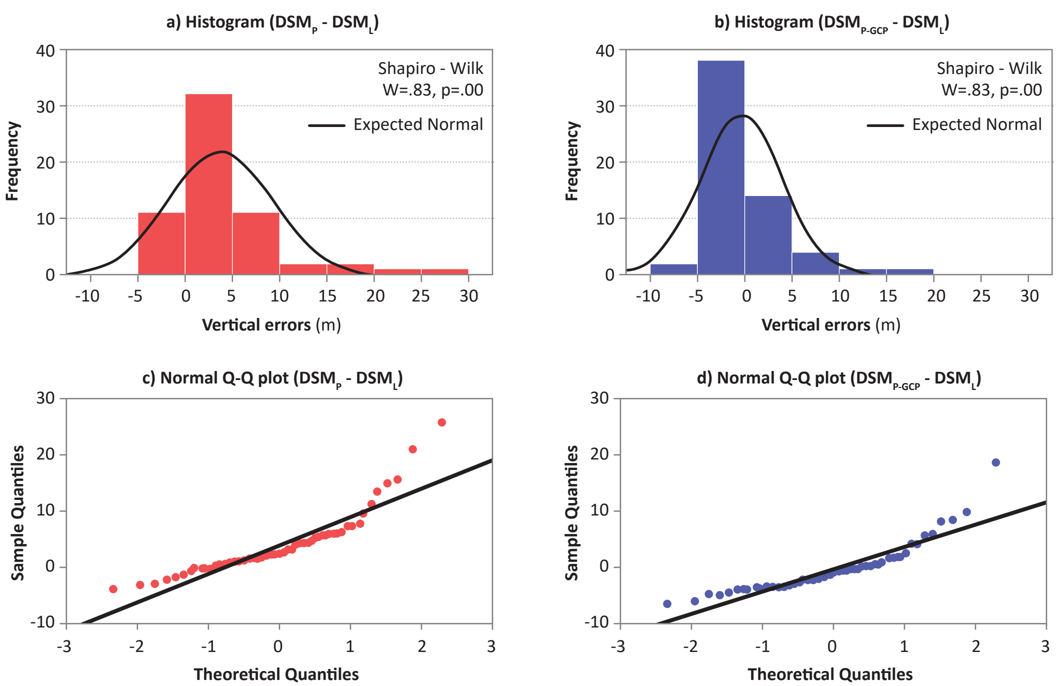

FIGURE 2. Normality test of residuals (vertical errors between UAV- and LiDAR-based DSMs): **(a)** and **(b)** histograms with a superimposed curve indicating normal distribution with accompanied results of the Shapiro-Wilk test; **(c)** and **(d)** indicate normal Q-Q plots.

TABLE 3. Information on UAV image orientation and DSMs processing.

Model	DSM_P	DSM_{P-GCP}
Number of images	488	488
Number of GCPs	0	7
GSD (cm)	5.26	5.27
Coverage area (ha)	121	122
Images with EOP	474	474
Number of tie points	353,025	352,530
Reprojection error (pixels)	0.874	0.885
$RMSE_{XY}$ (m)	5.686	0.161
$RMSE_Z$ (m)	8.194	0.059
$RMSE_{XYZ}$ (m)	9.974	0.171
Number of point cloud points	2,487,740	2,389,107
DSM resolution (m)	0.5 × 0.5	0.5 × 0.5
Processing time: computer + manual (min)	88 + 10	89 + 30

GCP - ground control point; GSD - ground sample distance; EOP - exterior orientation parameters; $RMSE_{XY}$ - root mean square error (horizontal); $RMSE_Z$ - root mean square error (vertical); $RMSE_{XYZ}$ - root mean square error (overall)

DSM_L is understandable. This is especially evident in Figure 3c, which shows a comparison of DSMs' profiles through the exemplary area. By observing profiles at greater peaks, it can be seen that DSM_{P-GCP} profile follows the DSM_L profile, whereas for DSM_P profile the horizontal displacement of 5-10 m compared to DSM_L profile can be observed. The improvement in vertical agreement of UAV-based DSMs with DSM_L when GCPs are used can be observed visually on difference models (Figure 4). Similarly, when comparing two DSMs derived from WorldView-2 images, Hobi and Ginzler [38] found clear improvement of the DSM's vertical accuracy when GCPs were used.

Furthermore, Figure 3c shows that DSM_L provides the highest discrimination of vertical forest structure clearly describing very steep variations in height (e.g. small gaps in the forest canopy, forest road). On the contrary, the profiles of both UAV-based DSMs are considerably smoother. Only bigger gaps in the forest canopy and a forest road (Figure 3a and 3b) can be detected, but in both cases, the vertical profiles of UAV-based DSMs do not reach the ground elevations. This is reasonable because LiDAR is an active sensor whose beams can penetrate through smaller gaps in the forest canopy and reach the ground, whereas the digital camera of UAV system used in this research (Table 1) is a passive optical sensor whose signal can characterize only the canopy surface [39].

TABLE 4. The vertical agreement assessment of the UAV-based DSMs with LiDAR-based DSM.

Agreement measure	DSM_P	DSM_{P-GCP}
Median (m)	2.23	-1.33
NMAD (m)	3.22	2.77
68.3% quantile (m)	4.34	0.11
95% quantile (m)	15.04	8.15
RMSE (m)	6.61	4.26
$N_{outliers}$	2	1
RMSE* (m)	5.10	3.54

NMAD - normalised median absolute deviation; RMSE - root mean square error; $N_{outliers}$ - number of outliers; RMSE* - root mean square error without outliers

Besides the technical limitations of low-cost UAV (e.g. camera quality, GNSS precision) used in this study and non-regular spatial distribution of GCPs, it can be suggested that the weather conditions (windy and cloudy weather) during UAV survey influenced image quality to a certain extent and consequently DSMs quality. The uncertainties are larger due to the complexity of the forest environment (e.g. moving trees, occlusions, shadows, images radiometric quality, etc.), which seriously affect the image matching procedure, and thus DSM quality [23, 25, 40, 41].

CONCLUSIONS

This research confirmed great potential of images obtained by low-cost UAV for forestry applications, even if they are surveyed in non-optimal weather (windy and cloudy weather) and environmental (inaccessibility for regular spatial distribution of GCPs) conditions. This could be of importance for cases when urgent UAV surveys are needed (e.g. detection and estimation of forest damage) which do not allow careful and longer survey planning.

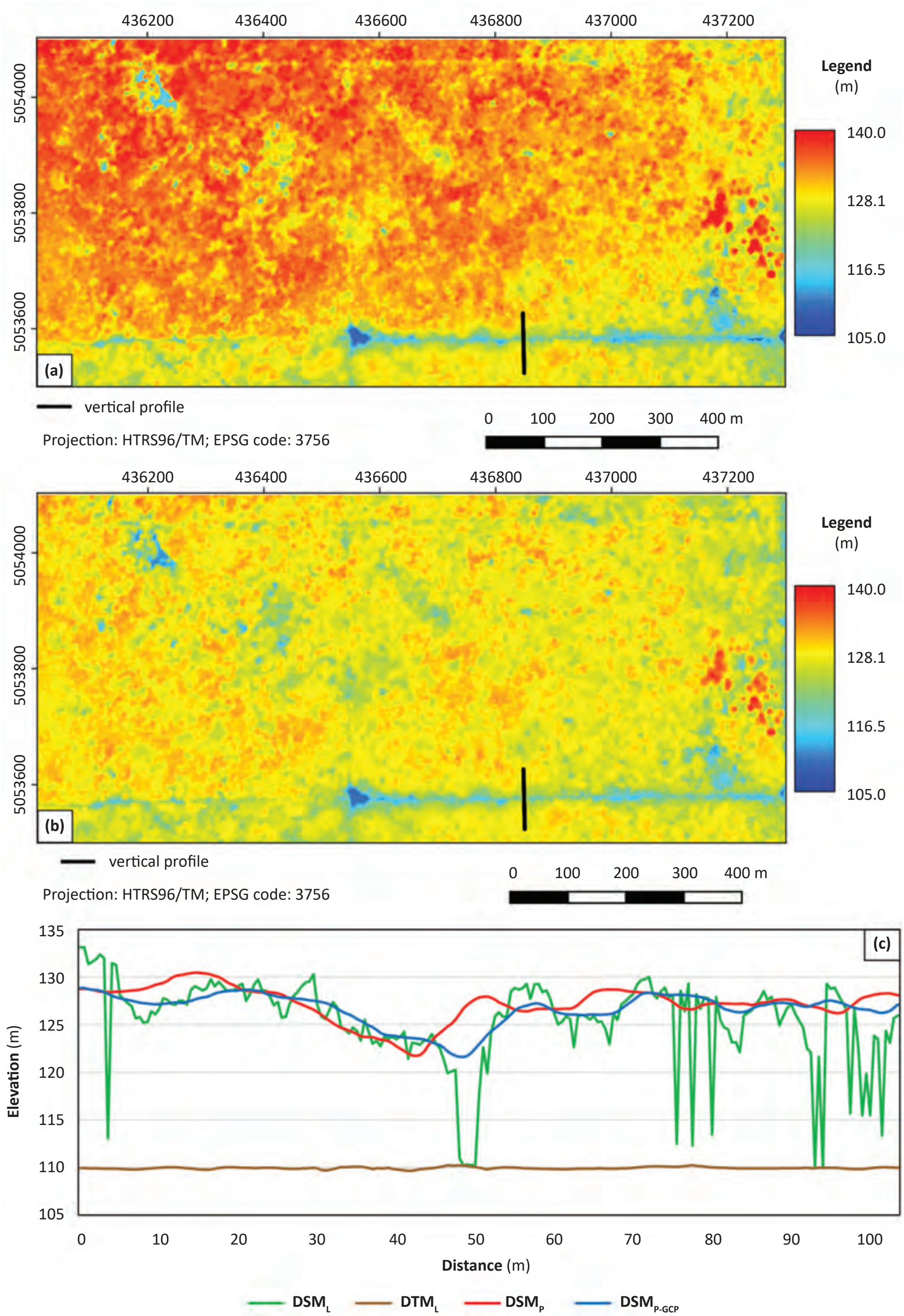

FIGURE 3. (a) UAV-based digital surface model generated without using GCPs (DSM_P); **(b)** UAV-based digital surface model generated using GCPs ($DSM_{P\text{-}GCP}$); **(c)** Vertical profile throughout the exemplary area marked with black line on figures (a) and (b) (DSM_L - LiDAR-based digital surface model; DTM_L - LiDAR-based digital terrain model).

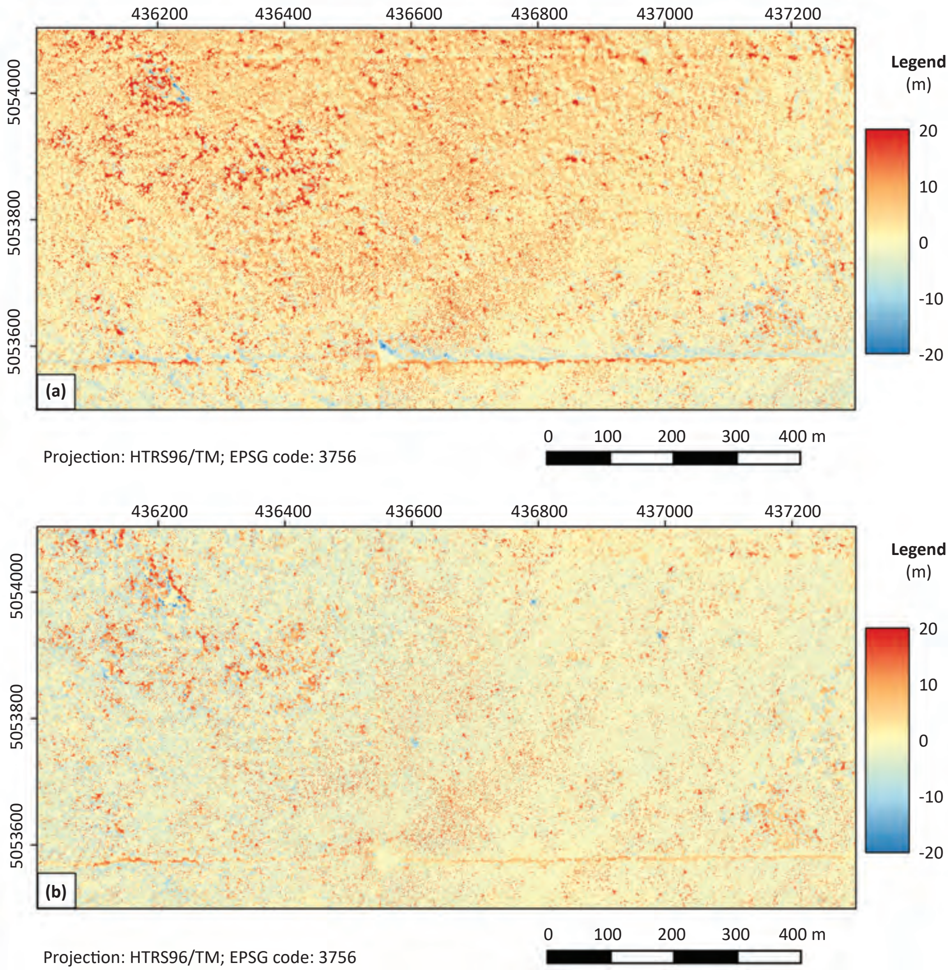

FIGURE 4. (a) Difference model generated by subtracting DSM_L from DSM_P; **(b)** Difference model generated by subtracting DSM_L from $DSM_{P\text{-}GCP}$.

The vertical agreement assessment of UAV-based DSMs with LiDAR-based DSM confirmed the importance of GCPs for image orientation and DSM generation. Namely, a considerable improvement in vertical accuracy of UAV-based DSMs was observed when GCPs were used. While DSMs generated without GCPs can be used for visualisation and monitoring purposes, DSMs generated with GCPs have potential to be used in forest inventory. To confirm this, further research should focus on estimating the accuracy of tree and stand attributes.

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Structure, Yield and Acorn Production of Oak (*Quercus robur* L.) Dominated Floodplain Forests in the Czech Republic and Croatia

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ABSTRACT

Background and Purpose: The study aims at comparing two (over 100 years old) floodplain oak-predominated forests in the Czech Republic (CZ) with two in of Croatia (HR) with regards to: i) their structure and yield and, more specifically, ii) individual oak tree characteristics including acorn production.

Materials and Methods: In both countries a different silvicultural concept is preferred (CZ: clear-cutting management with artificial regeneration, HR: shelterwood management with natural regeneration). The main research goal was to create a basic decision tool for forest managers and open some questions for future research.

Results: Despite the different natural and management practices, the total standing volume of floodplain forest was found to be similar in both countries, ranging from 500 to 700 $m^3 \cdot ha^{-1}$ (basal area: 34-41 $m^2 \cdot ha^{-1}$). In CZ generally more poor structure diversity was detected. Although in CZ the number of crop oaks (130-160 oaks per hectare) was almost double as compared with HR, the CZ oaks had shorter crowns, almost twice smaller crown projection, lower mean volume and lower share of valuable assortments.

Conclusions: Despite the total standing volume of oaks in HR being lower than in CZ, the total yield was observed in Croatia (loss in CZ ca. 22,000 $€ \cdot ha^{-1}$). The acorn density and quality were generally higher in HR with a more even distribution as well. Despite more favourable climatic conditions in HR, the currently used management system in CZ floodplain forests should be gradually converted to the Croatian model with a multi-layered forest structure, more focused on individual tree growth and stability with high economical value and high reproductive potential.

Keywords: floodplain forest, silvicultural system, pedunculate oak, structure diversity, assortment structure of oak, yield, acorn production

INTRODUCTION

Pedunculate oak (*Quercus robur* L.) is considered to be one of the most important economic tree species in floodplain forests in Europe [1]. Natural regeneration of oak, as in the case of other tree species, is a complex process influenced by many biotic and abiotic factors. The main negative factors are fungal infections and diseases (*Microsphaera alphitoides*), consumption by animals (insects, birds, rodents and wild boars), light, water availability and climatic factors such as late frosts [2]. From a different viewpoint, the social position and individual growth characteristics of oak trees such as growing space, crown size and architecture are included amongst the key factors for the abundance and quality of acorns [2-5] and for highly valuable timber production as well [6]. In this context, the forest structure (species and spatial diversity) and its targeted management can significantly influence the successfulness ofnatural forests.

In natural forests, pedunculate oak with its high-age growth strategy has enough time and space to create great stem and crown dimensions. Here, one oak generation equals two to four generations of hornbeam and other accompanying species. This makes the spatial structure of natural floodplain forests relatively rich and dynamic in time [7-8].

A predominant silvicultural system in floodplain forests in the Czech Republic (CZ) is clear-felling (with a maximum size of 2 ha) with mechanical soil preparation and artificial regeneration [9]. Reasons for this are: insufficient acorn crops, strong weed competition and high impact of small and big vertebrates [10]. This management results in the floodplain forest structure being less diverse and more homogeneous with a high number of trees in the overstorey and under-developed crowns with poor fructification in adult age [3]. On the other hand, in a number of cases in the southern part of CZ, Dobrovolný [11] and Martiník *et al.* [3] demonstrated success of natural regeneration of oak if certain conditions were met.

Matić [12] and Oršanić and Drvodelić [13] consider pedunculate oak to be a tree species with a climax strategy and recommend, the traditionally used natural regeneration of oak under the shelter of the mother stand in three or two cuts. This method takes into account the biological and economic properties and ecological requirements of acorns and causes minimal stress to the soil and the stand [1, 14]. Diaci *et al.* [27] admit even irregular group felling in floodplain forests in Slovenia.

This study was focused on comparing two types of management of adult floodplain oak-predominated forests in the Czech Republic and Croatia with regards to: i) their structure and yield and, more specifically, ii) oak individual tree characteristics and acorn production. The main research goal was to create a basic decision tool for forest managers and to open some questions for future research.

MATERIAL AND METHODS

In each country (Czech Republic "CZ", Republic of Croatia "HR") in the year 2013, two managed adult floodplain forest stands before regeneration felling that represented a typical species and spatial structure of that experimetal region were selected (Table 1). The selected stands in CZ and HR differed primarily in species composition (CZI - oak and ash, CZII - oak, HRI - oak and ash, HRII - oak, ash and hornbeam).

In CZ, specifically in the South Moravian region (Židlochovice), the research was conducted in floodplain forests (managed by the State), located along the Morava, Dyje, Svratka and Jihlava rivers. The predominating soil type, cambic fluvisol, was slightly gleyic, eubasic in double substrates with chernozem fossils (ca. from 160 cm) on fluvial Holocene sediments. In HR, the research was conducted in the floodplain forests of pedunculate oak within the area of the Sava River. Research encompassed the management unit of "Opeke" (managed by the Faculty of Forestry of the University of Zagreb). The dominant soils included pseudogley level terrains, deep, illimerised brown soil, pseudogleyic, and eugley epigleyic (in micro depressions). A comparison of long-term and short-term HR and CZ climatic data (Table 1, Figure 1) indicates a higher average annual (and monthly) temperature and annual (and monthly) amount of rainfall in HR.

In each of the four selected stands, one representative circular research plot (RP) of 0.25 ha in size was established - CZ I, CZ II, HR I, HR II (Tab. 1). Within each RP, the following variables were collected for all trees with a diameter at breast height (DBH) of more than 7 cm: the coordinates (using Field-Map technology-Institute of Forest Ecosystem Research Ltd., Czech Republic), DBH, tree height (h), crown length (CL) - difference between the tree height and crown base and crown projection (CP). Outside the RP, all the crop oaks (with a DBH above 30 cm) that extended with their crowns into the RP and could affect the abundance of fallen acorns were also measured.

TABLE 1. Basic information on research stands.

Country; Region; Location	Research plot (stand indication)	Altitude; annual precipitation; temperature	Floristic association	Tree composition	Stand age (year)	Area (ha)	Stock density
Czech Republic; Židlochovice; 49°0'N, 16°37'E	CZ I (121A11)	177 m a.s.l.; 550 mm; 9°C	*Querco-Ulmetum*	oak 63%; ash 37%	110	10.7	1.0
	CZ II (236C12b)			oak 85%; ash 14%; black alder 1%	120	8.6	0.9
Croatia; Lipovljani; 45°22´S, 16°50´E	HRI (136)	96 m a.s.l.; 915 mm; 10.3°C	*Genisto elatae-Quercetum roboris*	oak 65%; ash 29%; black alder 5%; OHS 1%	131	32.4	0.9
	HRII (157a)		*Carpino betuli-Quercetum roboris*	oak 58%; ash 16%; black alder 2%; hornbeam 23%; OHS 1%	140	30.9	1.0

OHS - other hardwood species

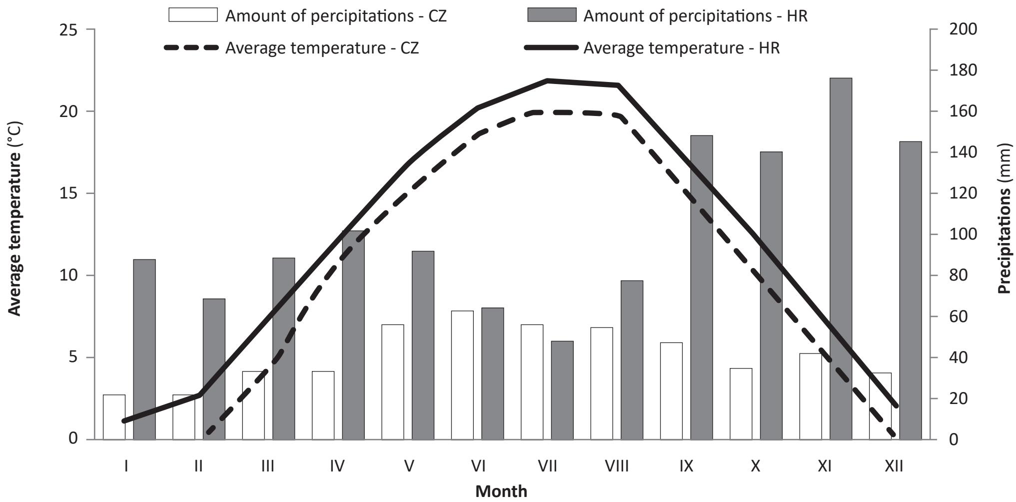

FIGURE 1. Development of the average monthly temperature and average monthly amount of rainfall in CZ and HR (years 2000 - 2012). A comparison of climatic data indicates a higher average annual (and monthly) temperature and annual (and monthly) amount of rainfall in HR.

Model height curve was constructed according to the Michajlov formula [15]. The stem volume without bark (V) was calculated using volume functions [16]. Canopy cover (CC) of the stand was calculated as sum of individual crown projections. The competitive situation or space surrounding each of crop oaks was evaluated as the mean distance (D) of the targeted crop oak to all nearest neighbours of any species (with tree height over 20 m). The following indices of forest structure were calculated with the aid of BWINPro 6.3 (Northwest German Forest Research Station, Germany) [17]: (1) indices of species diversity: (1.a) Shannon index (SI) and (1.b) Evenness (EI) (standardized Shannon) based on the abundance of the species (depending on the number of trees (N) and the basal area (G) - the higher the values, the greater the diversity, (1.c) Species-profile index (API) based on species abundance in three height stand layers - the higher the values, the greater the diversity; (2) indices based on the spatial pattern ofthe zero tree and its three nearest neighbours: (2.a) Mixing index (MI) - the values express the spatial species diversity of each situation (MI=0.00 - all trees belong to the same species, MI=0.33 - one tree belongs to a different species, MI=0.67 - two trees belong to a different species, MI=1.00 - all trees belong to a different species), (2.b) Index of DBH differentiation (DI) (0.0-0.3 = no or low differentiation, 0.3-0.5 = medium differentiation, 0.5-0.7 = high differentiation, 0.7-1 = very high differentiation), (2.c.) Index of DBH dominance (DDI) (the higher the positive values, the greater the dominance of the zero tree over its neighbours; values nearing 0 indicate an indifferent relation and the higher the negative values, the greater the suppression of the zero tree). The spatial patternof crop oaks with the distance to the nearest neighbouring oak was evaluated in ArcGis 10 (Esri, Inc., USA) according to the formula of Clark and Evans [25].

The assortment structure of oak was assessed according to assortment tables of Dejmal [26]. The stems were sorted according to class: I. sliced venner log; II. peeled lower quality veneer log; III.a and III.b saw log; V. pulpwood; VI. fuelwood. The economic profit was assessed according to volume and the current Czech price list of oak assortments.

Acorn abundance was evaluated using 36 seed traps (round wire hoops with collection sacks) per RP, 0.25 m^2 each (r= 0.28 m), arranged in a lattice format and placed 0.5 m above the ground. The spatial coordinates of all seed traps were measured. All the seed traps were installed before the acorns began to fall in September 2013. They were collected every two weeks. The amount of collected acorns was evaluated as the amount of seeds per square metre and the germination capacity was tested according to the Czech and ISTA standards [18].

The statistical differences between the RPs in terms of tree or acorn characteristics were tested using the non-parametric Kruskal-Wallis one-way analysis of variance (using Statistica 10 - StatSoft, Inc., USA). The spatial pattern of acorns (see Figure 7) in 5 categories of density (0; 0.1-5; 5.1-15; 15.1-30; 30.1-50 acorns per m^2) was estimated on each RP using ArcGis 10 with Kernel statistics (interpolation) tool (Esri, Inc., USA). This analysis was a basis for deriving the share of area covered by acorns and the share of crop oaks belonging to different categories of acorn density (see Table 10).

TABLE 2. Basic inventory data of research plots.

Research plot	N total (trees·ha^{-1})	N oak (trees·ha^{-1})	BA total (m^2·ha^{-1})	V total (m^3·ha^{-1})	CC total/oak (%)
CZ I	512	148	40.38	706.4	80/56
CZ II	176	160	34.39	496.4	76/74
HR I	380	100	41.66	712.2	114/66
HR II	332	64	37.75	634.6	143/43

N - tree number; BA - basal area; V - volume stock; CC - canopy cover

RESULTS

Structure and Yield

The standing volume and the basal area were found to be similar in both countries. Surprisingly, for two stands (RP CZ I and HR I) both values were identical - about 700 m^3·ha^{-1} or 40 m^2·ha^{-1} (Table 2). As expected, CZ II (with its poor structure) had the lowest total number of trees and the smallest basal area and standing volume.

The highest number of trees per hectare on CZ I was due to the high number of trees (namely ash) in the lowest diameter classes (Figure 2). The total canopy cover was always higher in HR (over 100%), mainly due to the presence of the middle tree layer (Figure 2 and 4).With respect to tree species composition (Table 3), in CZ, it was ash that dominated on CZ I and oak on CZ II in terms of the number of trees, while in HR it was alder with oak that dominated on HR I and hornbeam on HR II. In terms of basal area and standing volume it was oak that dominated in both countries; however, the total standing volume of oak was higher in CZ.

The most diverse species structure in HR was found for HR I (a total of six species), while in the CZ hornbeam and alder were absent in all cases. A more diverse species structure (even the vertical profile) in HR was confirmed also by the structure indices (SI, EI, API, MI) (Table 4).

The diameter distribution of all species in HR was broader compared to CZ (Figure 2). While in CZ the single- or double-peak distribution indicates the highest representation of trees of moderate thickness or very thin (CZ I) trees (Figure 2), in HR single-peak distribution with the highest representation of thin trees was observed. In HR, oaks were relatively evenly represented within a wider range of diameters, while in CZ oaks were clustered into several diameter classes around 50 cm (Figure 3). Nevertheless, the values of the diameter DI (Table 4) show a relatively high spatial variability on all RPs, unlike the homogenous CZ II. The DDI index indicates a more neutral relationship among the trees.

Similarly, the height structure was more diverse in HR with at least three distinct tree layers formed, the heights being about 10 m, 24 m, and 36 m (Figure 4). In CZ I, only two layers were formed (around 14 m and 36 m) and in CZ II only a single layer was formed (ca. 30 m).

Differences between the countries in oak assortments and values are shown in Table 5. The greatest differences

TABLE 3. The share of species composition in regard to the number of trees (N), basal area (BA) and volume (V).

Research plot	Variable	Oak	Ash	Elm	Field maple	Hornbeam	Alder
CZ I	N (%)	28.9	68.8	2.3	-	-	-
	BA (%)	80.4	19.4	0.6	-	-	-
	V (%)	84.4	15.5	0.1	-	-	-
CZ II	N (%)	93.0	4.7	2.3	2.3	-	-
	BA (%)	91.8	3.5	2.1	2.7	-	-
	V (%)	93.0	3.0	2.3	1.7	-	-
HR I	N (%)	26.3	17.9	21.1	3.2	7.4	24.2
	BA (%)	62.3	29.7	1.9	0.2	0.9	5.1
	V (%)	69.7	27.2	0.4	0.1	0.3	2.4
HR II	N (%)	19.3	8.4	-	-	72.3	-
	BA (%)	52.0	16.1	-	-	31.9	-
	V (%)	62.2	15.3	-	-	22.6	-

TABLE 4. Structure indices.

Structure indices	Research plot			
	CZ I	CZ II	HRI	HRII
SI-N	0.70	0.40	1.63	0.76
SI-G	0.51	0.37	0.94	1.00
EI-N	0.64	0.29	0.91	0.69
EI-G	0.46	0.27	0.52	0.91
API	1.12	1.04	2.07	1.41
MI	0.52	0.19	0.80	0.50
DI	0.51	0.17	0.52	0.42
DDI	-0.07	0.03	0.04	0.00

SI-N - Shannon index based on tree number; SI-G - Shannon index based on basal area;EI-N - Standardized Shannon index based on tree number; EI-G - Standardized Shannon index based on basal area; API - Species-profile index; MI - Mixing index; DI - Index of DBH differentiation; DDI - Index of DBH dominance

between countries were in the share of valuable assortments (classes I and II). There is only about 5% of this class in CZ and about 20-30% in HR. Despite the total volume of oak in HR being lower than in CZ, the total yield was higher (loss in CZ - ca. 22,000 €·ha^{-1}).

Crop Oaks (DBH > 30 cm)

HR was found to contain less crop oaks compared with CZ (Table 6). In general crop oaks in HR reached higher mean DBH and V (Table 6); however, significantly only when CZ I was compared with HR II and CZ II with HR I and HR II (Table 9). Tree heights were similar, except for CZ II. Crop oak crown characteristics, i.e. CL and CP, were significantly greater in HR (except for CL of CZI when compared with HRI); the mean CP here being almost twice as large as those in CZ (Table 6 and 9). Mean distance (D) of the targeted crop oak to the nearest neighbours was greater in HR (significantly only when CZ II was compared with HR I and II) (Table 6 and 9). These results confirmed also the growth relationships (DBH vs. h vs. CP) of CZ-HR oak trees with the similar direction and shape of constructed curves (Figure 5 and 6).

In both countries, oaks showed the same significant and even distribution across the plot with spacing (i.e. the

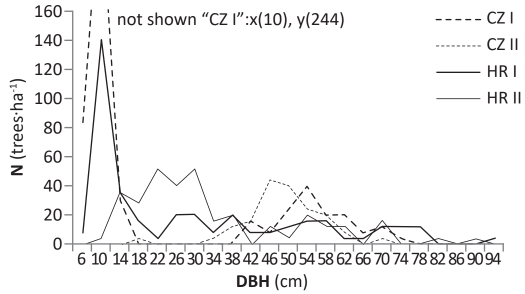

FIGURE 2. Distribution of DBH classes of all tree species. The diameter distribution in HR was more broad compared to CZ.

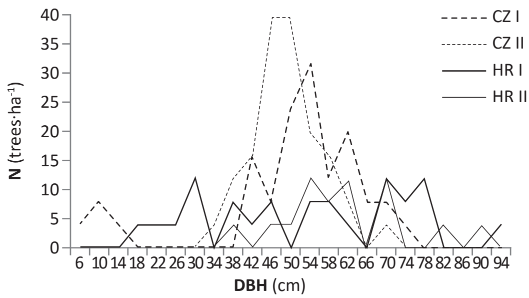

FIGURE 3. Distribution of DBH classes of oak. In HR, oaks were relatively evenly represented within a wider range of diameters, while in CZ oaks are clustered into several diameter classes around 50 cm.

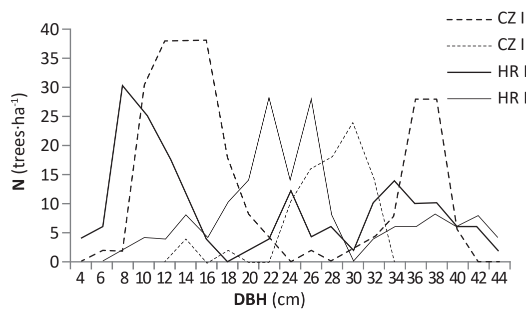

FIGURE 4. Distribution of height classes of all species. The height structure was more diverse in HR with at least three distinct tree layers.

TABLE 5. Share of oak assortments and assessment of economical value.

Assortment	CZ I (%)	CZ II (%)	HRI (%)	HRII (%)	CZ I (€·ha^{-1})	CZ II (€·ha^{-1})	HRI (€·ha^{-1})	HRII (€·ha^{-1})
I.	3.2	5.8	22.3	28.6	8,611.2	12,332.3	50,759.6	51,770.4
II.	0.8	0.0	0.9	0.5	939.2	0.0	892.2	385.4
III.a	55.6	53.9	32.4	28.2	38,795.4	29,138.7	18,805.6	13,005.2
III.b	5.7	6.7	7.2	6.2	3,945.0	3,619.1	4,208.3	2,871.7
V.	26.0	25.3	27.0	26.6	6,423.0	4,837.5	5,544.0	4,350.6
VI.	8.8	8.2	10.2	9.9	2,203.4	1,597.2	2,130.9	1,644.4
Total	100	100	100	100	60,917.3	51,524.8	82,340.5	74,027.7

I. sliced venner log; II. Peeled lower quality veneer log; III.a and III.bsaw log; V. pulpwood; VI. fuelwood

TABLE 6. Individual crop oak characteristics (mean, SD - standard deviation, min - minimum, max - maximum values).

Plot	N (trees·ha^{-1})	DBH mean (SD/min-max) (cm)	h mean (SD/min-max) (m)	V mean (SD/min-max) (m^3)	CL mean (SD/min-max) (m)	CP mean (SD/min-max) (m^2)	D mean (SD/min-max) (m)
CZ I	132	51.3 (15.2/7.4-73.8)	34.7 (6.4/10.2-40.4)	4.1 (2.0/0.01-8.5)	14.5 (4.0/4.3-25.3)	40.2 (27.7/2.5-110.7	7.8 (1.3/5.8-10.7)
CZ II	160	48.9 (7.3/33.1-70.3)	28.2 (3.3/14.5-34.3)	2.8 (1.0/1.3-5.9)	13.8 (3.8/5.4-24.1)	44.7 (19.9/11.8-113.3)	7.2 (1.2/4.9-9.6)
HR I	84	56.5 (15.3/30.9-92.3)	35.1 (5.0/24.5-43.5)	5.0 (3.2/1.0-14.9)	17.2 (3.9/10.5-25.0)	74.1 (39.4/25.8-188.8)	9.0 (2.1/6.1-13.2)
HR II	64	66.6 (12.8/38.2-90.1)	38.8 (3.0/32.5-45.0)	7.2 (3.0/1.9-14.6)	18.8 (3.2/10.0-24.0)	82.1 (37.9/22.6-195.7)	9.3 (1.8/6.4-12.4)

N - tree number; DBH - diameter at breast height; h - tree height; V - volume; CL - crown length; CP - crown projection; D - mean distance of the targeted crop oak to the all nearest neighbours of any species expressed in growth space

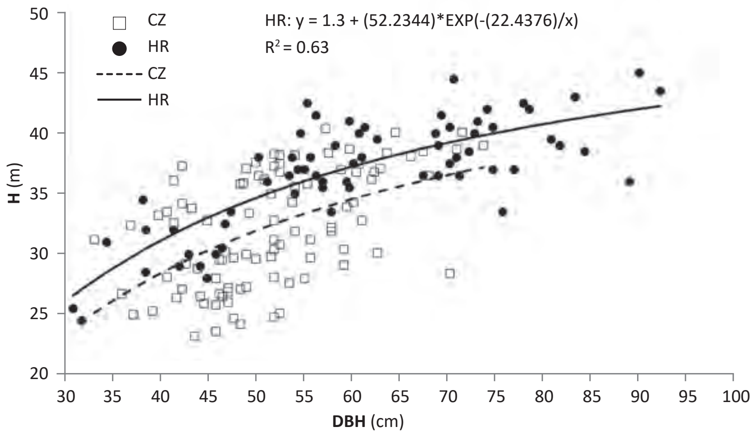

FIGURE 5. Height / diameter curves of CZ-HR crop oaks. HR oaks showed better height growth, but with the similar shape of both curves.

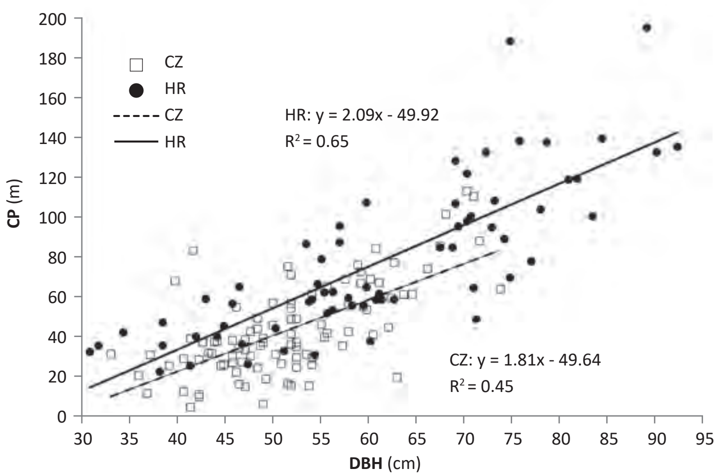

FIGURE 6. Relationships between DBH and crown projection "CP" of CZ-HR crop oaks. HR oaks showed larger crowns, but with the similar direction of both curves.

distance to the nearest neighbouring oak) being greater for HR (Table 7).

Acorn Production

In CZ I, acorn density was the lowest of all plots (Table 8), but not significantly when compared with CZ II (Table 9). In CZ II, the density was significantly lower only when compared with HR I. Differences in acorn abundance in HR were not statistically significant. Despite very different germination rates in each stand, there were generally more germinable seeds per square metre in HR. In HR, more even spatial coverage of the totalarea by acorns was found compared with CZ (Figure7).

The share of covered area by acorns was higher in HR (about 80% of the total area covered by medium or high density of acorns) compared with CZ (about 50-80% of the total area covered by null or low density of acorns) (Table 10). In HR medium or high acorn density / seedfall was observed in 80% of all oak trees, while in CZ null or weak seedfall was observed in 50-80% of all oaks (Table10).

TABLE 7. Distribution pattern of crop oaks.

Research plot	Observed mean spacing (m)	Ratio	z-score	p-value	Distribution pattern
CZ I	5.99	1.31	3.97	0.0001	Even
CZ II	4.87	1.21	2.98	0.0029	Even
HR I	6.53	1.27	3.16	0.0016	Even
HR II	9.17	1.39	4.10	0.0000	Even

TABLE 8. Acorn characteristics (mean, SD - standard deviation, min - minimum, max - maximum values).

Research plot	Acorn density mean (SD/min-max) (No·m^{-2})	Germination capacity mean (%)	Germinable seeds mean (No·m^{-2})
CZ I	1.67 (4.52/0-24)	53	1
CZ II	11.11 (21.25/0-100)	33	4
HR I	16.78 (18.16/0-76)	27	5
HR II	11.22 (14.71/0-60)	70	8

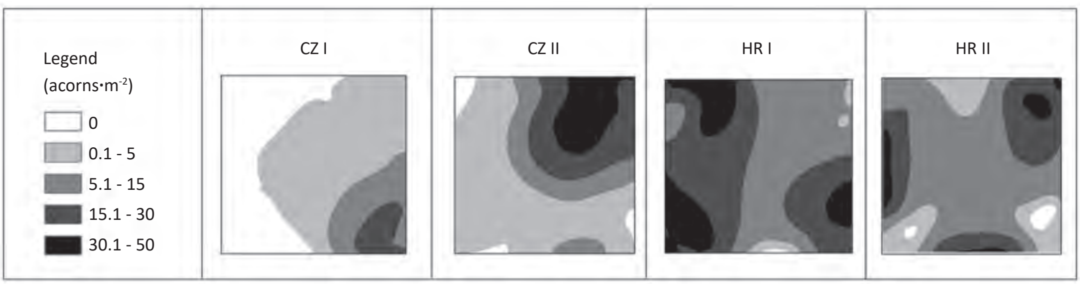

FIGURE 7. Spatial density of acorns with in the RPs. In HR, more even spatial cover age of area by acorns with heigher density was found compared with CZ.

TABLE 9. The results of Kruskal-Wallis analysis of variance.

	H	df	p	Stat. diff. (multiple comparison)
DBH	37.498	3	0.000	CZI vs. CZII+HRII; CZII vs. CZI+HRI+HRII; HRI vs. CZII+HRII; HRII vs. CZI+CZII+HRI
h	93.333	3	0.000	CZI vs. CZII; CZII vs. HRI+HRII; HRI vs. CZII+HRII; HRII vs. CZII+HRI
V	53.896	3	0.000	CZI vs. CZII+HRII; CZII vs. CZI+HRI+HRII; HRI vs. CZII+HRII; HRII vs. CZI+CZII+HRI
CL	35.150	3	0.000	CZI vs. HRI; CZII vs. HRI+HRII; HRI vs. CZII; HRII vs. CZI+CZII
CP	35.713	3	0.000	CZI vs. HRI+HRII; CZII vs. HRI+HRII; HRI vs. CZI+CZII; HRII vs. CZI+CZII
D	17.978	3	0.000	HRI vs. CZII; HRII vs. CZII; CZII vs. HRI+HRII
Acorn density	31.050	3	0.000	CZI vs. HRI+HRII; CZII vs. HRI; HRI vs. CZI+CZII; HRII vs. CZI

DBH - diameter at breast height; h - tree height; V - volume; CL - crown length; CP - crown projection; D - mean distance of the targeted crop oak to the all nearest neighbours of any species expressed in growth space

TABLE 10. The share of area (1 RP = 0.25 ha) covered by different categories of acorn density and the share of crop oaks belonging to different categories of acorn density.

Acorn density - categories ($No \cdot m^{-2}$)	Share of area (%)				Share of crop oaks (%)			
	CZ I	CZ II	HR I	HR II	CZ I	CZ II	HR I	HR II
0 (null)	34.2	3.9	0.4	1.9	50.0	6.4	0.0	4.2
0.1-5 (weak)	47.4	50.8	2.1	14.0	26.2	51.1	0.0	4.2
5.1-15 (medium)	12.9	15.9	39.6	56.6	19.0	12.8	30.3	70.8
15.1-30 (high)	5.5	17.5	39.8	23.1	4.8	14.9	57.6	16.7
30.1-50 (very high)	0.0	12.0	18.1	4.4	0.0	14.9	12.1	4.2

DISCUSSION

Our results based on comparisons of forest structure, yield and acorn production in HR - CZ cleared the way for basic silvicultural decisions (Table 11).

Despite different natural conditions, the volume production was found to be similar in both countries. For two stands (CZ I and HR I) the volume was identical - about 700 $m^3 ha^{-1}$. It is necessary to point out that the analysed stands in CZ were about 20 to 30 years younger than those in HR. According to the existing growth tables for both countries, this involves the most productive stands on top quality soil [19, 20]. The comparable volume yield is also given by the greater number of trees, especially oaks, in the upper layer in CZ, which is related to the silvicultural strategy of the clear-cutting management model applied. Surprising were also the similar oak parameter relationships, which indicate similar dynamics in both countries.

TABLE 11. Silvicultural decision tools.

Characteristic	CZ	HR	Comparable
Site and forest type of stands			•
Stand age			•
Altitude			•
Annual precipitation	–	+	
Annual temperature	–	+	
Growing stock and basal area			•
Total number of trees per ha			•
Canopy area	–	+	
Structure diversity	–	+	
Oak – number of crop trees per ha	+	–	
Oak – individual tree characteristics	–	+	
Oak – growth relationships (shape of curves)			•
Oak – economic value	–	+	
Oak – acorn production	–	+	

In contrast, the analysis of stand structure confirmed the expected differences between these two countries. While in CZ the poor structure and the tree characteristics observed are given by the clear-cutting management model, the more diverse structure of the forest in HR corresponds to the Croatian model with a multi-layered floodplain forests [12]. Such a model is also closer to the natural conditions in virgin floodplain forests, where the relatively dynamic structure is characterised by a multi-layer distribution of tree species and a distinct diameter differentiation, which particularly applies to the optimum stage [7, 8, 21].

Comparing the individual growth characteristics for crop oaks found in CZ to have up to twice more individuals (130-160 trees per hectare) with smaller spacing than in HR. These oaks, however, had a lower mean volume, shorter crowns and nearly twice smaller crown projection compared with HR oak trees. For instance, Spiecker [6] recommended supporting only about 60 target trees per hectare through crown thinning to optimise the radial increment in oak, which corresponds to the Croatian model. These usually thickest oak trees also have larger crowns (the relationship was confirmed similarly for both countries - see Figure 5 and 6), thus having better prerequisites for fructification [2, 3].Croatian system also provided higher economic benefits. Despite lower cubic volume of oak per ha in HR, we can expect higher economic profit from oak trees in HR due to more valuable assortments (loss in CZ - ca. 22,000 €$\cdot ha^{-1}$).

The acorn crop values obtained for the analysed stands in both countries (2-17 acorns per square metre) were below the threshold of the mast year (20-50 acorns$\cdot m^{-2}$) [2, 22]. Years of rich crop are likely to occur more frequently in HR than in CZ [1, 9, 23]. While in mast years the presence of richly and regularly fruiting individuals is not crucial for seeding to be sufficient, in the years with medium and lower crop rates the opposite is true [22, 24]. To this end, the size and quality of the crown and sufficient space for growth, where applicable, are the prerequisites for individual trees to be fruiting richly and on a regular basis [3, 24].

In Croatian management with a multi-layered floodplain forests shelterwood felling in three cuts (preparatory, seeding and final) is used with the regeneration period of 6-10 years, when the average density of oak seedlings and other species is about 40,000-50,000 individuals per ha [12]. However, in CZ shelterwood felling is limited by pure even-aged structure of unprepared adult oak stands which (after opening) causes strong weed expansion and stem sprouting. Dobrovolný [11], however, inventoried (in the southern part of CZ in Židlochovice region with 3355 ha of floodplain forests) in total 8 ha of young pedunculate oak stands (with age 5-7 years) established from natural regeneration with density ranging between 15,000-100,000 individuals per ha. The original mother stands, characterized by lower stock density (that ranged between 0.5-0.8), were harvested by clear-cutting immediately after the acorn fall.

The growth relationships of CZ-HR oaks showed a similar trend (or shape of constructed curves). Thus, the stem and crown characteristics (and also the amount and quality of produced acorns) of new CZ oaks could be probably changed if changing silvicultural system. However, based on the results presented in this paper we can not determine exactly which concrete factor caused the observed differences between HR and CZ. Probably there exists a complex of various factors such as climate, water regime, tree vitality and physiological stress, genetic predispositions, etc. This study should be a start and a challenge for future cooperation and long-term research in this field.

CONCLUSIONS

Our results showed elementary differences not only in the forest structure, but also in the management approach in floodplain forests of CZ and HR. While different concepts and stand structures may involve a comparable production level, the approach of clear-cutting management in the Czech Republic brings a range of problems. Despite complex of biotic and abiotic factors and more favourable climatic conditions in HR, the silvicultural system of CZ floodplain forests should be gradually converted to the Croatian model with a multi-layered forest structure, more focused on individual tree growth with high economical value and high reproductive potential. To achieve these goals primarily young and middle-aged stands in CZ should be managed through releasing of crowns of high-quality (and vital) crop trees (60-80 trees per hectare), as well as structuring the stands by preserving the lower tree layers consisting of accompanying tree species.

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Training Programmes in Sustainable Forest Management in Austria, Croatia and Slovenia

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ABSTRACT

Background and Purpose: During the Erasmus+ project "Cooperation for Innovative Approach in Sustainable Forest Management Training (CIA2SFM)" a study of the existing vocational education and training (VET) and lifelong learning (LLL) programmes in the field of sustainable forest management (SFM) was conducted in Austria, Croatia and Slovenia. The aim of this paper is to get an overview of and analyse SFM-related VET and LLL programmes in the study area, with an emphasis on the identification of good practice examples and providing recommendations for improvement.

Materials and Methods: A combined approach of literature review, Internet search and consultations with training providers was applied in order to collect data on training programmes conducted in the period 2006-2015 in Austria, Croatia and Slovenia. The programmes were analysed based on topics, types of methods used, existence of specified learning outcomes, programme evaluation by participants and how the programme was advertised. The analysis employed basic descriptive statistics. Topics were grouped into broader themes. Only training programmes targeting private forest owners, forestry professionals, and forestry entrepreneurs were analysed. Three examples of good practice in each country were selected based on collaboratively developed criteria.

Results: In Austria, Croatia and Slovenia numerous training courses related to SFM were conducted in the analysed period, predominantly addressing target groups in forestry sector and covering a variety of topics. The relative importance of themes varied among countries. In order to facilitate the knowledge uptake by participants various methods were applied. Although indoor ex-cathedra approaches prevailed, it could be recognized that there is a growth in interest for foster demonstrations in the field, organizing field trips, emphasize on practical work and combining methods and approaches in most countries.

Conclusions: Even if national providers of training programmes may relate to individual needs within national forestry sectors, SFM-related training programmes should be regularly screened and updated according to international agendas and emerging issues. In order to cope with increasing uncertainty and expanding risks forest ecosystems are facing, it is an important task to open up the recent training offer to innovative forms of learning, combinations of topics and learning environments.

Keywords: vocational education and training, lifelong learning, adult education, knowledge transfer, e-learning, forestry

INTRODUCTION

Education has ever since played a crucial role in the development of human communities and society in general. Before the late 18th century and the Age of Enlightenment, access to education had been restricted and limited to privileged individuals [1]. Since then, significant social, economic and political changes have occurred. We are now living in the Knowledge Age that is putting knowledge in focus of socio-economic development and growth [2, 3].

Knowledge can be defined as "the outcome of assimilation of information through learning" [4]. However, there are numerous other definitions [5, 6]. Modern theoreticians often distinguish among declarative (theoretical), procedural (practical) and conditional knowledge [5]. Declarative (theoretical) knowledge refers to knowing factual information about something; procedural (practical) refers to how to use this knowledge in certain processes or routines, while conditional knowledge refers to understanding when and where this knowledge would be applicable. Knowledge management literature also distinguishes between explicit and tacit knowledge. The former refers to knowledge that the learner is conscious of and easier to transfer, while the latter refers to knowledge that the learner might not be aware of and is largely experience-based [4].

Gaining knowledge implies learning, which is defined as "a process by which an individual assimilates information, ideas and values and thus acquires knowledge, know-how, skills and/or competence" [4]. According to Cedefop [4], there is a difference among formal, informal and non-formal learning. Formal learning occurs in an organised and structured environment and is intentional, such as learning while taking a part in formal educational system. On the other hand, informal learning is mostly non-intentional and resulting from activities related to work, family or leisure. Finally, non-formal learning is planned and intentional activity, but is not necessarily designed as learning in terms of learning objectives, time and resources.

The quality of human capital is at the heart of the Europe 2020 strategy aiming at smart, sustainable and inclusive growth [7]. Reaching important priorities such as the development a high-employment economy based on knowledge and innovation is not possible without knowledgeable and skilful professionals on the labour market. Hence, Strategic Framework for Education and Training ('ET 2020') puts an emphasis on lifelong learning (LLL) and vocational education and training (VET), and urges them to be more responsive to change and societal needs [8]. VET is defined as education or training that aims to prepare learners for particular occupations, traditionally non-academic and practically oriented, or to equip them to have more advantageous position on the labour market in general [4, 9]. On the other hand, LLL includes the entire range of learning (formal, informal and non-formal) undertaken throughout life, as well as skills, knowledge, attitudes and behaviours that people acquire in their everyday lives [10].

However, participation of adults in VET and LLL varies across Europe as well as the EU [11]. According to the Education and Training Monitor 2016, adult participation in learning in EU28 is only 10.7%[1] on average, whereas target by 2020 is set to 15%. In that sense some Member States are underperforming, for instance Croatia, while others are close to or even beyond the target. In Austria, participation of adults in educational programmes is 14.4%, which is an increase in comparison to 2012 (14.2%) [12]. On the other hand, in Croatia participation has even dropped (from 3.3% in 2012 to 3.1% in 2015) [13]. Even though Croatian Strategy of Education, Science and Technology strongly supports LLL [14], the implementation of the Strategy has been facing serious obstacles due to a lack of political will to tackle the national curricular reform [11]. Furthermore, in 2015 Slovenia was above the EU average in adult participation in learning (11.9%), but a drop of almost 2% has been recorded in comparison to 2012 [11].

EU funds and programmes offer possibilities to access funding for VET and LLL. Erasmus+ is such a programme that offers opportunities to various types of organisations or individuals regardless of the profession to participate in training programmes often through mobility [15]. The programme's key actions are mobility of individuals, cooperation for innovation and the exchange of good practice, and support for policy reform. ERASMUS+ project 'Cooperation for Innovative Approach in Sustainable Forest Management Training' (CIA2SFM) refers to the second key action and aims at developing collaborative transnational multilingual e-learning modules on sustainable forest management[2] (SFM) tailored for forestry professionals, forestry entrepreneurs, private forest owners and professionals in public institutions in charge of protected area management [17]. The three-year project involves six public educational and/or research organisations and a forest management company from Austria, Croatia and Slovenia.

Forests and forestry sector are important assets we as a society have on the way towards reaching the European Commission's Bioeconomy Strategy targets [18, 19]. However, forestry sector in Europe is facing many challenges, such as climate change, a shift in forest ownership, as well as increasing and often conflicting societal demands (e.g. timber production, biodiversity, wood-based bioenergy, scenic beauty, protection from natural hazards, provision of drinking water, etc.) [20]. Hence, forestry and other forest-related professionals work in complex and constantly changing (policy) environment urging them to stay on top with their forest-related knowledge, skills and competences [21]. Furthermore, to a various extent there is a mismatch in EU and other European countries between skills obtained through formal educational systems and labour market needs hampering current and future economic competitiveness with forestry sectors not being an exception [22-24]. Consequently, there is a constant need for continuous participation in VET and LLL related to SFM.

After finishing formal education in forestry or adjacent sectors, forestry and other forest related professionals

1 - SFM refers to the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economical and social functions and that does not cause damage to other ecosystems [16]

2 - The share of 25 to 64 year olds who received formal or non-formal education or training in the four weeks preceding the survey.

and individuals in project countries do not have equal opportunities for constant upgrade of their knowledge, skills and competences related to SFM. For example, in Croatia, two main providers of systematic professional trainings in SFM were established only 10 years ago. Hence, it is not surprising that 30 years ago in Croatia 65% of the employed forestry professionals never participated in any kind of professional training whatsoever [25]. On the other hand, Austria has a long tradition of providing SFM-related professional training [26]. This affects, among other things, their transition from somewhat protected educational environment to often harsh realities of the labour market. This is especially true in countries with struggling economies, such as Croatia.

Recently a number of studies addressing training programmes have been published in Austria, Croatia and Slovenia. Those were mainly focused on the correlation between VET and the labour market [27-31], the innovative approach in LLL [32, 33], VET and LLL policy and state [34-38], the processes of assessment and evaluation of VET [39, 40], and specific methods of LLL [41]. However, those addressing VET and LLL in SFM are scarce [25, 42-46]. Furthermore, none of these analysed the state of the art in SFM-related VET and LLL programmes offered in Austria, Croatia and Slovenia. Hence, the aim of the paper is to present the results of such analysis carried out within the frame of the CIA2SFM project with the purpose of taking stock and providing recommendations for the improvement. The results of this study will be useful for national providers of SFM-related professional training, as well as forestry and education policy actors to improve the existing VET and LLL programmes.

MATERIAL AND METHODS

Initially, we made a list of VET and LLL providers on topics related to SFM (Table 1). Since we were interested in relatively recent training programmes and because in Croatia main providers of SFM-related training were not established prior to 2006, we agreed on collecting only information on programmes that took place in period 2006-2015. The convenient sampling was applied based on our knowledge, Internet search and direct contact with providers. The following information about each training programme was collected:

- Programme's name, topic and short content: for the purpose of analysis of the programme's topics these were roughly divided into five groups - Forest management and planning, Forest products and services, Safety issues, Forest threats, and Others;
- Year when the programme was conducted, duration and number of training courses: to calculate the average number of provided programmes per year;
- Programme's target group(s): only programmes referring to CIA2SFM project target groups, namely forestry professionals, private forest owners, and entrepreneurs in forestry were analysed in order to see whether and how these groups were addressed by VET and LLL;
- Types of methods used: for the purpose of analysis the methods were roughly divided into four groups – Lectures/presentations, Practical work, Field demonstrations, and Others;
- Specific learning outcomes: in order to see whether they were specified or not;
- Evaluation of the program: in order to see whether the programme was evaluated or not, and if yes, how it was done;
- Programme advertising (promotion): in order to see whether and how the programme's participants were recruited;
- Assessment of the progress of participants: in order to see whether and how the assessment was done.

TABLE 1. A list of major providers of VET and LLL programmes in SFM by country.

Country	Provider/URL
Austria	National Chamber of Agriculture/ www.lko.at
	Austrian Forest Research Centre (BFW)/ www.bfw..ac.at
	Forest Training Centres/ www.fastossiach.at; www.fastort.at
	University of Natural resources and Life Science (BOKU)/ www.boku.ac.at
Croatia	Croatian Agriculture and Forestry Advisory Service / www.savjetodavna.hr
	Croatian Chamber of Forestry and Wood Technology Engineers/ www.hkisdt.hr
	European Forest Institute/ www.efi.int
	Faculty of Forestry/ www.sumfak.hr
Slovenia	Slovenia Forest Service/ www.zgs.si
	Slovenian Forestry Institute/ www.gozdis.si
	Secondary Forestry and Wood Processing School in Postojna/ sola.sgls.si/
	University in Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources/ www.bf.uni-lj.si/
	Higher professional school Postojna/ www.vspo.si/
	Union of forestry associations of Slovenia/ zgds.si/
	Slovenian Institute for Adult Education/ www.acs.si

NB: Name of the Service in the period 2007-2010 was Forest Extension Service. In the period 2011-2014 it was merged with state forest company Croatian Forests Ltd. From 2014-2017 the name of the Service was Advisory Service. The latest name is Croatian Agriculture and Forestry Service.

The rationale for taking into account programmes targeting forestry professionals, forestry entrepreneurs and private forest owners is because they were identified during project development phase as those who are lacking continuous (lifelong) training related to SFM. Forestry professionals, especially straight-out-of-faculty forestry engineers, lack specific knowledge and skills to increase their employability on the job market. Experienced forestry engineers who finished faculty long time ago need continuous update, especially due to frequent changes in forest-related polices on the national and EU level. Private forest owners do not necessarily have knowledge and skills needed to perform management activities in their forests since they do not necessarily have formal education in forestry [47]. They are also facing complex administrative and other barriers when trying to engage in management of their forests [48]. In the time of financial austerity, what became essential for these target groups, beside SFM-related knowledge and skills, is having knowledge and skills on how to find additional funding, such as by making a project application.

The available data on the conducted VET and LLL programmes in SFM were collected from official websites of the providers or directly from the providers in case the data were not available online. For that matter, an Excel sheet specifying what information is needed was sent to providers of VET and LLL programmes in SFM, one in Austria, two in Croatia and three in Slovenia, who provided us with the missing information.

Data was collected between November 2015 and January 2016. Due to quite heterogeneous data, a basic descriptive analysis was applied and will be presented in this paper.

After the overview of VET and LLL programmes in SFM was done, the seven criteria (Table 2) were developed collaboratively in the team and used for a selection of examples of good practice. According to the criteria, programmes of higher value were those developed for diverse target groups, offering topics related to the state of the art of SFM, implementing a multi-method approach, as well as those adequately advertised. Less important criteria referred to programme evaluation by its participants and participants' progress assessment. Based on these criteria three examples of good practice per country were selected.

RESULTS

State of VET and LLL programmes in SFM in Austria, Croatia and Slovenia

In the given period, several organisations offered a range of VET and LLL programmes in SFM to the target groups in Austria, Croatia and Slovenia. Of particular relevance are four providers in Austria, three in Croatia and seven in Slovenia (Table 1). In Croatia, two major providers, namely Croatian Chamber of Forestry and Wood Technology Engineers, and Forest Extension Service[3], were established in 2006 as a result of changes in forest policy, which among others aimed at boosting private forest-related entrepreneurship and improving private forests [49, 50]. Before 2006, there had been no systematical and continuous provision of VET and LLL programmes in SFM. In addition to these major providers, a small number of trainings was provided by the European Forest Institute through a regional project FOPER ("Forest Policy, Economics, Education and Research"), forestry professionals, and the Faculty of Forestry, University of Zagreb, who provided trainings to employees of the Forest Extension Service, state forest company Croatian Forests Ltd., and professionals working on data collection for national forest inventory.

On average around 80 VET and LLL programmes in SFM were conducted every year in Austria in the period from 2006-2015, depending on the interest and resources available because some of them were held only on demand. In Croatia, in the period from 2007-2015, 879 VET and LLL programmes in SFM were held in the period 2007-2015 or on average 98 annually. The Forest Extension Service offered most of them (73%) targeting private forest owners. However, there was no programme specifically targeting employees of public institutions in charge of the protected areas (nature and national parks), even though in Croatia, forests are the main feature in many of these protected areas. According to Annual reports of Slovenia Forest Service in the period from 2008 to 2015, about 300 VET and LLL programmes in SFM were implemented annually. A relatively high number of offered VET and LLL programmes in SFM could be a result of constantly changing (policy) environment [21] and legislation accordingly, as well as the emergence of challenges, such

TABLE 2. Criteria for the identification of good practice examples of VET and LLL programmes in SFM and their rationale (source: [3]).

Criterion	Rationale
Target groups	A multi-stakeholder approach addressing several target groups at the same time
Topics covered	Addressing cutting-edge SFM-related content (e.g. emerging and relevant issues) is preferable
Specified learning outcomes	Mandatory (learning outcomes must be specified)
Methods applied	A multi-method approach is preferable, particularly relevant are practical applications (e.g. training in the field)
Programme evaluation	Mandatory (although less important)
Programme marketing	Multiple marketing channels are preferable
Assessment of the progress of participants	Mandatory (although less important)

3 - The name of the Service in the period 2007-2010 was Forest Extension Service. In the period 2011-2014 it was merged with state forest company Croatian Forests Ltd. From 2014-2017 the name of the Service was Advisory Service. The latest name is Croatian Agriculture and Forestry Service.

as climate change impact, new (invasive) pests, or new technology for forest management.

The analysed programmes covered a wide range of topics grouped into several overarching themes (Figure 1) [3]. The majority of programmes in Austria addressed the theme of Forest management and planning (40%), followed by programmes addressing Forest products and services (25%), as well as Safety issues (20%). Other themes were less frequent, such as Forest threats (10%) or Policies (5%).

In Croatia the theme of Forest products and services (29%) was the most relevant, followed by Policies (20%) and Forest management and planning (19%). Themes of Forest threats (13%) and Safety issues (5%) received less interest. Category Other (14%) included a variety of topics, such as topics related to project management or VET and LLL in general.

In Slovenia the most relevant themes were Forest management and planning (38%), as well as Safety issues (36%). Less relevant were themes of Forest threats (12%), Forest products and services (7%), or Education and training in general (3%).

The analysis of methods used for knowledge transfer showed differences in approaches in project countries (Figure 2) [3]. In Austria there was a good balance of broad portfolio methods applied in order to train different target groups in SFM-related topics. Although ex-cathedra teaching (lectures and presentations) represented a common way to distribute knowledge across classrooms, it can be denoted that object teaching was used often as well. The share of field demonstrations and practical work (altogether 44%) indicate that hands-on experience was of high relevance. Other methods referred to moderated discussions (11%) and tests (4%) complementing the indoor-based teaching methods. In Croatia there was a clear emphasis on traditional ex-cathedra classroom teaching (Figure 2). Field demonstrations played a minor role in current curricula, while least relevant were practical work and seminars. Quite contrary, practical work in workshop settings dominated as means of knowledge transfer in Slovenia (Figure 2). Seminars and study circles (labelled as 'Other') together with lectures/presentations, as well as field trips complemented the indoor-based teaching methods. Therefore, in overall there was a good mixture of indoor and outdoor teaching approaches applied in SFM training in Slovenia.

The analysis revealed a room for improvement when it comes to the advertising of training programmes. For instance, some were announced only on website and/or by e-mail (for instance when targeting licenced forestry engineers), while other were advertised also in public places (when targeting private forest owners). This might

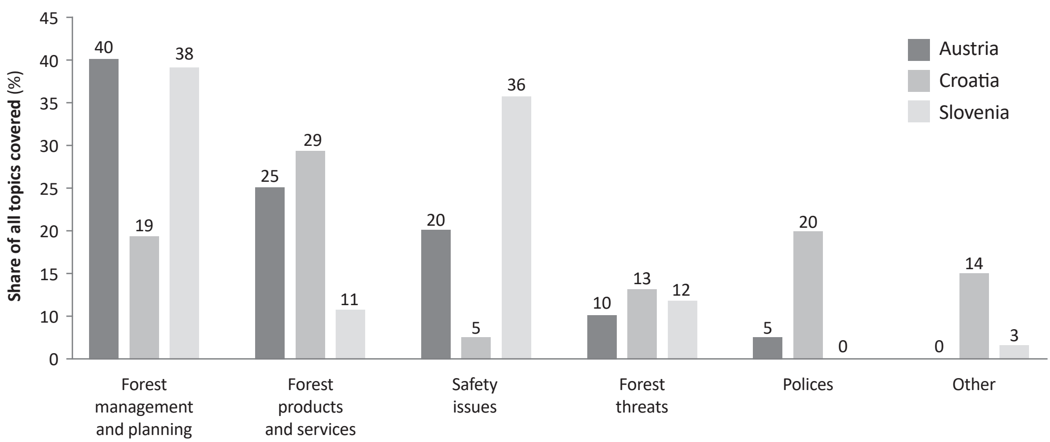

FIGURE 1. Relative share of themes covered in VET and LLL programmes in SFM by country (source: [3]).

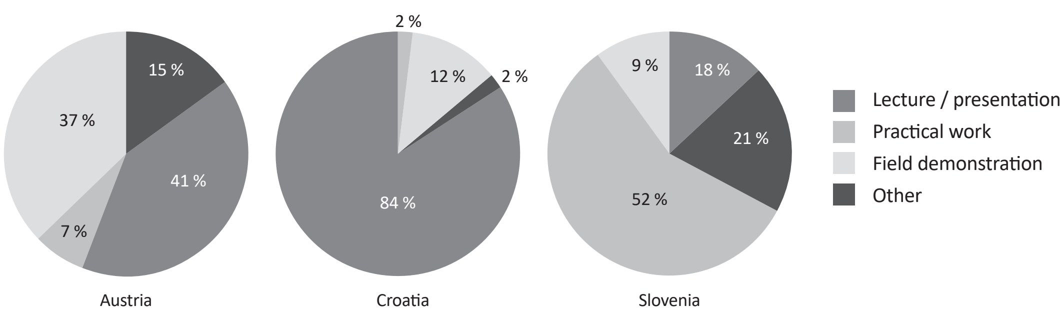

FIGURE 2. Methods applied in SFM-related training programmes by country (source: [3]).

have affected programme outreach and the number of participants in the end.

When it comes to specifying learning outcomes, the share of programmes with specified learning outcomes varied, while programme evaluation and assessment of participants' progress were less common practices (Table 3).

High share of VET and LLL programmes in SFM in Austria and Slovenia specifically addressed the main competences VET and LLL learners should gain after the completion of individual courses, while in Croatia this has not been a widespread practice. Programme evaluations as well as the assessment of participants´ progress have been practiced rarely in all countries (Table 3).

Examples of Good Practice in VET and LLL Programmes in SFM

We identified three examples of good practice in each project country based on a commonly developed set of criteria (Table 4). In Austria these were 'Forest Management Course I', 'Forest Management Course II' and 'The Forest Dialogue' [3]. The first two training programmes were provided by the Austrian Forest Research Center in its Forest Training Centres in Ort and Ossiach. Both training programmes combined lectures with field demonstrations and targeted forest owners and forest workers as well as the general public, hence meeting the multiple target group criterion (Table 4). These programmes were evaluated by participants, learning progress was assessed by exam and participants received certificates of completion. The Forest Dialogue, provided by the Austrian Ministry of Agriculture, Forestry, Water Management and Environment met almost all of the criteria for being qualified as an example of good practice (Table 4). The training programme addressed multiple target groups (forest owners, forestry professionals, forest owner associations, forest scientists, forest administration) and applied the multiple method approach (lectures and presentations complemented by moderated discussions). Apart from being extremely relevant for forest policy in Austria, the programme had specified learning outcomes and was evaluated by participants, but still failed to meet the criteria related to the advertising and assessment of participants' progress.

TABLE 3. Relative shares for selected criteria for the identification of good practice examples of SFM-related training programmes by country (source: [3]).

Criterion	Austria	Croatia	Slovenia
		(%)	
Specified learning outcomes	87	36	91
Programme evaluated	27	6	34
Participants´ progress assessed	27	4	9

TABLE 4. SFM-related training programmes deemed as the examples of good practice per country according to the criteria for their selection.

Criterion	Training programmes deemed as examples of good practice								
	Austria			Croatia			Slovenia		
	Forest Mana-gement Course I	Forest Mana-gement Course II	Forest Dialogue	Silvicultural work/ biological regene-ration	Course on forest preser-vation	Recreational forest functions	Forest manage-ment and silvicultu-ral measures after natural disasters	PAWS MED training course for forest pedagogy	Course for Study Circle leader and mentors
Multiple methods	+	+	+	+	+	+	+	+	+
Multiple target groups	+	+	+	-	-	-	+	+	+
Topic relevance	+	+	+	+	+	+	+	+	+
Learning outcomes	+	+	+	+	+	+	+	+	+
Programme evaluation	+	-	+	-	+	-	+	+	+
Multiple advertising channels	-	-	-	+	+	+	+	+	+
Participants' progress assessment	+	-	-	+	+	+	-	+	+

Legend: (+) criterion met; (-) criterion not met

In Croatia, the Forest Advisory Service provided all selected examples of good practice (Table 4). Those referred to training programmes on ‘Silvicultural work on biological regeneration’, ‘Course on forest preservation’ and ‘Recreational forest functions’ [3]. In all these training programmes learning outcomes were specified, multiple methods were applied (lectures accompanied with demonstrations, exercise and practical examples) and assessment of participants’ progress was conducted. Through a short questionnaire the participants evaluated only the ‘Course on forest preservation’. The course ‘Recreational forest functions’ addressed an increasingly relevant topic due to increasing societal demands toward forests, especially in urban areas.

Several providers implemented Slovenian examples of good practice. The course ‘Forest management and silvicultural measures after natural disasters’ was provided by the Biotechnical Faculty, University of Ljubljana, Slovenian Forestry Institute and Slovenia Forest Service. The second example of good practice, the ‘PAWS MED training course for forest pedagogy’, was provided by the Slovenia Forest Service and the PAWS MED project group, while ‘The basic training for Study Circle leader and mentors’, was provided by the Slovenian Institute for Adult Education [3]. Each Slovenian example of good practice addressed various target groups, such as forestry professionals, forestry students and teachers, hunters, nature conservationists, civil society, forest owners, researchers, etc. Furthermore, in all examples, multiple methods were applied (beside indoor and outdoor presentations, methods included practical work, group work and discussion), learning outcomes were specified, programme evaluation by participants conducted, and various means for promotion of the training programmes used.

DISCUSSION AND CONCLUSIONS

Lessons Learnt and Suggestions for the Improvement of SFM-Related VET and LLL Curricula in Austria, Croatia and Slovenia

Although the existence of various SFM-related professional training programmes in the study area is evident, still there is room for improvement. In all countries, there is a need for (i) upgrading educational approaches through specification of learning outcomes, programme evaluation, assessment of participants´ progress and increase of advertising efforts, (ii) clustering potential participants according to their knowledge level, and (iii) integrating innovative means of knowledge transfer.

Specified learning outcomes should be stated in each VET and LLL programme in SFM in order to give clear indication of the main skills and competences the trainees are supposed to obtain during a course. This is of special importance for Croatia (Table 3). The analysis showed that programme evaluation and the assessment of participants’ progress were weak spots in all countries. While programme evaluation is pertinent for receiving feedback from participants on the respective training, programme assessment is important for assessing the level of gained knowledge and trainees’ readiness for further career [39]. However, both may be taken up for the further development and/or improvement of the courses [3, 39, 40, 51]. In order to secure the successful knowledge transfer, the assessment of participants´ progress should be further developed and conducted through various tools, such as an exam, a portfolio, a short essay, practical work or a certification [3, 39, 51].

The importance of dissemination of respective information material to potential learners in order to attract them to participate in VET and LLL programmes in SFM is indisputable today. Although the utilization of multiple channels exists, the suggestion is to use social media as well, which is becoming more popular nowadays and is offering a diverse set of tools for communication beneficial to foster the broad distribution towards specific target audiences [3].

Further advancement may be achieved by clustering potential participants according to their knowledge level. Since forestry and forest-related sectors include various stakeholders (from private forest owners over nature conservationists to forestry professionals) who can become lifelong learners in SFM, a pyramid of needs may well represent their learning demands (Figure 3). It represents the level of knowledge that might be appropriate for a certain group of learners and highlights an approach to cluster individuals according to the level of knowledge they may need to obtain in order to gain a certain level of expertise. The pyramid is divided into three categories and indicates the entry point at which trainee accesses SFM-related VET and LLL. Basic denotes the lowest level of knowledge provided and offers learners a starting point in SFM. L1 provides professional knowledge and skills on a broad portfolio of topics related to SFM, and L2 ensures gaining expert level know-how in a certain domain of SFM [3].

The use of innovative methods for knowledge transfer such as study circles and e-learning in the existing or new curricula is highly recommended in all countries in the study area. Study circles represent non-individual learning approaches with an emphasis on dialogue and aim at linking educational or training messages with local needs and specifics and to empower by engagement in self-selected topics, usually representing the strengths of the target group [52]. This includes i) setting learning goals in a small group, ii) self-selected location, intensity and structure, and iii) obligatory final public presentation of

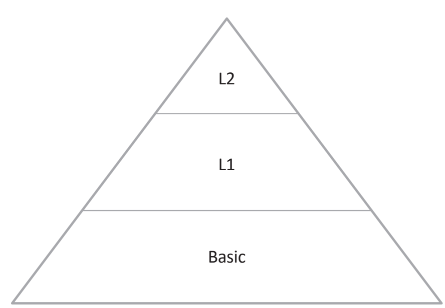

FIGURE 3. Generic scheme for clustering adult learners based on the level of knowledge (source: [3]).

learning results and gains [3]. Study circles directly address local needs, engage local people and materialize results [52], thus they are useful for complex issues such as SFM [3] and for learners with basic level of knowledge. E-learning refers to distance education and training supported by information and communication technologies [4]. Some of the major advantages of e-learning adoption are: improving access to education, improving student choice over when, where and how to engage in the learning processes, improving efficiency and effectiveness of education, saving time and money since there is no need for the trainees or teachers to travel and possibility to upgrade the learning material up-to-date [53, 54]. However, main disadvantages are related to the physical separation between the teacher and the trainee, especially when there is a problem which may be difficult to solve or a problem in comprehending course information [53]. With regard to our target groups, e-learning courses are more suitable for younger forestry professionals, and employees of public institutions related to nature protection. They often work in remote areas and have main preconditions for e-learning, which are computer literacy and Internet access. On the other hand, study circles are applicable for all target groups regardless of age, but could be especially useful for older participants that are often not tech savvy.

Even if programmes' topics may relate to national needs within forestry sectors, they should be regularly screened and updated according to international agendas and emerging issues [3]. In order to cope with increasing uncertainty and expanding risks forest ecosystems are facing, it is an important task to open up recent training offer to innovative forms of learning, combinations of topics and learning environments.

Limitations of the Study

The analysis took into account training programmes that we were able to obtain either from Internet search on providers' websites or directly from major providers. We did not take into account trainings that may be related to SFM but were not specifically targeting our target groups. For instance, in Croatia training on how to operate safely with chain saw is provided by several other providers. However, these providers are targeting general population. Provided data did not allow exploration of programmes' outreach in terms of the number of participants in each programme. We are aware that the final list of programmes provided to our target groups is not comprehensive, and probably some programmes have been left out due to sampling procedure. However, we think that we succeeded in mapping the majority of training programmes and the most important providers in these countries, allowing us to identify examples of good practice, as well as weak points, and provide recommendations for the improvement.

We believe this paper is valuable in its attempt to provide suggestions and recommendations on how to improve VET and LLL programmes related to SFM in the analysed countries. Hence, it would be primarily relevant for training providers in analysed countries, but also for other organisations promoting VET and LLL or those working on the development of education policies.

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PRELIMINARY COMMUNICATION

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First Record of Biocontrol Agent *Torymus sinensis* (Hymenoptera; Torymidae) in Bosnia and Herzegovina

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ABSTRACT

Background and Purpose: *Dryocosmus kuriphilus* is an invasive insect species of sweet chestnut (*Castanea* spp.) originating from China, and the only effective control measure against this pest is classical biological control with introduced parasitoid *Torymus sinensis.* This parasitoid has been widely released in many European countries, but it also has the ability to rapidly spread naturally. No official releases have been done in Bosnia and Herzegovina.

Material and Methods: *D. kuriphilus* galls were collected in July 2017 on 6 localities in forest district Unsko (Una Sana canton) in Bosnia and Herzegovina. Presence and parasitism rates of *T. sinensis* were recorded in the entomological laboratory, Croatian Forest Research Institute. *T. sinensis* larvae were identified morphologically and by being compared with the voucher specimens.

Results and Discussion: *Torymus sinensis* larvae were positively identified in the examined *D. kuriphilus* galls from all localities in Bosnia and Herzegovina. Parasitism rates ranged from 44.83 to 74%. Occurrence and high parasitism rates in Bosnia and Herzegovina observed in this study are not results of biocontrol releases of *T. sinensis*, but can be attributed to natural spread from Croatia. High parasitism rates observed in this study can indicate that the parasitoid was present in Bosnia and Herzegovina in 2016.

Conclusions: This study presents the first record of *Torymus sinensis* in Bosnia and Herzegovina. We predict that the parasitoid will continue its spread over Bosnia and Herzegovina in sweet chestnut forests and orchards and that it will act as effective biological control agent against *D. kuriphilus.*

Keywords: parasitoid, invasive species, *Dryocosmus kuriphilus*, natural spread, classical biological control, parasitism rate.

INTRODUCTION

Dryocosmus kuriphilus Yasumatsu (Hymenoptera; Cynipidae) is an invasive insect species, originating from China, which has spread in sweet chestnut (*Castanea* spp.) forests and orchards around the word [1]. In Europe, it has been first introduced to Italy [2] and from there it spread to the majority of European countries [1]. In Bosnia and Herzegovina *D. kuriphilus* was first recorded in 2015 in Una Sana canton [3]. *D. kuriphilus* is regarded as a serious threat to chestnuts, especially to fruit production [4] and crown leaf area loss [5]. Parasitoid *Torymus sinensis* Kamijo [Hymenoptera; Torymidae] has successfully been used as a classical biological control agent against *D. kuriphilus* and it has been released in biocontrol campaigns in Japan, the USA, Italy, France, Slovenia, Croatia and Hungary [6, 7, 8, 9, 10, 11]. *Torymus sinensis* is native to China, phenologically well synchronised with *D. kuriphilus*, it is highly specific, and lowers the outbreak levels of its host [9, 12, 13]. This parasitoid has shown high dispersal ability by being able to cover more than 70 km in only a few days aided by wind [13]. Croatia has done extensive biocontrol releases of *T. sinensis* since 2014, and apart from releases, the parasitoid has also rapidly spread from Italy over Slovenia to Croatia and has built a viable population with parasitism rates up to 90% [11, 14]. Based on this experience, we have expected

T. sinensis to spread towards Bosnia and Herzegovina. Bosnia and Herzegovina has so far done no official releases of *T. sinensis* on its territory.

The aim of this paper is to report first record of biocontrol agent *T. sinensis* and its parasitism rates in sweet chestnut (*Castanea sativa* Mill.) forests of Bosnia and Herzegovina.

MATERIALS AND METHODS

D. kuriphilus galls were collected in July 2017 on 6 localities in forest district Unsko (Una Sana canton) in Bosnia and Herzegovina (Table 1). The galls were collected from randomly selected sweet chestnut trees from a height of 1.5-2.5 m. From each locality a sample of 100 galls was taken. Each gall from the sample was sliced open and examined under a binocular microscope Olympus SZX7 in entomological laboratory, Croatian Forest Research Institute. In dissected galls, larval chambers, the number of *T. sinensis* larvae, *D. kuriphilus* larvae and pupae (if present), and other parasitoid larvae were counted and parasitism rates were calculated: PR = (the number of *T. sinensis* specimens/the number of *D. kuriphilus* larval chambers) ×100 (%). *T. sinensis* larvae were identified morphologically [11, 15] and by being compared with the voucher specimens deposited at the Department for Forest Protection, Croatian Forest Research Institute. The larvae were stored in absolute ethanol at -20°C in entomological laboratory, Croatian Forest Research Institute, for further analyses.

RESULTS AND DISCUSSION

Torymus sinensis larvae were positively identified in examined *D. kuriphilus* galls from all six localities. Parasitism rates ranged from 44.83 to 74% (Table 1).

The results of our study show presence of *T. sinensis* in Bosnia and Herzegovina. Occurrence and high parasitism rates in Bosnia and Herzegovina observed in this study (Table 1) are not results of biocontrol releases of *T. sinensis*, but can be attributed to natural spread [13, 14]. This biocontrol agent spread naturally from Croatia over interconnected sweet chestnut forests and wooded chestnut patches bordering Croatia and Bosnia and Herzegovina in Una Sana canton. It has already been documented that *T. sinensis* is rapidly spreading naturally eastwards from Italy all over Croatia [14]. This rapid natural spread was additionally assisted by releases from laboratory rearing in Croatia in the area near the border with Bosnia and Herzegovina in 2016 and 2017 [14]. High parasitism rates observed in this study can indicate that the parasitoid was present in Bosnia and Herzegovina in 2016, but was not sampled and identified. We predict that the parasitoid will continue its spread over Bosnia and Herzegovina in sweet chestnut forests and orchards and that it will act as effective biological control agent against *D. kuriphilus*, lowering its population and damages in sweet chestnut forests.

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TABLE 1. Localities, coordinates and parasitism rates of *Torymus sinensis* for the samples taken in Una Sana canton, Bosnia and Herzegovina, in 2017.

Locality name (management unit/compartment/locality)	WGS coordinates (x; y)	*Torymus sinensis* parasitism rates (%)
Gomila/54/Projsa	15,960596; 44,979998	44.83
Gomila/61/Pivnice	15,995468; 45,001145	53.75
Baštra-Ćorkovača/50/Ćorkovača	16,143863; 45,060535	51.98
Glinica/22/Radoč	16,118054; 45,078491	61.64
Glinica/46/Zaradostovo	16,062802; 45,074912	65.43
Kladušnica/24/Šiljkovača	15,785067; 45,150493	74.00

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Plantation Silviculture of Black Locust (*Robinia pseudoacacia* L.) Cultivars in Hungary – A Review

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ABSTRACT

Background and Purpose: Black locust (*Robinia pseudoacacia* L.) is the most widespread tree species in Hungary, occupying approximately 24% of the forested land and providing 25% of the annual timber output of the country. Due to the demands of consumers new cultivars are to be produced by improvement techniques and introduced into practical forestry use. This review provides a practice-oriented survey on black locust cultivar's management in Hungary.
Material and Methods: There are several cultivars and cultivar-candidates for high volume, high quality saw logs; for pole and prop, fuelwood and fodder production, of which there are several multipurpose varieties. Tending guidelines of stands established with the selected black locust cultivars are in some ways different from stands established by seedlings or regenerated by coppicing.
Results and Conclusion: It is important to know how stand density influences production and how it can be manipulated. This has already been worked out for most of the major European tree species that can be grown plantation-like. Many countries have some form of production or yield models based on various spacing and thinning regimes, which are usually entered via site index curves based on height and age. Black locust plantation silviculture can come to be synonymous with high-input intensive management of monocultures for the production of a relatively narrow range of industrial products. However, there is no doubt that plantation silviculture will become increasingly important in more and more countries with special regard to the marginal site conditions.

Keywords: clonal approach, growth, growing space, yield

INTRODUCTION

Black locust (*Robinia pseudoacacia* L.) is the most widespread tree species in Hungary, occupying approximately 24% of the forested land (465 thousand hectares) and providing 25% of the annual timber output of the country [1]. The mean wood volume of all black locust forests is 125 $m^3 \cdot ha^{-1}$, with a mean volume of 190 $m^3 \cdot ha^{-1}$ at the final cutting age (31 years on average). Black locust forests in Hungary have been established on good, medium and poor quality sites. The production of good-quality timber is only possible on sites where adequate moisture is available and the soil is loose, well aerated, and rich in nutrients and organic matter. Black locust forests on medium and poor quality sites are managed for the production of fuel wood, fodder, poles, props, and for amelioration [2, 3].

Black locust can be regenerated naturally, from root suckers, or artificially, with seedlings. To establish new black locust plantations (stands) seedlings are used. There are some favourable biological features of black locust, which make both regeneration methods possible. For seedlings production seeds are produced in a wide range of climatic conditions, they germinate rapidly, and preserve their germination capacity for a long time. Black locust cannot be regenerated by seeds in natural way due to its very hard seed coat. On the other hand, the root system is very plastic, its vegetative growth from fragments is intensive and it is hard to uproot [4].

Besides Hungary, Romania, and Bulgaria where black locust has a great importance in forestry practice, there are two big regions where the fast spread of this tree species can be expected: in the Mediterranean countries of Europe (Italy, Greece and Turkey) and in Asia, where China and Korea may be the most prominent black locust growers. In these regions, black locust has been widely valued as a tree species that performs well in reclaiming disturbed lands as well [5].

MATERIAL AND METHODS

Black Locust Selection Programme in Hungary

Since the introduction of black locust into Hungary this tree species has been closely associated with agriculture, since its wood can be utilized for many agricultural and domestic purposes. After World War II its significance changed, because large-scale farms had less demand for wood and the timber industry was not willing to buy black locust wood. It was necessary to improve the quality of final products of black locust forests in order to meet the demands of consumers. Therefore, new cultivars had to be produced by improvement techniques introducing them into the practical forestry use [5].

To fulfil the above-mentioned tasks, a new strategy of several stages started in the Hungarian Forest Research Institute in 1961. The improvement strategy aimed to improve the quality of black locust stands, which were considered to be separate provenances. In the best black locust stands, tree groups of shipmast stem forms, and then plus trees were selected by B. Keresztesi and his colleagues [6]. The offspring of these selected trees were vegetatively propagated and grouped together into cultivars. Thus, cultivars are mostly composed of several clones, but there are also some one-clone-cultivars, too [7].

Grafts with shoots taken from plus trees were made and planting stocks were raised from them by green cuttings. The basic material produced in this way served as starting material with the help of a variety trial established in the Arboretum of the Hungarian Forest Research Institute in Gödöllő, on a rusty brown forest soil developed over sand. The development of this trial continues up to date. In the meantime, breeding aims were widened by taking the demands of bee-keeping into consideration, such as the onset and length of flowering, and nectar yields [6, 8]. Some trees were selected abroad and others in Hungary and were chosen by beekeepers, due to their excellent honey production.

The main target of improvement is to improve the quality of stem, so to increase the output of industrial wood. Based on timber volume at felling age the following cultivars may be assessed as best: *'Jászkiséri'*, *'Üllôi'*, *'Nyirségi'*, *'Kiskunsági'*, *'Kiscsalai'* and *'Pénzesdombi'*. At the moment 7 black locust cultivars are approved by the competent Hungarian national office.

Propagation of cultivars was first planned by seedlings, but seed orchards produced small quantities of seed, and therefore it was necessary to develop techniques for vegetative propagation (with green cuttings, root cuttings and micropropagation) [6].

Site Requirements for Successful Black Locust Plantation Silviculture

The variable nature of geographical conditions in Hungary and the large area of black locust stands have made it possible to determine its site demands and to characterize suitable sites. This task has been solved by the Hungarian system for forest site classification [9, 10]. The classification is based on four dominant factors, which are: climate, hydrologic conditions (non-precipitation water resources, such as ground-water, inundation waters etc.), genetic soil type, physical make up and rootable depth.

The climatic conditions in the sessile oak - Turkey oak (Table 1) and forest-steppe zones of Hungary (Table 2) cover the black locust's requirements [11]. It is susceptible to late and early frosts, and therefore it is not recommended for sites in higher hilly zones and in areas where frost hollows are present. Good results can be attained in regions where the mean annual temperature is over 8˚C.

The genetic soil type, soil depth and physical properties of the soil are the factors which must be regarded before the planting operation as well. From this point of view soils of shallow rootable depth, of poor water regime and coarse sand or with many stones are unfavourable. Clay texture is also unfavourable due to poor aeration and compact condition. Fine sands and light loamy soil types are good for black locust, provided the depth of the soil is enough [10].

RESULTS

Recommendations for Tending Operations (Enlargement of Growing Space) for Black Locust Cultivar Plantations

Tending guidelines of stands established with the selected black locust cultivars are in some ways different from the stands established by seedlings or regenerated by coppicing. It is harder to separate the tending phases (cleaning, thinning), which are typical for common black locust stands, because growth properties of monoclonal cultivars are theoretically identical, while multiclonal ones are similar to each another. The aim of certain tending cuttings particularly is to form the growing space for optimal growth of the trees [12].

On good and excellent sites altogether two enlargements of growing space are applicable to produce basic material of sawmilling industry in stands planted in 2.5×2.0 m spacing (5 m^2·tree growing space^{-1}) (Table 3). During the first enlargement of the growing space (at the age of 9-10) stem number reduction is approximately 50%, so spacing will be 2.5×4.0 m (10 m^2·tree growing space^{-1}) after the tending. The second enlargement of the growing space (at the age of 16-17) also reduces the number of stems by 50%. During this, the greater part of the yield is already suitable for industrial utilization, so growing technology can be considered economically profitable.

Prospective tree plantations of the selected black locust cultivars with tending according to the demonstrated model in Table 4 are rentable only on excellent and good sites. In case of planning to reduce harvest rotation ages (20-25 years) the aim of the growing can be manufacturing pole, or saw log of lower size limit.

TABLE 1. Site types suitable for black locust in the sessile oak - Turkey oak climate zone [8].

Site type variety				Expected yield and rotation age
Genetic soil type	**Hydrology**	**Rootable depth**	**Physical make-up**	
Humic sand	free draining	shallow	sand	poor
Rusty brown forest soil	free draining	shallow medium deep deep	sand sand sand loam	poor medium, 25 years good, 30 years good, 30 years
„Kovárvány" brown forest soil	free draining	shallow medium deep deep	sand sand sand	medium, 25 years good, 30 years good, 30 years
Chernozem brown forest soil	free draining	shallow medium deep	loam loam	poor medium, 25 years
Brown forest soil with residual carbonate	free draining	medium deep	loam loam	medium, 25 years good, 30 years
Colluvial forest soil	free draining	medium deep	loam	good, 30 years
Rusty brown forest soil	periodic water influence	medium deep deep	sand sand	good, 25 years good, 30 years
„Kovárvány" brown forest soil	periodic water influence	medium deep deep	sand sand	good, 25 years good, 30 years
Meadow soil	periodic water influence	shallow	sand	medium, 25 years
Meadow forest soil	periodic water influence	medium deep	sand	medium, 25 years

TABLE 2. Black locust site types in the forest-steppe climate region [8].

Site type variety				Expected yield and rotation age
Genetic soil type	**Hydrology**	**Rootable depth**	**Physical make-up**	
Humic sand combinations	free draining	medium deep deep very deep	sand sand sand	poor medium, 25 years good, 30 years
Colluvial soil	free draining	medium deep	sand loam	medium, 25 years medium, 25 years
Rusty brown forest soil	free draining	medium deep deep	sand sand	poor (afforestation) medium, 25 years
„Kovárvány" brown forest soil	free draining	medium deep deep	sand sand	poor (afforestation) medium, 25 years
Leached chernozem soil	free draining	medium deep deep very deep	loam loam loam	medium, 25 years good, 30 years good, 30 years
Lime-carbonate coated chernozem	free draining	medium deep deep	loam loam	medium, 25 years good, 30 years
Meadow chernozem	free draining	medium deep deep very deep	loam loam loam	medium, 25 years good, 30 years good, 30 years
Alluvial chernozem soil	free draining	medium deep deep very deep	sand loam sand loam sand loam	medium, 25 years medium, 25 years good, 30 years good, 30 years good, 30 years good, 30 years

Yield of the Selected Black Locust Cultivars

Based on growth examinations of the selected black locust cultivars, mainly with shipmast locust character, characteristics of their growth pattern are similar to the common black locust's [8]. A yield table has been compiled for those black locust cultivars that are suitable for log production ('Nyírségi', 'Kiskunsági', 'Jászkiséri', 'Appalachia', 'Üllői' black locust) by using the data of the growing trial established in the Arboretum of the Forest Research Institute in Gödöllő, and other areas of the country (Tét, Szentkirály,

TABLE 3. Models of enlargement of the growing space of the selected black locust cultivars. The aim of growing: saw log. Initial spacing: 2.5x2.0 m. Initial number of seedlings: 2000 stems·ha^{-1} [3].

Label		Age (year)	H (m)	DBH (cm)	N (stems·ha^{-1})	V (m^{3}ha^{-1})
		Yield Class I				
1.	Enlargement of growing space	9–10	14	12	1000	90
2.	Enlargement of growing space	16–17	20	17	500	120
3.	Harvest cutting	30	25	25	400	300
		Yield Class II				
1.	Enlargement of growing space	9–10	14	12	1000	90
2.	Enlargement of growing space	16–17	20	17	500	120
3.	Harvest cutting	30	25	25	400	300
		Yield Class III				
1.	Enlargement of growing space	9–10	12	10	1000	60
2.	Enlargement of growing space	16–17	18	16	500	100
3.	Harvest cutting	30	23	23	500	240

H – height; DBH – diameter at breast height; N – number of stems per hectare; V – expected total volume
Notation: Data are referred to the dominant stand, that is stand part, after finishing enlargements of the growing space. Yield table: Rédei *et al.* [8].

TABLE 4. Models of enlargement of the growing space of plantations established by the selected black locust cultivars. The aim of growing: poles, perspectively saw log. Initial spacing: 3.0 x 3.0 m. Initial number of seedlings: 1100 stems·ha^{-1} [3].

Label	Age (year)	H (m)	DBH (cm)	N (stems·ha^{-1})	V (m^{3}ha^{-1})
		Model I			
Before enlargement of growing space	10	13	10	1100	65
After enlargement of growing space	10	14	11	700	55
Harvest cutting	20	20	18	700	180
		Model II			
Before enlargement of growing space	8	10	8	1100	40
After enlargement of growing space	8	11	9	750	35
Before enlargement of growing space	15	17	14	750	105
After enlargement of growing space	15	18	15	500	85
Harvest cutting	25	22	20	500	180

H – height; DBH – diameter at breast height; N – number of stems per hectare; V – expected total volume

Ófehértó). Table 5 shows informative data on the yields of the main stands of selected black locust cultivars suitable for saw log production.

Height growth related to the age of the main (dominant) stands of the mentioned cultivars can be seen in Figure 1 for five yield classes. The explanatory equation of the relative growth pattern is:

$$H_{gmean}=19.4669 - 57.08546 \times [\log(A)] + 73.57742 \times [\log(A)]22.80025 \times [\log(A)]3 + 28.08599 \times x [\log(A)]4,$$

where: A = age (year), and H_{gmean} at the age of 20 = 100%.

Height values at the age of 20 (base age, 100%) are: yield class I: 22 m; yield class II: 20 m; yield class III: 18m; yield class IV: 16 m; yield class V: 14 m.

Volumes related to the age of the main stands of the same varieties are shown in Figure 2. The explanatory equation for describing the relationship between mean height (H_{mean}) and volume (V_{mean}) is the following:

$$V_{mean}= 23.750 – 2.325H_{mean} + 0.512H^2_{mean}$$

DISCUSSION AND CONCLUSIONS

Since spacing influences the total production and the dimensions of forest products, it can have a profound effect on the value of a crop. It is important to know how stand density influences production and how it can be manipulated.

In practice, there are two main aspects of spacing to consider – the effects of early or initial spacing and the effects of thinning. Initial spacing are quite often the densities at which plantations remain, except for mortality, especially where thinning is uneconomic or leads to windthrow. Since the initial spacing of forestation by the selected black locust cultivars is concerned with the basis

FIGURE 1. Height of the main stands of the selected black locust cultivars for saw log production related to the age in different yield classes.

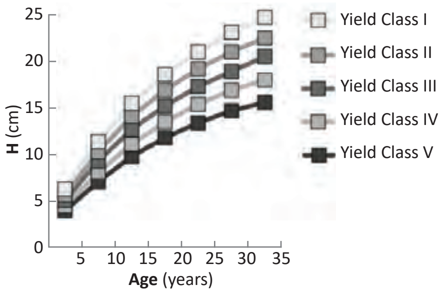

FIGURE 2. Volume of the main stand of the selected black locust cultivars for saw log production in different yield classes.

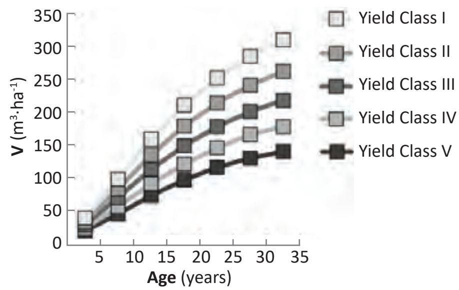

TABLE 5. Yield of the main stands of the selected black locust cultivars suitable for saw log production [3].

Yield class	Age (year)	Mean DBH (m)	Mean H (m)	V ($m^3 \cdot ha^{-1}$)	G ($m^2 \cdot ha^{-1}$)	N ($stems \cdot ha^{-1}$)
I	5	8.7	6.4	40	7.5	2327
	10	14.8	11.5	99	12.6	1214
	15	19.2	15.6	160	16.5	863
	20	22	18.7	212	19.4	703
	25	23.8	21.2	253	21.6	612
	30	25	23.2	286	23.4	554
	35	25.7	24.8	311	24.9	513
II	5	7.9	5.8	34	6.9	2588
	10	13.5	10.4	84	11.5	1350
	15	17.4	14.2	136	15.1	960
	20	20	17	180	17.8	782
	25	21.7	19.3	215	19.9	681
	30	22.7	21.1	242	21.5	616
	35	23.4	22.6	263	22.9	571
III	5	7.1	5.2	29	6.2	2911
	10	12.1	9.4	71	10.5	1518
	15	15.7	12.8	114	13.9	1080
	20	18	15.3	150	16.2	880
	25	19.5	17.4	179	18.2	766
	30	20.5	19	202	19.6	693
	35	21	20.6	219	20.8	642
IV	5	6.3	4.6	24	5.6	3374
	10	10.6	8.2	57	9.3	1769
	15	13.8	11.2	92	12.3	1249
	20	16	13.6	122	14.6	1006
	25	17.4	15.5	147	16.4	869
	30	18.3	17	167	17.8	784
	35	18.7	18.1	179	18.8	731
V	5	5.6	4.1	20	5.1	3834
	10	9.3	7.2	46	8.3	2046
	15	12.1	9.9	74	11	1343
	20	14	11.9	98	13	1168
	25	15.2	13.5	117	14.5	1014
	30	15.9	14.8	131	15.7	915
	35	16.2	15.7	141	16.6	857

of growing experiments in the Danube–Tisza sandy soil region (Central Hungary) and in the Nyírség (East Hungary), 2.5×2.0 m spacing seems to be most appropriate [12]. In forestation, those are established on sites that expectedly enable medium growing (the cultivars) varieties in wider spacing than the recommended which cannot close sufficiently because of their loose crown. Therefore, the soil is extremely weedy, even in the case of soil cultivation that corresponds to regulation, too.

It is very important to execute the stem and crown shaping according to the technological prescription. In base spacing recommended by us [5], first crown shaping is to be carried out when the mean height of the plantation reaches 5-6 metres. The second crown shaping should be done in time when the mean height of the plantation is 8-10 metres (reach of about 4 m branch-free stem is desired).

Forest tending technologies applicable for different cultivars have not yet been elaborated sufficiently. A useful indicator of the size of the removed tree, and hence for describing the thinning type, is the ratio of the mean volume of thinnings (v) to the mean volume of the main stand found before thinning (V) [5]. There are three types of thinning which can be distinguished: systematic, selective and combination [6]. According to our experiences the selective thinning method is to be used mostly in the plantations established with selected black locust cultivars. The best trees (superior trees) are marked when they are young and favoured in subsequent thinnings. Because some inevitably become damaged or do net grow as well as expected, it is necessary to work at the outset two or three times the number that will actually form the final crop.

Black locust plantation silviculture can come to be synonymous with high-input intensive management of monocultures for the production of a relatively narrow range of industrial products. But, there is no doubt that plantation silviculture will become increasingly important in even more countries with special regard to the marginal site conditions.

At the moment the total area of black locust globally is about 2.5 million ha. In the near future there are two continents, where the fast spread of black locust can be expected. The first is the Asian continent, in China and South and North Korea, while in the European continent France, Turkey, Romania and Germany may be the most prominent black locust growers.

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