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Health Condition of European Beech (*Fagus sylvatica* L.) According to Provenances in International Provenance Trial

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ABSTRACT

The performance of European beech (*Fagus sylvatica* L.) is severely threatened by abiotic and biotic stresses, but the resilience of its provenances from distinct geographic areas has not been sufficiently studied. Therefore, the performance of European beech was investigated in an international provenance trial consisting of twenty-one natural populations originating from Central Europe and Southeast Europe located on Medvednica Mountain (Croatia). The performance of European beech was investigated by characterizing I) damage types, II) crown damage intensity, III) damage frequency, and IV) clustering of provenances based on damage types. Anthracnose, galls, chewing damages, and aphids were recorded on leaves, and canker on the trunk and branches. The crown damage intensity was minute (less than 10%) for all types of disease. Anthracnose was the most common damage, followed in descending order by galls, canker, chewing damages and aphids. When the types of damage were analysed using descriptive statistics (frequency analysis and clustering), significant differences were recorded between provenances (χ^2=322.19, p<0.0001). European beech provenances were classified into four clusters. Aphids and galls caused the least and the highest damage, respectively, in each cluster, except for Cluster 4, where anthracnose caused the highest damage. The results of this study showed generally good health condition of European beech provenances originating from Central and Southeast Europe in the period of the investigation.

Keywords: European beech; pests; diseases; international provenance trial

INTRODUCTION

European beech (*Fagus sylvatica* L.) is a deciduous, monoecious, anemophilous tree species in the *Fagaceae* family. As the dominant tree species in Europe, European beech has a large distribution range extending from Sicily in southern Italy (ca. 37.7N) to Bergen in southern Norway (ca. 60.7N) (Fang et al. 2006). It covers approximately 14 million hectares of forest land in Europe (Wühlisch 2010). In Croatia, European beech is a native tree species, accounting for 47 percent of the forest area. Its natural structure has been preserved in pure or mixed stands (Vukelić and Rau 1998). Moreover, it has a wide ecological valence at altitudes in Croatia; ranging from the Mediterranean vegetation region at about 20 m above sea leavel to the sub-mountainous vegetation region at about 1570 m above sea level (Pilaš et al. 2016). The wide geographical distribution of European beech indicates high adaptability to climatic, local edaphic, and soil hydrological parameters (Rennenberg et al. 2004, Bolte et al. 2007, Gessler et al. 2007, Kramer et al. 2010;). Studies on the genetic composition of European beech populations indicated that ecotypes are formed by both local and macroclimatic factors (Gömöry et al. 2007, Ivanković et al. 2008a, 2008b Mátyás et al. 2009). Considering the influence of climatic factors on the distribution range of European beech, climate change-based models predicted that European beech can expand its northern range while losing habitat at its southern distribution area (Bréda et al. 2006, Gessler et al. 2007, Kramer et al. 2010).

The adaptability and growth characteristics of European beech were investigated in a beech provenance trial series. The study was conducted as part of the European Union project "European Network for the Evaluation of the Genetic Resources of Beech for Appropriate Use in Sustainable Forestry Management" (AIR3-CT94-2091) of the Institute of Forest Genetics, Grosshansdorf, Germany (Muhs and Wühlisch 1993, Wühlisch 2008). Croatia contributed to the International Beech Provenance Trial project by supplying beechnuts and by establishing three international European beech provenance trials (Gračan 2001, Ivanković 2010).

European beech is thought to be threatened by changing climatic conditions (Gessler et al. 2007), although it is less affected by severe diseases than other forest tree species (FAO 2009). Still, the damages caused by biotic and abiotic stresses to European beech threaten its survival (Bahnweg et al. 2005, Tomiscek 2006, FAO 2009, Gossner et al. 2014, Unterseher et al. 2016). For example, defoliation of European beech was caused by a combination of climate change, edaphic factors, and various biotic factors (FAO 2009). In addition, sun exposure or logging accidents caused cracks in beech bark accompanied by secondary fungal and insect infestations (Tomiscek 2006). However, fungal colonization was reduced more during the hot and dry seasons than during ozone treatment or sun exposure (Bahnweg et al. 2005). Local stand conditions in interactions with fungi in the phyllosphere, as well as leaf physiology influenced the diversity and composition of the leaf mycobiome (Unterseher et al. 2016). Microclimatic conditions had an important influence on the variability of herbivory (Gossner et al. 2014).

In Croatia, the health condition of European beech is influenced by biotic factors, insects, and fungi. The detected insects were bark beetles (*Typhorychus bicolor* and *Ernoporus fagi*), sucking insects (*Cryptococcus fagi, Phyllapsis fagi*), gall midge (*Mikiola fagi*), and pests of cambial tissue and wood-boring beetles (*Trypodendron domesticum*), long-horned beetle (*Hylecoetus dermestoides*), beech buprestid (*Agrilus viridis*), and small weevil (*Rynchaeus fagi*) (Hrašovec 2003). The beech fungal diseases included root Phytophthora infection, Nectria bark diseases, leaf diseases, red heart and decay fungi (Diminić 2003, Arač 2010, 2016, Pernek et al. 2011). The drought was identified as the most significant abiotic factor threatening European beech in Croatia (Harapin 2003). Particularly, the predominant climatic parameter affecting the crown condition of European beech trees on Medvednica Mountain were annual temperature and precipitation during the vegetation period (Potočić et al. 2008, Seletković et al. 2009).

The aim of the study was to provide insight into the differences in hypersensitivity to pests and diseases between provenances of international European beech provenance trial, considering local climatic conditions. It investigated: I) damage types, II) crown damage intensity, III) damage frequency, and IV) clustering of provenances based on damage types.

MATERIALS AND METHODS

Study Site

International European beech provenance trial is situated on Medvednica Mountain (45° 53'N, 15° 55'E, elevation 730 m, slope with west-northwest exposure). It consists of twenty-one natural populations (150 plants each) originating from Central Europe (DE, CH, AT, and HU) and Southeast Europe (HR, BA, SR, and RO) (Table 1). It was established by the Croatian Forest Research Institute in March 2007 (Ivanković et al. 2008a, 2008b, Bogunović et al. 2020).

Health Status Assessment

The damage types in the European beech provenance trial were recorded by an overall visual tree assessment in July 2015. The presence of surviving and visually healthy trees was documented. For symptomatic trees, the overall crown, trunk, and branches were assessed for damage types. The damage types were classified according to symptoms caused by insect pests and pathogenic fungi. The following labelling was used for the damage types: colour change and curling of leaves caused by aphids (A), chewing damages (CD), galls (G), anthracnose (A), canker on the branch and trunk (C). The intensity of crown damage types was expressed as a percentage of the affected crown and scaled with an ordinal scale: 1=slight crown damage (<10%), 2=moderate crown damage (10%-50%), 3=severe crown damage (>50%). Canker infestation on the tree trunk and branch bark was recorded as follows: 0 represented the absence of a canker and 1 represented the presence of a canker.

Data Analyses

Descriptive statistics were carried out for the variables analysed. The data were calculated as follows and expressed as percentages: (I) survival = surviving trees / total planted tree; (II) health = healthy trees / surviving trees; (III) intensity of damage per provenance = damaged trees / surviving trees, and (IV) average intensity of damage (slight, moderate and severe) of each provenance. The calculations and graphs were performed with Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA). For statistical analyses, the sum of damaged trees per type of damage was calculated regardless of damage intensity. Chi-square statistics was used to test the distribution of damage types between European beech provenances, without data for aphids (Sokal et al. 1995). The data for aphids were excluded from the calculation due to small numbers. The statistical analyses for each type of damage are shown in frequency distribution tables and the mosaic maps. The optimal

Table 1. Data of the international European beech provenance trial (Medvednica Mountain, Croatia).

No.	Provenance label	Provenance name	Country	Latitude (N)	Longitude (E)	Elevation (m)
1.	HR24	Dilj Čaglinski	Croatia	45° 17'	18° 01'	350
2.	HR25	Vrani kamen	Croatia	45° 37'	17° 19'	600
3.	HR26	Lovrin kal	Croatia	45° 19'	14° 23'	900
4.	HR27	Miletka	Croatia	45° 24'	15° 01'	800
5.	BA30	Tajan, Zavidovići	Bosnia and Herzegovina	44° 23'	18° 03'	700
6.	HU42	Valkonya	Hungary	46° 30'	16° 45'	300
7.	DE46	Pfalzgrafenweiler	Germany	48° 46'	8° 35'	700
8.	DE47	Schelklingen	Germany	47° 59'	9° 59'	650
9.	DE48	Hoellerbach	Germany	49° 01'	13° 14'	755
10.	DE49	Hasbruch	Germany	53° 08'	8° 26'	35
11.	AT56	Scharnstein	Austria	47° 54'	13° 96'	480
12.	BA59	Bugojno Vranica, Bistrica	Bosnia and Herzegovina	43° 33'	17° 49'	750
13.	BA60	Tešanj, Crni Vrh	Bosnia and Herzegovina	44° 33'	17° 59'	500
14.	BA61	Bosanska Krupa, Bastra Čorkvaća	Bosnia and Herzegovina	44° 45'	16° 14'	720
15.	BA62	Dinara Devrek Tefen	Bosnia and Herzegovina	44° 06'	16° 30'	950
16.	RO63	Alesd	Romania	47° 11'	22° 15'	490
17.	RO64	Alba-Iulia	Romania	46° 10'	23° 05'	860
18.	CH65	Sihlwald	Switzerland	47° 12'	7° 21'	1050
19.	RS66	Avala	Serbia	44° 23'	20° 45'	475
20.	RS68	Fruška gora	Serbia	45° 10'	19° 55'	370
21.	RS69	Cer	Serbia	44° 12'	19° 50'	745

number of clusters was identified by hierarchical cluster analysis using complete linkage and Euclidean distance. K-means non-hierarchical cluster analysis was used to determine subsets of European beech provenances based on damage types. All statistical analyses were performed using the STATISTICA 13.5 statistical software (TIBCO Software, Palo Alto, CA, USA). Map generation was done with the QGIS software, version 2.16 (http://qgis.osgeo.org).

Local Climate Condition on Medvednica Mountain

The Croatian Meteorological and Hydrological Service provided meteorological data (maximum, average and minimum monthly temperatures, monthly precipitation, days with snow and frost) from August 2014 to July 2015, based on records from the state hydro-meteorological station Puntijarka (15°58'E, 45°55'N, 988 m), the closest weather station to the study site. A measure of site aridity proposed by de Martonne (1926) was given by the following relationship: $I = 12P/(T + 10)$, where ***I*** was aridity index, and input parameters were local monthly precipitation (P) in millimetres and average temperature (T) in degrees Celsius.

The values of the aridity index (***I***) were estimated according to the scale given by de Martonne (36): Dry ($I<10$); Semi-dry ($10 \leq I \leq 20$); Mediterranean ($20 \leq I \leq 24$); Semi-humid ($24 \leq I \leq 28$); Humid ($28 \leq I \leq 35$); Very Humid ($35 \leq I \leq 55$); Extremely humid ($55<$). Tables (S4 a, b, c) showed the meteorological data. These data confirm that the local climate could be described as Cfb according to the Köppen-Geiger climate classification, i.e. as a moderately warm, humid climate with warm summers and differences between the seasons (Zaninović et al. 2008). This climate has been termed „the climate of beech" (Šegota and Filipčić 1996).

RESULTS

Types of Damage

The survey of the provenance trial started with determination of the number of surviving and healthy trees to provide data for descriptive statistics. The surviving ranged from 60% (RO6) to 94.67% (HU42) and healthy trees ranged from 4.67% (RO63) to 68.00% (DE47) (S1). The health condition survey of the provenances was performed on the damaged trees. Four types of leaf damage were recorded: colour change and curling caused by aphids, chewing damages, galls, and anthracnose. Bark and wood damages recorded canker on the trunk and on branches. *Phyllaphis fagi*, a woolly beech aphid, was found on the underside of young beech leaves, causing yellowing and reddening as well as buckling of the leaf margins towards the underside (S2a). The winged and wingless viviparous beech leaf aphids were oval, pale yellow, and covered with dense waxy wool. Leaves chewing damages were present as bitten leaf sections (S2b) and leaf-mining (S2c). The causal insects of leaf bites and miners can be diagnosed by the mine shape, gallery and blotch. Many *Lepidoptera* and *Coleoptera* species produce leaf bites. Oval or elongated mines between veins with green lower epidermis without reticulation were caused by larvae of the moth *Phyllonorycter maestingella*. Mines that meandered between two lateral veins towards the leaf margin were caused by the larvae of the leaf miner moth *Stigmella* sp. The miner tunnels were filled with granular faeces. Also, larvae of the leaf miner beetle *Orchestes fagi* mine the leaves of beech. The mine begins as a duct on the midrib of the leaf and ends in a blotch. Woody, ovoid, unilateral galls (S2g), 4-10 mm long, produced by the beech gall midge *Mikiola fagi*, were present on the upper surface of beech leaves. Anthracnose disease symptoms on leaves were caused by the fungus *Apiognomonia errabunda*. The symptoms, i.e. leaf spots, develop from the leaf veins and spread over the leaf (S2e). Canker was observed on branches and the trunk. Symptoms included necrosis, sunken tissue, orange to reddish bark coloration, open canker, and tissue dieback. Twig and branch canker were caused by *Nectria cinnabarina* (Tode); trunk canker (S2f) by *Neonectria ditissima* (Tul.). Thus, a total of four damage types were recorded on beach leaves, with three damage types caused by insects and one by a pathogenic fungus. Canker, recorded on the bark of the trunk and on branches, was caused by pathogenic fungi.

The analysis of types of damage per tree showed a prevalence of three damage types. However, in provenances DE47, RS68, RO64, BA6, HU42 and provenance HR27, two and four types of damage per tree were observed, respectively. Trees with five damage types were not observed in this study. In general, trees with one damage type were most common, ranging from 63.92% (HR27) to 91.43% (DE47) (Figure 1).

Intensity of Crown Damage

The survey of the intensity of the European beech crown damage is shown in Figure 2. Eleven provenances were not infested by aphids; ten provenances showed slight crown damage by aphids, except RS66, showing 0.83% of the trees had severe crown damage (Figure 2a). Although galls were present in each provenance (Figure 2b), the most moderate and severe crown damage was observed in DE48 and DE46 (15.04% and 46.72% of the trees, respectively). BA62 was the least affected by galls and showed slight crown damage (7.07% of the trees). Moderate chewing crown damage was present in the HU42, DE48, RS66, BA62, and BA30 ranging from 0.70% to 1.41% of the trees. Severe chewing crown damage occurred in RS66 (0.83% of the trees) and BA62 (3.03% of the trees) (Figure 2c). Slight anthracnose crown damage was present in all provenances up to 48.89% of the trees (RO63) (Figure 2d). The provenance with the highest percentage of moderate anthracnose crown damage was RO64 (9.32% of the trees). The most severe anthracnose crown damage was found in BA60 (4.26% of the trees). Taken together, the lowest and the highest average slight crown damages were related to aphids (0.59% of the trees) and anthracnose (31.53% of the trees), respectively. The lowest average moderate and severe crown damages were related to aphids (0.00% and 0.83% of the trees, respectively). The highest average moderate and severe crown damages were related to galls and anthracnose (5.63% and 31.53% of the trees, respectively). The significant statistical difference between intensities of crown damages was shown: aphids (sample size=2473, $\chi2=26.430$; $p<0.0001$), galls (sample size=2473, $\chi2=1110.780$; $p< 0.0001$), chewing damages (sample size=2473, $\chi2=243.950$; $p<0.0001$) and anthracnose (sample size=2473, $\chi2=1.286$; $p< 0.0001$). Thus, examination of the intensity of crown damage in the provenance trial showed the predominance of slight crown damage (less than 10%) in four types of damage (aphids, galls, chewing damages, and anthracnose).

Branch canker was the lowest on the provenance DE49 (0.78% of the trees), the highest on HR26 (6.98% of the trees), and was not present on RO64, RS66, and CH65. Trunk canker was the lowest on DE49 (0.78% of the trees) and the highest on BA60 (13.83% of the trees) (Figure 3). The significant statistical difference between intensity of canker on trunk and branch was shown (sample size=2473, $\chi2=37.923$; $p< 0.0001$).

Table 2. Types of damage on European beech trees in the international provenance trial.

Type of damage	Cause of the damage (insects and fungi)
Color changing and curling of leaves	*Phyllaphis fagi* (L.)
Chewing damages on leaves	*Orchestes fagi* (L.), *Phyllonorycter maestingella* (Müller), *Stigmella hemargyrel-la* (Kollar), *Operophtera brumata* L., *Erranis defoliaria* (Clerck)
Galls on leaves	*Mikiola fagi* (Hartig)
Anthracnose on leaves	*Apiognomonia errabunda* (Rob.) Hohn.
Canker on the branch	*Nectria cinnabarina* (Tode)
Canker on the trunk	*Neonectria ditissima* (Tul.)

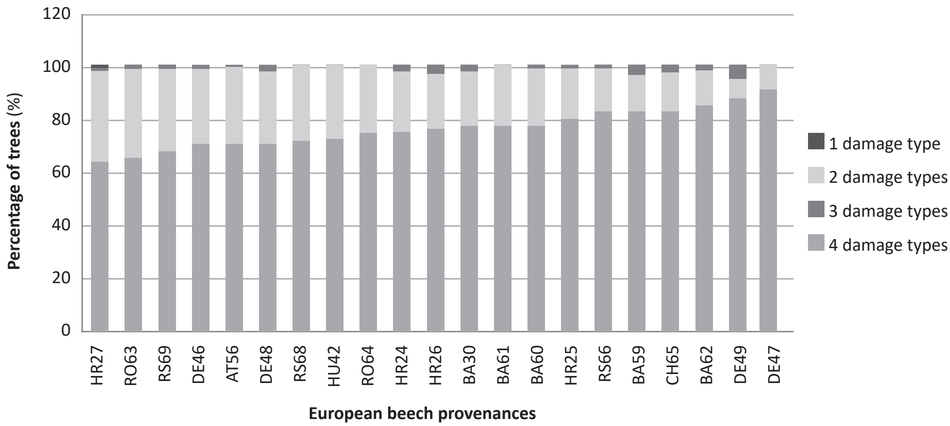

Figure 1. Percentage of trees of European beech provenances damaged by different damage types (Coding label of provenances: see Table 1).

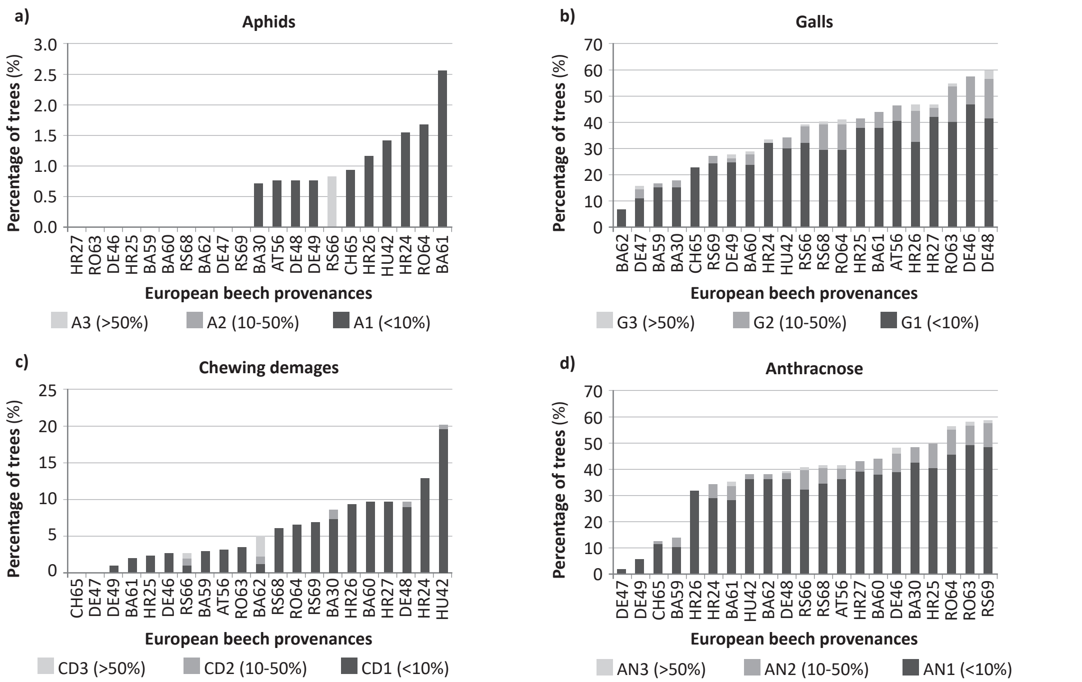

Figure 2. Intensity of crown damage by damage types: **(a)** aphids, **(b)** galls, **(c)** chewing damages, **(d)** anthracnose on European beech provenances (Coding label of provenances: see Table 1).

Frequency and Provenance Clustering Based on Damage Types

Frequency analyses of damage types are shown in frequency table (S3) and the mosaic map (Figure 4). According to damage frequency, anthracnose was the most common damage (42.62%), followed by galls (41.72%), canker (7.88%), chewing damages (7.02%), and aphids (0.76%). Anthracnose, galls and canker were found in each provenance. Provenances DE47 (0.09%) and BA30 (3.23%) were the least, HR25 (3.23%) the most anthracnose-damaged provenances. The provenances that were the least and the most damaged by galls were BA62 (0.33%) and DE48 (3.75%), respectively. The lowest and the highest canker damages were observed on DE49 (0.09%) and DE47 (0.85%),

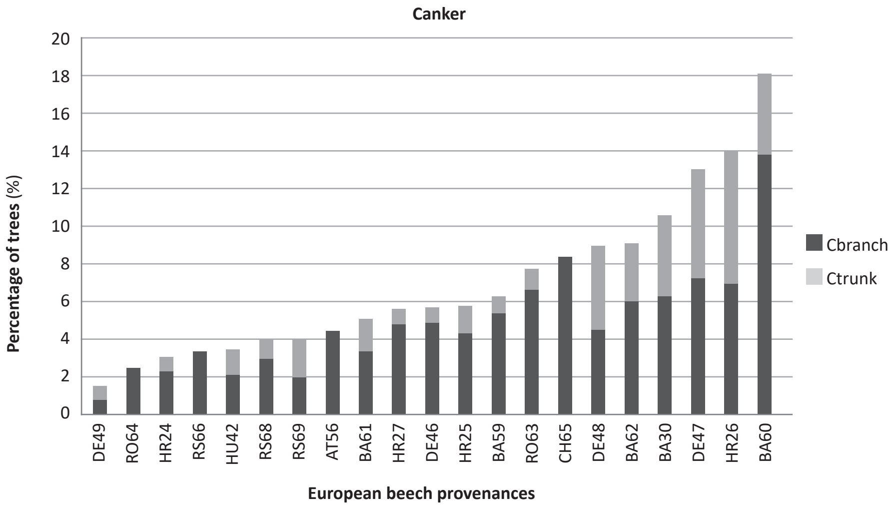

Figure 3. Percentage of canker per provenances (Coding label of provenances: see Table 1).

respectively. Chewing damages were detected in the range of 0.05% (DE49) to 1.38% (HU42) in most provenances, except for DE47 and CH65. Aphids were detected in the range from 0.05% to 0.14% in 11 provenances: AT56, BA30, HR26, DE48, DE49, CH65, RS66, HU42, HR24, RO64, and BA61. In the absence of aphid damage, the statistical chi-square test for damage to European beech provenances showed that there were significant statistical differences between provenances based on damage types (sample size=2091, $\chi 2$=322.19; $p<0.0001$). Thus, the dominant types of damage, anthracnose and galls, showed a total frequency of 84.34%, while canker, chewing damages, and aphids showed a total frequency of 15.66%.

The European beech provenances were grouped into four clusters based on damage type (Figure 5-7). Cluster 1 was characterized by the highest damage type of galls, followed in descending order by anthracnose, chewing damages, canker, and aphids. Cluster 1 included six provenances from Southeast Europe: RO63, BA61, HR24, HR26, RS68, and RS66, as well as one from Central Europe, HU42. Cluster 2 was characterized by the highest damage type by galls, followed in descending order by anthracnose, canker, chewing damages, and aphids. Cluster 2 included three Central European provenances (DE49, CH65, DE47) and Southeast European provenance BA59. Cluster 3 was characterized by the highest damage type due to galls, followed in descending order by anthracnose, chewing damages, canker, and aphids. Cluster 3 consisted of ten provenances from Central and Southeast European origins: DE48, HR27, AT56, DE46, HR25, RO64, BA30, BA60, BA62, and RS69. Cluster 4 was characterized by the highest anthracnose damage, followed in descending order by galls, canker, chewing damages, and aphids. Cluster 4 consisted of Southeast European provenances BA30, BA60, BA62 and RS69. Based on these data, aphids and galls caused the least and most damage, respectively, in all clusters except Cluster 4, where anthracnose caused the most damage. Provenances from Southeast Europe and Central Europe predominated in Cluster 1 and Cluster 2, respectively. Cluster 3 contained provenances from both origins. Cluster 4 was the smallest and most homogeneous, consisting of Southeast European provenances at approximately the same latitude (44°06'N-44°33'N). Taken together, the provenances (DE46, HR25, HR27, AT56, RO64 and DE48) with the most damaged trees were grouped in Cluster 3 whereas the provenances (DE49, DE47, CH65 and BA59) with the least damaged trees were grouped in Cluster 2. The Central and Southeast European provenances did not form discrete clusters based on clustering analysis.

The international European beech provenance trial was set up with a different number of representative provenances from each country. Germany was represented by four provenances. Two of the German provenances, the southwestern (DE46) and the southeastern (DE48) provenances, were assigned to Cluster 3 and the other two provenances (DE49 and DE47) to Cluster 2. DE49 originated from the northern part of Germany and was the northernmost provenance in the entire provenance trial. The other three German provenances were from the southern part of the country. The southernmost provenance was DE47 with the lowest damage among the German provenances, but the highest canker damage among the 21 provenances. The German provenances showed the highest susceptibility to galls, followed in descending order by anthracnose, canker, chewing damage, and aphids. The Swiss provenance (CH65) originated from the northwest of the country, near the French border, and was grouped into Cluster 2. Interestingly, chewing damage was not observed on CH65. Canker was the highest damage type of CH65, followed in descending order by galls, anthracnose and aphids. The Austrian provenance (AT56) was from the central part of the country and was grouped to Cluster 3. The highest damage type of AT56 was galls, followed in descending order by anthracnose, canker, chewing damage and aphids. Hungarian provenance (HU42) from the country's southwestern region, close to the Croatian border,

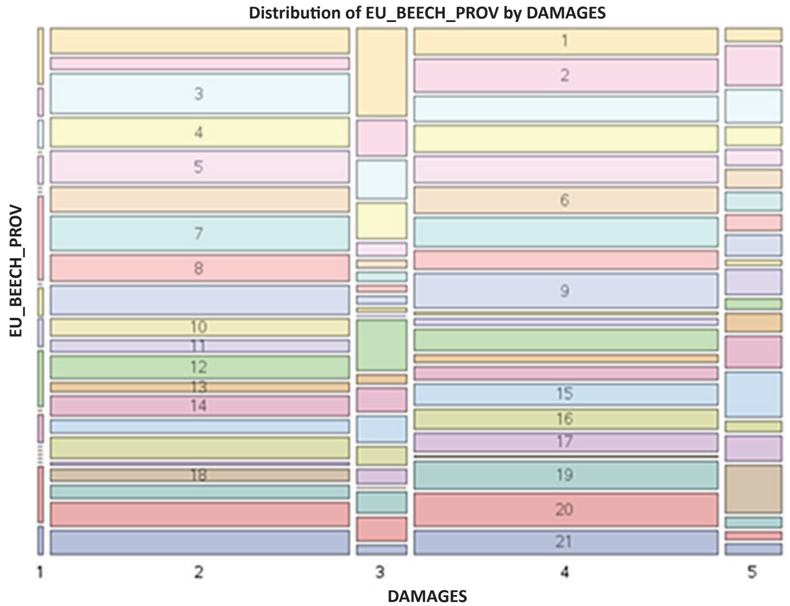

Figure 4. Mosaic plot of the distribution of damage types in European beech provenances based on S3. Axis X: 1. Aphids, 2. Galls, 3. Chewing damages, 4. Anthracnose, 5. Canker. Axis Y European beech provenances 1. HU42, 2. BA30, 3. DE48, 4. HR27, 5. AT56, 6. RO63, 7. DE46, 8. BA61, 9. HR25, 10. DE49, 11. CH65, 12. HR24, 13. BA59, 14. HR26, 15. BA60, 16. RS68, 17. BA62, 18. DE47, 19. RS69, 20. RO64, 21. RS66 (Coding label of provenances: see Table 1).

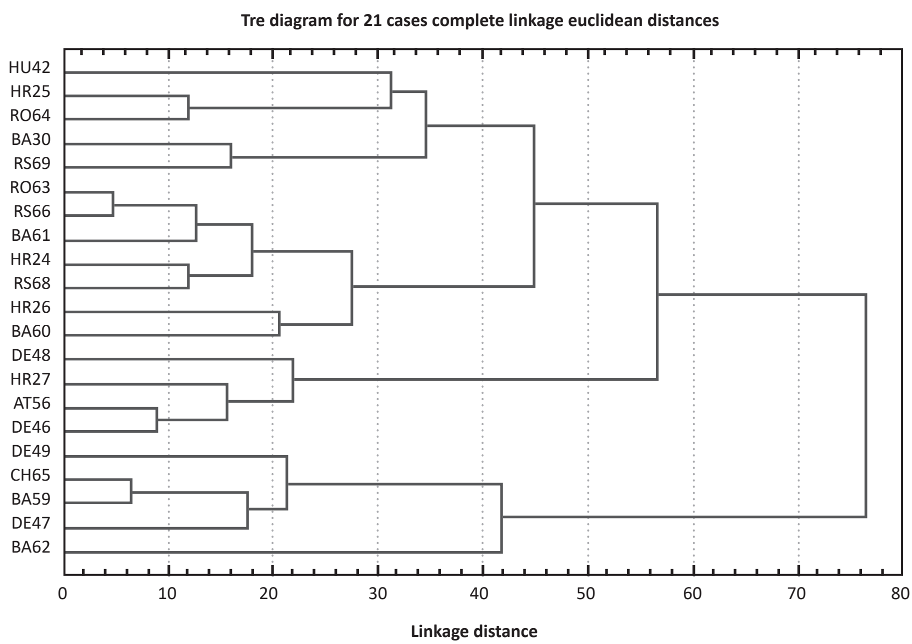

Figure 5. Dendrogram of 21 European beech provenances using five types of damage (aphids, galls, chewing damages, anthracnose and canker) produced by cluster analysis (complete linkage, Euclidean distance) using a cut point with four clusters (Coding label of provenances: see Table 1).

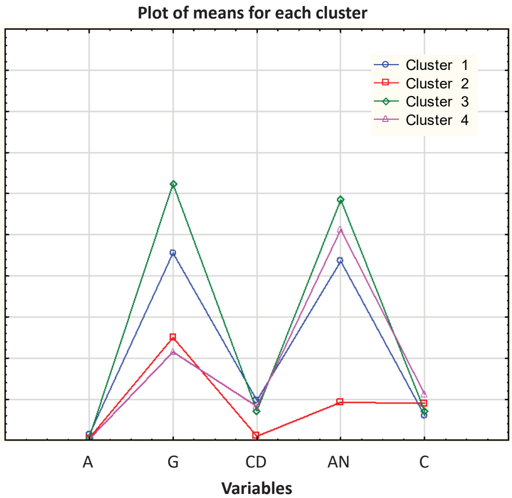

Figure 6. The plot of means for clusters of damage (X axis: A–Aphids, G–Galls, CD–Chewing damages, AN–Anthracnose, C–Canker, Y axis: % of damaged trees) of European beech provenances using the non-hierarchical k-means procedure.

was grouped into Cluster 1. The highest damage type of HU42 was anthracnose, followed in descending order by galls, chewing damages, canker and aphids. Two of the four Croatian provenances (HR26 and HR27) originated from the southwestern part of the country. HR26 originated from the Istrian peninsula. The remaining two provenances (HR24 and HR25) originated from the eastern part of the country, Slavonia. Interestingly, HR 24 and HR26 were grouped in Cluster 1, HR25 and HR27 were grouped in Custer 2. HR25 was the most damaged. HR26 was the least damaged provenance. Galls were the highest damage type of the Croatian provenances, followed in descending order by anthracnose, chewing damage, canker and aphids. Bosnia and Herzegovina had the highest number of provenances. They were divided into three clusters: Cluster 1 (BA 61), Cluster 2 (BA59), and Cluster 4 (BA 62, BA60 and BA30). BA61 was the most damaged while BA62 was the least damaged. The highest damage type was anthracnose, followed in descending order by galls, canker, chewing damages and aphids. Serbia was represented by three provenances originating from the centre of the country. Two of the provenances were grouped into Cluster 1 (RS68 and RS66) and one provenance (RS69) was grouped into Cluster 4. RS66 was the most damaged provenance and RS68 was the least damaged provenance. Canker was present in all three provenances to the same extent. The highest damage type was anthracnose, followed in descending order by galls, chewing damages, canker and aphids. Romania had two provenances, RO63 and RO64, which were grouped into Clusters 1 and 3, respectively. They originated from the western part of the country. The highest damage type was anthracnose, followed in descending order by galls, chewing damages, canker and aphids. Thus, anthracnose and galls were the dominant damage types in all countries except for the Swiss provenance (CH65) where canker was the dominant damage type. Furthermore, the provenances of one particular country were generally classified into several clusters.

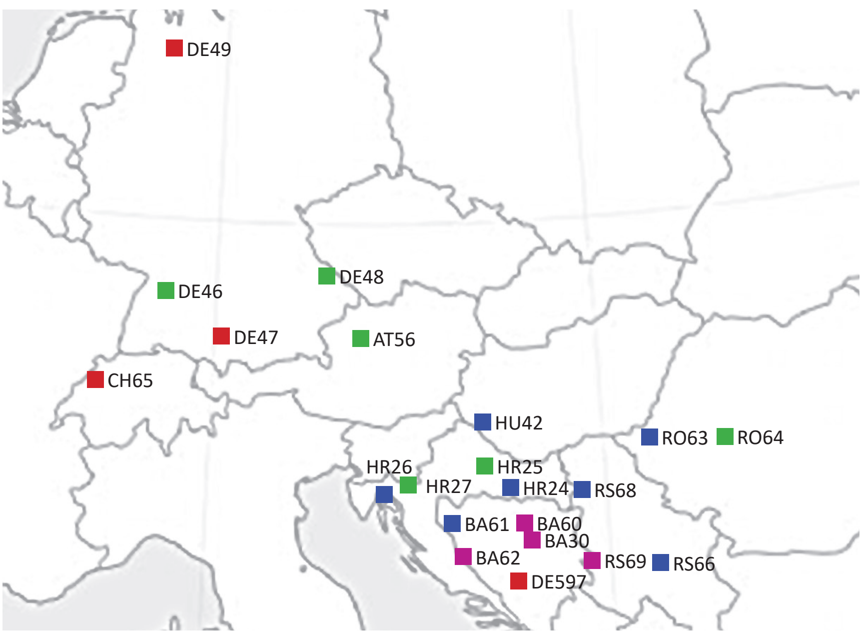

Figure 7. Map of origin of European beech provenances (coloured rectangles) of the provenance trial located in Croatia, Medvednica Mountain (black triangle). The colours represent different clusters of provenances analysed by the non-hierarchical k-means procedure: Cluster 1, blue; Cluster 2, red; Cluster 3, green; and Cluster 4, violet (Coding label of provenances: see Table 1).

DISCUSSION

The health condition of the European beech is concerning due to climate change. We investigated the health condition of European beech provenances in field trial located on Medvednica Mountain in Croatia. Medvednica Mountain in a natural environment for European beech covering 63.6% of the forest area. Thus, the provenance trial grows under the influence of abiotic and biotic environmental factors of the natural distribution area of this tree species. In addition, the international character of the provenance trial provided the opportunity to compare European beech provenances from Central and Southeast Europe.

The insect damages (aphids, galls and chewing damages) and damages from the fungal diseases (anthracnose and canker) of European beech provenances were almost equally represented (S3). Similar types of damage have already been reported (Gossner et al. 2014). Frequency analysis revealed that the presence of aphids was very low, less than 1%, while chewing damages were in the range of 10% and galls in the range of 50% (S3). Notably, aphids have a complicated life cycle with multiple developmental stages and morphology, and about ten generations of aphids of wingless and winged forms emerge annually in the ascending season (Van Driesche 2012). Sexual reproduction occurs in the autumn when eggs are produced for overwintering. In addition, aphid reproduction is more temperature-dependent than aphid generation (Ivrsen and Hardig 2007). The development of galls is promoted by light, warm temperatures and dry periods (Kelch 2016). Adult *M. fagi* leave the galls and mate in spring. The female lays eggs in April. The galls are well-developed by June. In autumn, the galls fall from the leaves with the larvae and overwinter on the ground. Considering the analysed meteorological data of Medvednica Mountain, the winter of 2015 was cold, with mean temperature between -0.2°C and 2.1°C from January to March. During the winter of 2015, most snowfalls occurred in January, February, and March (S4b). Thus, the high mortality of insects was favoured by low winter temperatures, as confirmed by the low percentage of trees affected by aphids and chewing damages. Galls affected a higher percentage of trees than aphids, indicating better overwintering of *M. fagi* larvae compared to aphid eggs. However, the milder winters and less snowpack will favour propagation and survival of the beech scale, as Stephonson and Ribarik Coe (2017) stated. Fungi are spread by wind and insects. They invade plants through wounded tissue, although they also enter through natural openings such as stomata, hydathodes, and lenticels. For infection, fungi require humidity, and fungal diseases are most commonly reported during rainy weather events (Bahnweg et al. 2005). *Apiognomonia errabunda* causes disease symptoms in leaves and twigs, resulting in premature leaf loss and the dieback of young shoots (Butin 1995). It occurs in buds, bud scales, and the bark of twigs and stems during the growing season (Sieber and Hugentobler 1987, Kowalski and Kehr 1996), sometimes without any disease symptoms (Petrini 1991, Sinclair and Cernauskas 1996, Stone et al. 2000). The fungus overwinters in leaf and branch canker tissue, and infection of emerging leaves occurs in the following spring by spores. However, the degree of destruction is highly dependent on climatic factors. During budburst and early leaf formation, constant temperatures of 10°C - 14°C are essential for spore growth and infection. During this period, higher or lower average temperatures reduce disease severity. Thus, the average temperatures on Medvednica Mountain were below 10°C in March and April 2015, indicating unfavourable conditions for spore development. In May, the average temperature was above 10°C (S4a), favouring spore development. In addition, *A. errabunda* requires water to spread and infect; it does not spread under dry conditions. During the period of budburst and spore production in the early spring in April, the aridity index was semi-humid. The aridity indices ranged from extremely humid in May to humid in June (S4c). As a result, anthracnose was found in more than 40% of the damaged trees (S3) because of the high humidity.

Canker diseases are caused by the fungi *Nectria cinnabarina* and *Nectria ditissima*. *N. cinnabarina* is indicated by branch necrosis and dieback of young stems. In contrast, *N. ditissima* causes cankers on the trunk. These pathogens attack weakened trees under stressful conditions such as frost, drought, physical damage and fungal influence. They are saprophytes and weak parasites. Sites of infection include frost-damaged beech bark, bits of rodents or game, and openings such as lenticels (Montecchio 2011). Once the canker has infected the branch, dieback cannot be prevented. In beech forest stands, canker affects beech more frequently at lower altitudes and warm and dry areas (Metzler and Erffa 2000). In the present study, a low percentage of trees, ranging from 0.09% (DE 49) to 0.81% (BA60), were infested at low intensity (less than 10%) by *N. cinnabarina* and *N. ditissima* (Figure 3).

Clustering analysis allowed the grouping of provenances into four clusters, showing no grouping of Central and Southeast European provenances into separate clusters. Cluster 2 consisted of three Central European provenances (DE49, DE47 and CH5) and Southeast Europa provenance BA59, while Cluster 3 consisted of three Central European provenances (DE46, DE48 and AT56) and Southeast European provenances (HR25, HR27 and RO64). Cluster 4 was composed of Southeast European provenances, mostly from Bosnia and Herzegovina (BA62, BA60 and BA39), and including one provenance from Serbia (RS69). Central and Southeast European provenances, as well as the provenances of each country, could not be clearly separated according to damages by cluster analysis.

Three factors should be present to support diseases, constituting a disease triangle: one side of the triangle is the host plant, the other side is the disease-causing organism, and the third side are the environmental conditions (Stevens 1960, Francl 2001). Considering the environmental conditions at the provenance trial location, European beech grows in an optimal habitat that ensures good physiological conditions for tree growth and development. The local climate on Medvednica Mountain is continental, typical for the Central European mountains, with high precipitation and low temperatures. The maximum precipitation occurs during the warm season. This type of climate has been called "the climate of beech" (Šegota and Filipčić 1996). Thus, damaging insects and pathogenic fungi were presented at low intensity in this provenance trial due to the significant number of days with low temperatures, snow and frost in 2014 and 2015.

The limitations of this study should be acknowledged. Data collection was conducted on an unequal number of provenances from each country. Bosnia and Herzegovina was represented by five provenances, Germany and Croatia by four provenances. Serbia and Romania were represented by three and two provenances, respectively. Switzerland, Austria, and Hungary were represented by one provenance. Therefore, the results refer only to these provenances and cannot be generalized. In addition, this study provided an overview of damage types occurring in the middle of the vegetation period (July 2015). Future multi-seasonal and multi-annual studies will obtain a broader picture of damage types and intensity.

CONCLUSIONS

The results of this study provide information on the health condition of the International European beech provenance trial on Medvednica Mountain in Croatia. Tree survival was very high, with a predominance of healthy trees and a dominance of one disease per damaged tree. The five types of damages analysed were mostly present at low intensity (less than 10%). Anthracnose and galls were the most common damages, followed in descending order by chewing damage, canker, and aphids. Statistically significant differences in damage were found among provenances (χ^2=322.19, p<0.0001). Cluster analysis of provenances according to damage showed four clusters. However, clustering did not separate Central European from Southeast European provenances, since both were found in the less and the most damaged cluster. Besides, the provenances of individual countries were clustered into multiple clusters. The favourable climatic and environmental conditions at the location of the provenance trials resulted in the good health of the European beech trees. These data are important for the projection of European beech forest survival and maintenance of the good quality of the forest stand. Considering climate change, continuous monitoring of the occurrence of European beech damage is necessary, drawing particular attention to extreme events.

Author Contributions

MI, SNA, NC and MGP conceived and designed the research, SNA, NC, ML and SB carried out the field measurements, NC processed the data, NC and AJ performed the statistical analysis, MI secured the research funding, supervised the research, MI, MGP, AD, and HR helped to draft the manuscript, NC, SNA, and AJ wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Materials

Supplementary File 1. Percentage of surviving and healthy trees of the international European beech provenance trail.

Supplementary File 2. Damage types observed on the international European beech provenances trial: (a) Phillaphis fagi on the leaf, (b) chewing damages - bitten parts of leaf, (c) leaf-mining, (d) galls of Mikiola fagi on leaf, (e) Anthracnose on leaf, (f) Canker on beech steam.

Supplementary File 3. Frequency table data of European beech provenances in the international European beech provenance trial.

Supplementary File 4. Meteorological data obtained from the Croatian Meteorological and Hydrological Service weather station Puntijarka in 2014–2015: (a) Monthly precipitation (MP), maximum (Max), average (AMT), and minimum (Min) monthly temperatures, (b) Snow and frost data, (c) Monthly de Martonne aridity index.

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Growth Dynamics and Tree Shape of Common Beech (*Fagus sylvatica* L.) in the International Provenance Test

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ABSTRACT

Provenance tests of forest tree species are important experiments in silviculture and tree breeding. Their results provide information about provenances' growth, adaptability, and other features. The research aimed to determine the dynamics of growth and tree shape of common beech plants per provenances in the international provenance test in Bosnia and Herzegovina to choose the best provenances considering wood production and quality. Research was conducted in the provenance test containing eight provenances from Bosnia and Herzegovina, four from Germany, three from Serbia, two each from Croatia, Romania, and Switzerland, and one from Hungary. Provenance test was established in 2007 by planting 2-year-old and 3-year old seedlings. Height and root collar diameter were measured, and tree shape was assessed in 2019. Data were processed in SPSS 26.0. Descriptive statistics, variance analysis, multiple Duncan's test for all traits, and Pearson's coefficient of corelation among morphological traits and tree shape were calculated. Variance for the height and root collar diameter showed statistically significant differences among different ages of plants and among provenances. Provenance from Croatia (Dilj Čaglinski) had the highest, and provenance from Romania (Alba-Iulia) had the lowest average height. The highest average value of root collar diameter had provenance Dilj Čaglinski, and the lowest value had provenance Sihlwald (Switzerland). The highest percentage of category 10 (ideal tree form) had provenance Bad Wildbad (Germany), and categories 1-4 (no silviculture value) had provenance Alba-Iulia (Romania). Pearson's coefficient showed that height, root collar diameter, and tree shape are highly correlated. Considering all the above, when planning forest-breeding works, it is recommended to continue the research and favor provenances with the best growth and tree shape.

Keywords: *Fagus sylvatica*; selection of provenances; wood productivity; wood quality

INTRODUCTION

Common beech (*Fagus sylvatica* L.) is the most common tree species in the total area of forests and forest lands in Bosnia and Herzegovina (Fukarek 1970), and researches on this species are especially significant. Studies of common beech provenances in different parts of its range indicated significant intra-population and inter-population variability (Kajba 2003).

Due to its importance, beech has been the subject of research by numerous scientists and researchers (Barriere et al. 1984, Kleinschmit 1985, Brus et al. 1990, Comps et al. 1991, 1998, Muhs and von Wuhlisch 1992, Gömöry et al. 1999, 2003, 2007, Gračan and Ivanković 2001, Gračan et al. 2006, Ivanković et al. 2008, 2011, Ballian and Zukić 2011, Ballian et al. 2012, Ballian et al. 2015, Ballian et al. 2019, Memišević Hodžić and Ballian 2021).

International experiments with common beech have been established intensively in recent decades due to the need to preserve the genetic resources of the species. In the early 1980s, the establishment of a network of field trials began (Muhs 1985). During that period, 15 experiments with 188 provenances were established. During the 1990s, new experiments were established and included the eastern part of the common beech range. Muhs et al. (1992) proved morphological, phenological, and genetic variability of common beech among and within populations. Muhs (1985) found that geographical variability is ecotypic rather than clinal.

Hussendörfer et al. (1996) investigated phenotypic traits (branching type, forkiness) in a 12-year-old common beech stand in Switzerland. They concluded that there was no correlation between these traits and that it was not possible to identify their genetic determinants.

This research aimed to determine the dynamics of growth and the shape of the tree of common beech provenances in the international provenance test in Bosnia and Herzegovina, to select provenances with the best characteristics in terms of wood mass production and wood quality for further afforestation with this species. The aim was also to determine whether there were statistically significant differences in morphological traits of provenances according to the age of the seedlings at the time of establishing the provenance test.

MATERIALS AND METHODS

Plants from the international provenance test of common beech in Bosnia and Herzegovina were measured and assessed in this research. The test includes 22 provenances, eight from Bosnia and Herzegovina, four from Germany, three from Serbia, two from Croatia, two from Romania, two from Switzerland, and one provenance from Hungary (Table 1, Figure 1).

The test was established in a randomized block system with three replications, planting seedlings aged 2+0 and 3+0 with a planting interval of 2x1 m. The provenance test was erected in the spring of 2007 on a surface with average coordinates of 44°04'15'' N 18°11'32''E. Administratively, it belongs to the forest management area "Kakanjsko", forest management unit "Donja Trstionica - Goruša", department 41, section c. It is located at 510 to 540 m above sea level. The average slope of the terrain is 7%, and the exposure is mostly northeastern. Rendzina and acid brown soil complex, and a complex of acid brown and ilimerized soil predominate. Brown soils are present on a small part of the surface. The area is influenced by a temperate continental climate, characterized by cold winters and moderately warm summers with abundant precipitation.

In the spring of 2019, plant heights and root collar diameters were measured, and tree shape was assessed. Heights were measured using a stick meter and root collar

Table 1. Data of studied provenances.

No	Label	Provenance	Country	Latitude	Longitude	Altitude	Seedlings' age at the time of establishing the test	Plants age at the time of measuring
1	9661	B. Krupa Baštra Čorkovaća	BiH	44°45'	16°14'	720	2+0	14
2	9659	Bugojno Vranica - Bistrica	BiH	43°33'	17°49'	750	2+0	14
3	9662	Dinara	BiH	44°06'	16°30'	950	2+0	14
4	9633	Grmeč - Jasenica	BiH	44°16'	16°18'	450	3+0	15
5	9631	Konjuh - Kladanj	BiH	44°16'	18°34'	840	3+0	15
6	9630	Tajan – Zavidovići	BiH	44°23'	18°03'	700	3+0	15
7	9632	Tešanj - Crni Vrh I	BiH	44°33'	17°59'	500	3+0	15
8	9660	Tešanj - Crni Vrh II	BiH	44°33'	17°59'	500	2+0	14
9	9624	Dilj Čanglinski	HR	45°17'	18°01'	350	3+0	15
10	9625	Vran kamen	HR	45°37'	17°19'	600	3+0	15
11	9646	Bad Wildbad	D	48°46'	08°35'	700	3+0	15
12	9642	Valkonya	H	46°30'	16°45'	300	3+0	15
13	9649	Hasbruch	D	53°08'	08°26'	35	3+0	15
14	9648	Hoellerbach	D	49°01'	13°14'	755	3+0	15
15	9647	Schwäbisch Alb	D	48°00'	10°00'	650	3+0	15
16	9663	Alesd	RO	46°10'	22°15'	490	2+0	14
17	9664	Alba-lulia	RO	46°10'	23°05'	860	2+0	14
18	9666	Avala	SRB	44°12'	20°45'	745	2+0	14
19	9669	Cer	SRB	44°12'	19°50'	745	2+0	14
20	9668	Fruška gora	SRB	45°10'	19°47'	360	2+0	14
21	9643	Herzogenbuchsee	CH	07°40'	47°11'	500	3+0	15
22	9665	Sihlwald	CH	47°12'	07°21'	1050	2+0	14

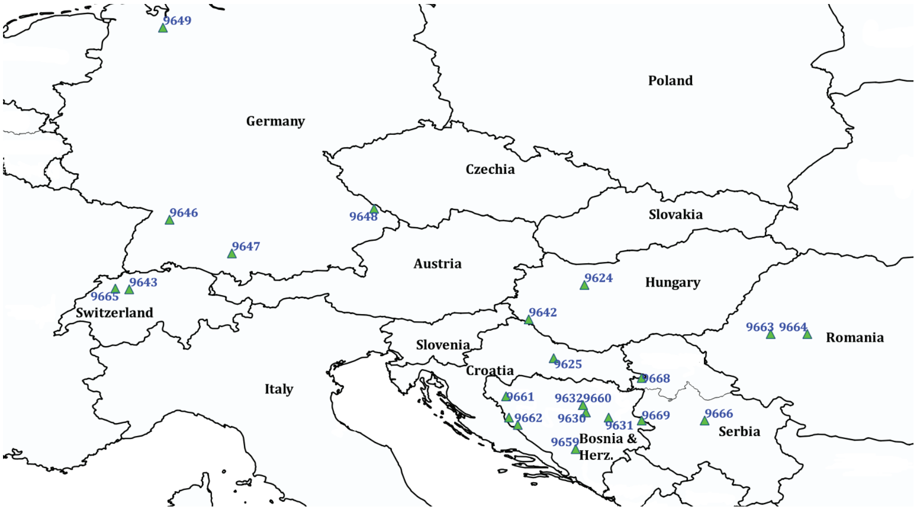
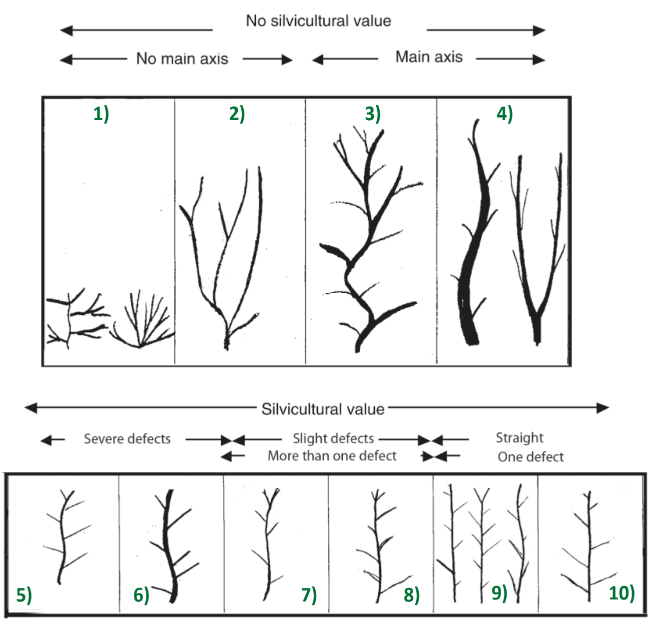


Figure 1. Researched provenances.

diameter using an electronic moving scale. Tree shape was evaluated according to the scoring system for beech and oak as shown in Figure 2 (Ducci et al. 2012). Trees that did not meet the criteria of cultivation value were marked by a common designation 1-4.

Data on height and root collar diameters were processed by the statistical program SPSS 26.0. Descriptive indicators, variance analysis, and Duncan's test were calculated according to the provenances and ages of the plants. Tree shape data were also processed in the SPSS 26.0 program. Frequencies of categories were calculated per provenances. The Pearson's correlation coefficient for height, root collar diameter, and tree shape was calculated.



1) No main stem or on a low height (“apple” shape);

2) no apparent stem; very many major defects;

3) presence of a visible stem, but several major defects;

4) presence of a visible stem, but a major defects eliminates any forestry quality;

5) trees having many defects (branching angle, branches diameter, branches' density, flexuosity), but could be recovered with pruning;

6) a big defects that could be recovered, or more mean defects;

7) two means defects or many small defects; maximum score for a tree with multiple stem;

8) two slight defects, or means defect;

9) a small defect (fork at the top of the crown, slight flexuosity, branches with greater average diameters,...);

10) ideal tree: no default.

Figure 2. The scoring system used for beech and oak (Ducci et al. 2012).

RESULTS

Heights

Average values of heights according to plant ages are shown in Table 2.

The average height of provenances whose seedlings were 2+ 0years old when establishing the provenance test was lower than the average height of those whose seedlings were 3 + 0 years old. T-test according to plant age (Table 3) showed that the differences caused by differences in seedlings' age were statistically significant (Sig. <0.05).

Average values of heights by provenances are shown in Table 4.

Provenance from Croatia (Dilj Čanglinski) had the tallest trees, the average height of 262.9 cm, while provenance from Romania (Alba-Iulia) had the lowest trees, and the average height of 161.3 cm. The second-highest average height had provenance Vran Kamen (Croatia) with 243.4 cm, and the third Konjuh - Kladanj (Bosnia and Herzegovina) with 241.80 cm.

When it comes to provenances with lower average heights, after Alba-Iulia, another provenance from Romania (Alesd) had a low average height (165.0 cm) and provenance from Switzerland (Sihlwald) (172. 4 cm). Plants of provenances with higher average heights at the time of measurement were 15 years old, and plants of provenances with lower heights were 14 years old.

Analysis of variance for height (Table 5) shows statistically significant differences among provenances (F calculated > F in the table, Significance < 0.005).

The results of the Duncan's test for height showed a grouping of provenances into six groups that overlap (showed in Table 4).

Root Collar Diameter

Table 6 shows the average values of root collar diameter according to plant ages in the provenance test.

As for the heights, average values of root collar diameters of 14 year-old plants were lower than the average values of provenances with 15 years old plants. T-test according to plant age (Table 7) showed statistically significant differences per plants' age (Sig. <0.05).

Table 8 shows the average values of root collar diameter (mm) per provenances.

The highest average value of the root collar diameter had the provenance from Croatia (Dilj Čanglinski) with 48.9 mm. The second highest value had provenance Vran Kamen with 45.8 mm and the third Tešanj Crni Vrh I with 45.4 mm. The lowest average size of root collar diameter had provenance Sihlwald from Switzerland with 29.5 mm, then provenances from Romania, Alba-Iulia 30.7 mm, and Alesd 32.6 mm. As for the root collar diameter, provenances with 14 year-old plants had lower values of root collar diameter than provenances with 15 year-old plants.

Variance analysis for root collar diameter (Table 9) showed statistically significant differences among provenances (F calculated > F in the table, Significance <0.005).

Duncan's test for root collar diameter showed a grouping of provenances into eight groups, which overlap each other.

Tree Shape

Figure 3 shows the percentages of plants with tree shape categories for all provenances together. The highest number of trees belong to category 10 (perfectly flat tree), and shapes without significance for forest cultivation occupy 9.8% of plants (Categories 1-4) .

Table 2. Descriptive statitstics for height according to plants' age.

Plants' age (years)	Average height (cm)	Standard deviations (cm)	Standard error (cm)	Minimum (cm)	Maximum (cm)
14	206.0	75.9	4.6	55	420
15	230.4	82.1	3.0	55	530
Average	223.7	81.1	2.5	55	530

Table 3. T-test for height per plants' age.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Equal variances assumed	553.599	0.000	-14.952	3066	0.000	-59.20579	3.95962	-66.9696	-51.4420
Equal variances not assumed			-15.299	2937.144	0.000	-59.20579	3.86981	-66.7936	-51.6180

Table 4. Descriptive statitstics for height per provenances.

Provenance	Age	Average height (cm)	Standard deviation (cm)	Standard Error (cm)	Minimum (cm)	Maximum (cm)	Group by Duncan's test
9624	15	262.9	99.9	10.9	70	530	6
9625	15	243.4	86.8	9.8	65	440	5/6
9630	15	238.3	81.3	9.7	110	440	5/6
9631	15	241.8	99.5	17.9	55	450	5/6
9632	15	239.9	93.1	14.2	85	420	5/6
9633	15	230.8	73.9	9.5	95	390	4/5/6
9642	15	235.3	73.2	8.0	80	395	4/5/6
9643	15	232.0	80.9	10.1	70	410	4/5/6
9646	15	178.4	49.8	10.0	100	290	1/2/3
9647	15	216.8	68.4	7.6	60	400	3/4/5
9648	15	209.9	67.3	9.9	85	360	2/3/4/5
9649	15	200.6	69.5	8.0	70	350	1/2/3/4/5
9659	14	217.9	85.9	16.2	105	420	3/4/5
9660	14	240.6	101.8	20.0	60	410	5/6
9661	14	193.1	47.9	10.4	100	280	1/2/3/4
9662	14	221.4	65.3	10.1	100	370	4/5/6
9663	14	165.0	53.8	10.6	55	330	1
9664	14	161.3	73.3	18.9	60	280	1
9665	14	172.4	64.9	12.3	80	305	1/2
9666	14	230.3	69.0	12.8	90	350	4/5/6
9668	14	212.7	75.2	14.2	60	400	2/3/4/5
9669	14	210.9	76.0	13.0	70	340	2/3/4/5
Average		223.7	81.1	2.5	55	530	-

Table 5. Variance analysis for height of the provenances.

Source of variability	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	578576.925	21	27551.282	4.486	0.000
Within Groups	6122980.590	997	6141.405		
Total	6701557.515	1018			

Table 6. Descriptive statitstics for root collar diameter according to plants' age

Plants' age (years)	Average root collar diameter (mm)	Standard deviations (mm)	Standard error (mm)	Minimum (mm)	Maximum (mm)
14	7.5	16.2	0.4	0.01	80.4
15	19.0	23.1	0.6	0.01	89.5
Average	13.7	21.0	0.4	0.01	89.5

Table 7. T-test for root collar diameter per plants' age.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	632.107	0.000	-15.854	3098	.000	-11.54696	.72832	-12.9750	-10.1189
Equal variances not assumed			-16.278	2985.931	.000	-11.54696	.70934	-12.9378	-10.1561

Table 8. Descriptive statistics of root collar diameter per provenances.

Provenance	Age (years)	Average root collar diameter (mm)	Standard deviation (mm)	Standard error (mm)	Minimum (mm)	Maximum (mm)	Group according to Duncan's test
9624	15	48.9	13.5	1.5	22.9	80.5	6
9625	15	45.8	13.6	1.5	20.4	81.7	5/6
9630	15	44.4	15.7	1.9	18.4	89.5	5/6
9631	15	43.9	12.9	2.3	19.1	73.0	4/5/6
9632	15	45.5	16.8	2.6	19.9	83.4	5/6
9633	15	42.6	13.7	1.8	17.7	82.8	4/5/6
9642	15	44.2	13.0	1.4	21.3	75.0	4/5/6
9643	15	40.7	13.0	1.6	16.6	81.7	5/6/7
9646	15	33.2	7.2	1.4	18.3	50.4	1/2/3/4
9647	15	40.0	12.3	1.4	22.3	77.6	5/6/7
9648	15	37.2	11.1	1.6	18.4	56.8	2/3/4/5/6
9649	15	39.4	10.4	1.2	20.6	73.8	4/5/6/7
9659	14	41.1	13.8	2.6	25.3	68.9	5/6/7
9660	14	40.8	16.4	3.2	14.7	80.4	5/6/7
9661	14	34.4	6.8	1.5	22.8	46.2	1/2/3/4/5
9662	14	45.4	12.4	1.9	25.6	70.3	5/6
9663	14	32.6	7.2	1.4	24.5	52.4	1/2/3
9664	14	30.7	9.0	2.3	18.5	42.9	1/2
9665	14	29.5	9.4	1.8	13.5	52.0	1
9666	14	43.0	12.0	2.2	20.4	64.0	4/5/6
9668	14	40.1	10.5	2.0	19.6	61.4	5/6/7
9669	14	39.1	12.2	2.1	18.3	71.6	3/4/5/6/7
Average		41.6	13.4	0.4	13.5	89.5	

Table 9. Variance analysis of root collar diameter per provenance.

Source of variability	Sum of Squares	df	Mean Square kvadrata	F	Sig.
Between Groups	21155.683	21	1007.413	6.216	0.000
Within Groups	161568.944	997	162.055		
Total	182724.627	1018			

Figure 4 shows the percentages of tree shape categories per provenances.

The highest percentage of category 10 had provenance 9646 (Bad Wildbad, Germany). Provenance 9664 (Alba-Iulia, Romania) had the highest share of categories 1-4 (no cultivation value).

If we analyze only categories 8, 9, and 10, as categories of trees with good shape, Baštra Ćorkovača from Bosnia and Herzegovina stands out with 76.2% of plants in these categories, Bad Wildbad from Germany with 72.0%, Dilj Čaglinski from Croatia with 69.0%, and Herzogenbuchsee from Switzerland with 68.8%.

Correlation of Tree Shape, Height, and Root Collar Diameter

Table 10 presents the values of the Pearson's correlation coefficient of investigated traits: tree shape, height, and root collar diameter.

Pearson's correlation coefficient showed high values of correlation among all three examined properties (height, root collar diameter, and tree shape).

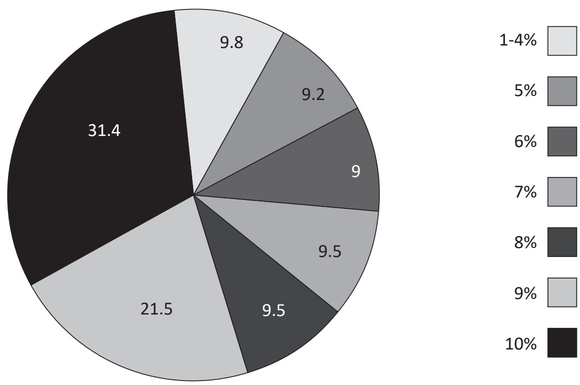


Figure 3. Percentages of plants per tree shapes categories for all provenances.

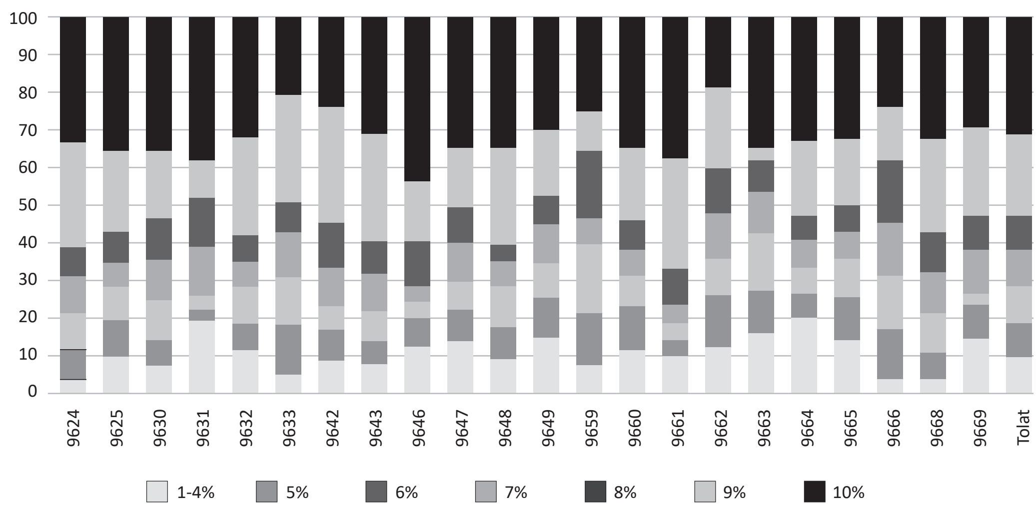


Figure 4. Percentages of plants per tree shape categories per provenance.

Table 10. Pearson's correlation coefficient of tree shape, height, and root collar diameter.

Traits	Pearson's correlation coefficient	Tree shape	Height	Root collar diameter
Tree shape	Pearson's Correlation	1	0.931**	0.929**
	Sig. (2-tailed)		0.000	0.000
	Sum of Squares and Cross-products	46864.699	1220252.887	228498.360
	Covariance	15.627	410.860	76.192
	N	3000	2971	3000
Height	Pearson's Correlation	0.931**	1	0.975**
	Sig. (2-tailed)	0.000		.000
	Sum of Squares and Cross-products	1220252.887	39376906.780	7033261.658
	Covariance	410.860	12838.900	2293.206
	N	2971	3068	3068
Root collar diameter	Pearson's Correlation	0.929**	0.975**	1
	Sig. (2-tailed)	0.000	0.000	
	Sum of Squares and Cross-products	228498.360	7033261.658	1368664.902
	Covariance	76.192	2293.206	441.647
	N	3000	3068	3100

DISCUSSION

Almost all previous research of common beech provenances treated morphological characteristics, especially height, diameter, and survival of plants, and results showed statistically significant differences among provenances (Ballian and Zukić 2011, Ballian and Jukić 2014-15, Bogunović et al. 2020, Memišević Hodžić and Ballian 2021, Popović et al. 2021). Ivanković et al. 2008 identified statistically significant differences among provenances in a provenance test in Slovenia, but in the same research, in a provenance test in Croatia, the effects of provenances were not statistically significant. Hoffman (1961) stated that the heights that reached a younger age cannot be taken as a reliable measure for determining the growth of provenances because changes in growth rate often occur at a later age. Some authors stated that conclusions about the growth of provenances are not reliable up to the age of 40 or one-third of the production period (Vidaković and Krstinić 1985, Kleinschmit 1985). Therefore, given the age of the provenances in this research, we still cannot reliably talk about the productivity of individual provenances, but the results are significant for the juvenile-adult correlation of investigated traits. Larsen (1985), based on an early test, stated that it is possible to predict that individual beech populations will maintain good growth at a later age. Therefore, this research results could help to obtain a general picture of all provenances and to predict their growth at a later age.

The highest values of the investigated traits had provenance from Croatia Dilj Čanglinski and the lowest Alba-Iulia from Romania, which is in accordance with the results of the research by Memišević Hodžić and Ballian (2021). This study also showed statistically significant differences between different ages of provenances.

In this paper, tree shape as an important indicator of the quality of the produced wood mass was also evaluated. The results showed statistically significant differences among the investigated provenances. The best tree shape had the provenance from Bosnia and Herzegovina (Baštra Čorkovaća). Also, provenances from Croatia and Germany had a large percentage of plants with good tree shape.

Correlation results among the growth properties (height and root collar diameter) and tree shape showed high values of the correlation among all three traits. Although there were no many studies on the correlation among morphological traits in common beech, Hussendörfer et al. (1996) investigated different types of branching and forkiness in 12-year-old common beech stand in Switzerland. They found no correlation among the traits and concluded that it is not possible to identify their genetic determinants.

Memišević Hodžić and Ballian (2020) investigated the shape of the pedunculate oak tree in Bosnian-Herzegovinian provenance test. The share of tree shape categories was less favorable, and only 14% of the total number of plants had the form of tree 10 according to the protocol of Ducci et al. (2012).

CONCLUSIONS

Analysis of variance for researched morphological traits (root collar diameter and height) showed statistically significant differences among the provenances, which was confirmed by Duncan's test. T-test showed statistically significant differences between plants of different ages.

Provenances whose plants were 15 years old at the time of the study had higher average values of traits, which implies that the age of seedlings is an important factor to consider for artificial afforestation. The highest average plant height in 2019 had the provenance from Croatia (Dilj Changlinski) with 262.90 cm, while the lowest average height had provenance from Romania (Alba-Iulia) with 161.30 cm. The highest average value of root collar diameter had the provenance from Croatia (Dilj Čanglinski) with 48.9 mm, while the lowest average value had the provenance from Switzerland (Sihlwald) with 29.5 mm. The provenances of Baštra Ćorkovača from Bosnia and Herzegovina, Bad Wildbad from Germany, and Dilj Čaglinski from Croatia have the best ratio of the percentage of trees of different categories of tree shapes. The correlation coefficient showed values of approximately 1, which indicates a positive correlation, i.e., provenances with higher increments in height and thickness also have a better tree shape. The results of this research are important for having a general picture of provenances' growth, and should be continued to determine the juvenile-adult correlation of these traits in common beech.

Author Contributions

MMH and DB conceived and designed the research; DB carried out the field measurements; MMH and DB processed the data and performed statistical analysis; MMH and DB supervised the research; MMH and DB wrote the manuscript.

Funding

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Conflicts of Interest

The authors declare no conflict of interest.

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Nitrogen Deposition in Different Mediterranean Forest Types along the Eastern Adriatic Coast

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ABSTRACT

Mediterranean forests along the eastern Adriatic coast have an important ecological role. However, few studies have been conducted on nitrogen deposition so far. To improve this knowledge, the main aims of our study were: (i) to estimate nitrogen inputs and determine differences among the four Mediterranean forests, (ii) to determine the seasonal behaviour of N deposition compounds, and (iii) to discuss the results in relation to forest type and precipitation. Measurements were carried out over a two-year period on four plots in two regions: holm oak and pubescent oak in Istria, Aleppo pine and black pine in Dalmatia. Bulk open field and throughfall deposition were sampled with continuously exposed collectors. Measurements, analyses and data validation of precipitation and N compounds were carried out. The results showed that the highest average monthly precipitation was recorded in the black pine plot and the lowest in the Aleppo pine plot. Nitrate and ammonia in conifer plots in throughfall samples were lower than in bulk open field samples, indicating possible retention by the tree canopy. The results revealed a higher amount of N deposition collected in broadleaved forests than in conifer forests indicating the washing out of N compounds previously deposited and accumulated in forest canopy. The chemistry of N deposition was strongly influenced by local and anthropogenic sources as well as neighbouring countries. Our results may fill the knowledge gap in understanding the influence of precipitation and seasonality of N compounds in different Mediterranean forest types along the eastern Adriatic coast.

Keywords: precipitation; nitrogen deposition; nitrate; ammonium; Mediterranean forests; pubescent oak; holm oak; black pine; Aleppo pine

INTRODUCTION

The emission of air pollution in Europe has significantly increased in the course of the twentieth century. Large amounts of nitrogen oxides (NO_x) are released by human activities, mainly fossil fuel combustion in industry, power plants, heating systems and transport, while ammonia (NH_3) from agriculture and farming. This increase has affected N cycling in ecosystems worldwide (Erisman et al. 2013) and is considered one of the threats to Mediterranean sustainability, along with climate change and ozone (De Marco et al. 2019, Jakovljević et al. 2021).

Nitrogen, as well as other air pollutants, is carried by air masses and rain from regional and long-range transport to the rural areas (Perez et al. 2008, Pey et al. 2009, Aguillaume et al. 2017). Atmospheric deposition and its transformation in contact with vegetation are of great importance in understanding its effects on forests. It has an impact on forest ecosystems through eutrophication by nitrogen and soil acidification, thus altering soil properties and processes (Clark et al. 2007). Changes in the soil chemistry may lead to imbalances in nutrient supply and subsequently to unbalanced nutrition of the trees. Nutrient imbalance will affect canopy photosynthesis and in turn decrease forest vitality (Lu et al. 2008, de Vries et al. 2014). For example, critical loads for nutrient nitrogen and their exceedances were both important for defoliation (De Marco et al. 2014).

It is known that cycling and deposition of N in Mediterranean-type ecosystems are highly seasonal processes conditioned by the Mediterranean climate

(Ochoa-Hueso et al. 2011). For airborne total nitrate (NO_3^-) and ammonium (NH_4^+), the spatial coverage is slightly better in the western Mediterranean than in eastern regions (Ochoa-Hueso et al. 2011). However, the potential ecological effects of N deposition in Mediterranean-type climates have been less investigated (Balestrini et al. 2007, Bobbink et al. 2010, De Marco et al. 2014, Ferretti et al. 2014, Aguillaume 2015, García-Gómez et al. 2018, Jakovljević et al. 2019) even though they are usually recognized as hotspots of biodiversity (Myers et al. 2000).

Mediterranean forest ecosystems along the eastern Adriatic coast are of very high significance because of ecological and social value and they are invaluable to the human and ecological functions they provide (Matić et al. 2011, Topić and Butorac 2011, HAZU 2013, Topić et al. 2020). These ecosystems are very sensitive and degraded due to numerous wildfires causing the reduction of the vegetative cover and enlarged flow of tourists during the summer season and the constant increase in human activity (Topić and Butorac 2011, Topić et al. 2020).

Nitrogen compounds in Mediterranean forests are transferred from other rural parts of Croatia or from neighbouring countries (Skevin-Sovic et al. 2012, HAOP 2015). The highest exceedances of NH_3 ceilings (25%) in Mediterranean part of Croatia was found in 2017 (EEA 2019) while the exceedance of NO_x was not recorded in 2017 and 2018 (AZO 2018, AZO 2019).

Considering the described peculiarity and fragility of the Mediterranean environment, there is an increasing need to improve the knowledge of Mediterranean forest ecosystems (Jakovljević et al. 2019).

The aims of our research were (i) to estimate nitrogen inputs and identified differences between the forests, (ii) to determine the seasonal behaviour of N deposition compounds, and (iii) to discuss the results in relation to forest type and precipitation.

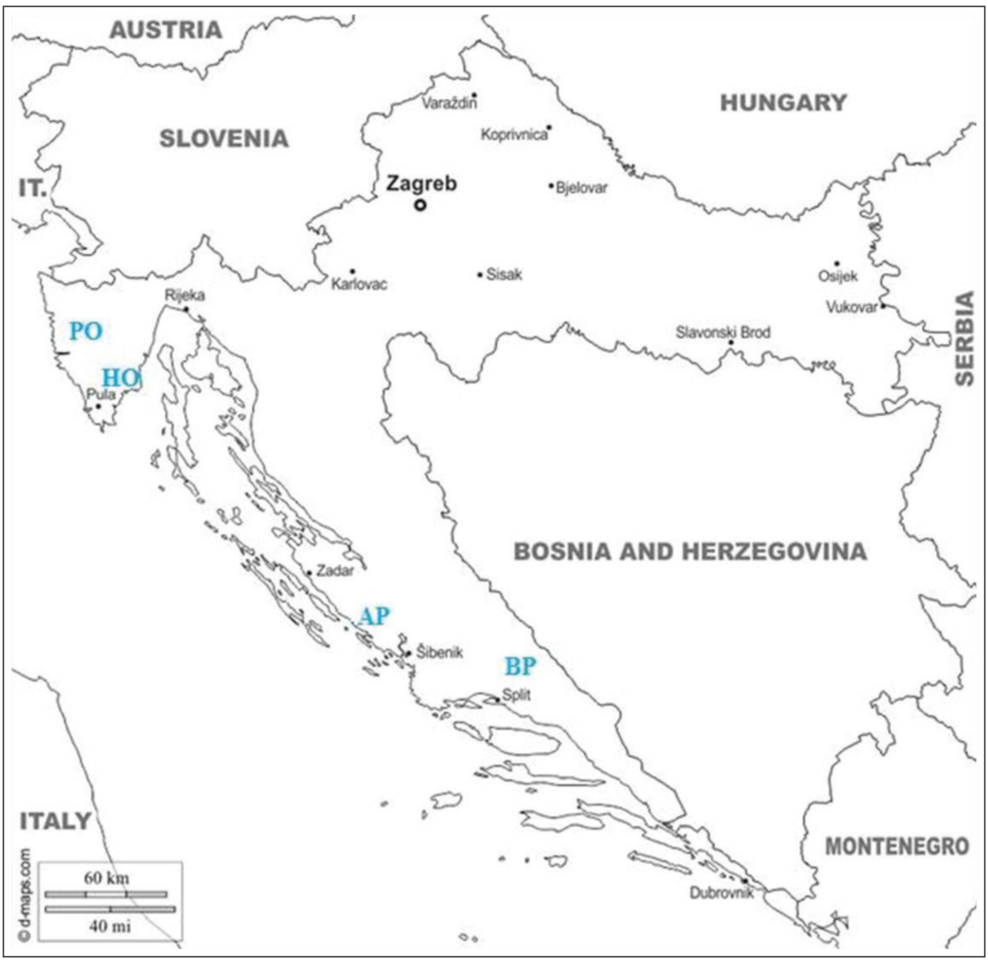

Figure 1. Location of the study area: pubescent oak (PO) and holm oak (HO) plots in Istria and Aleppo pine (AP) and black pine (BP) plots in Dalmatia.

MATERIALS AND METHODS

Study Area

The measurements were performed in different Mediterranean forest ecosystems along the eastern Adriatic coast (Figure 1) on the most dominant deciduous broadleaves species: pubescent oak (*Quercus pubescens* Wild.) and evergreen holm oak (*Quercus ilex* L.), and conifer species: black pine (*Pinus nigra* J.F. Arnold.) and Aleppo pine (*Pinus halepensis* Mill.).

According to the Köppen climate classification, the plots are distributed in the hot-summer Mediterranean climate subtype (Csa) (Köpen et al. 2011). Average annual precipitation ranges from 879 mm (AP-Vrana plot) to 1277 mm (BP-Split plot), while the mean air temperature varying from 12.4°C (BP-Split plot) to 13.4°C (PO-Poreč plot). Description of the sampling plots are shown in Table 1.

Sampling and Analysis

Sampling, measurements and analyses on the plots were all carried out according to the ICP Forests (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests) manuals (Clarke et al. 2016, König et al. 2016). The study period for N deposition was from January 2017 to December 2018. Deposition was sampled using continuously exposed, randomly placed collectors, comprising a 1-L graduated polyethylene bottle with a funnel with a 14 cm diameter. Nine collectors were placed beneath the forest canopy to collect throughfall deposition (THR) samples (Figure 2a, b). Bulk open field deposition (BOF) was sampled using three collectors, continuously exposed (Figure 2c, d). Samples were collected biweekly for the whole period from January 2017 to December 2018. The analyses of ion concentrations were performed on filtered samples (0.45 μm). Samples of atmospheric deposition were collected biweekly (Clarke et al. 2016, König et al. 2016). Ion chromatography was used to determine concentrations of two N compounds (NO_3^-, NH_4^+) (ISO 10304, ISO 14911).

After samples were collected and analysed, some samples were excluded due to contamination or precipitation less than 2 mm. These data were not included in the statistical analysis, but the precipitation volume of the excluded samples was included in calculating monthly/annual precipitation (Izquieta-Rojano et al. 2016). Some technical problems led to missing data during the study period, especially related to precipitation measurements. These problems included theft, vandalism and instrument failure due to extreme storms.

Statistical analyses were performed using programs Microsoft Office Excel 2010 and Statsoft Statistica 13. Data in the tables are expressed as the mean ± standard deviation (±SD). The annual mean concentrations of the measured N compounds were calculated as volume-weighted means. The monthly deposition fluxes were obtained following the same procedure. The Wilcoxon signed test was used to test whether BOF and THR depositions of N ions were significantly different. A significant difference was considered at the level of $p<0.05$. Data normality was tested using the Kolmogorov–Smirnov test, where the data was considered normally distributed if the D value was insignificant at $p<0.05$.

RESULTS AND DISCUSSION

The measurements were conducted on four different Mediterranean forest ecosystems to identify the amount and differences in seasonal precipitation and N deposition.

Total precipitation in the studied period at all plots was generally lower in THR, ranging between 1047 mm in Aleppo pine (AP) to 2193 mm in black pine (BP) (Table 2). The amount of rain collected in BOF for all four plots ranged between 1272 mm in AP to 2578 mm in BP. Average monthly precipitation differed markedly between the studied sites. The highest average monthly precipitation was determined at BP plot (123 mm) and the lowest at AP plot (85 mm) (Table 2).

However, exceptionally in summer on AP plot in July 2018, the value of THR was higher than BOF, 135 and 95 mm, respectively (Figure 3e, f). Several factors can influence the difference in rain volume between BOF and THR, such as maximum precipitation rate, vapour pressure deficit or wind speed (Mużyło et al. 2012, Aguillaume et al. 2017). In our case, the smaller amount of precipitation in BOF could be due to water evaporation from the collector due to high temperatures and wind drying during the summer months.

Furthermore, difference between precipitation in the BOF and THR samples indicated that the water quantity

Table 1. Description of sampling plots in two regions along the Adriatic coast.

Code Forest type	PO Pubescent oak	HO Holm oak	AP Aleppo pine	BP Black pine
Region	Istria	Istria	Dalmatia	Dalmatia
Latitude, N	45°14'59''	44°51'41''	43°53'23''	43°41'59''
Longitude, E	13°43'53''	13°59'24''	15°33'47''	16°26'34''
Elevation (m)	264	3	20	550
Distance to the sea (km)	9.78	0.50	2.90	17.19
Nearest town	Poreč	Pula	Zadar/Šibenik	Split
Distance to the nearest town (km)	19	10	38/36	24

Figure 2. Collectors for throughfall deposition (THR) in **(a)** pubescent oak (PO) and **(b)** Aleppo pine (AP) and bulk deposition (BOF) in **(c)** holm oak (HO) and **(d)** black pine (BP).

was intercepted by the canopies (Aguillaume et al. 2017, Avila et al. 2017). The interception of rainwater by the canopy depends on the dominant forest type of the plot. In pubescent oak (PO) plot interception was 8%, in holm oak (HO) plot it was 12% and in pine plots interception was 15% in BP and 18% in AP plot, respectively (Table 2). Similar interception values were found on deciduous plots in Italy where values ranged from 10% to 15%, and for coniferous species ranged from 23% to 24% (Balestrini et al. 2007). On the other hand, in Spanish holm oak forests higher interception values up to 34% were found (Aguillaume 2015).

Average monthly N deposition differed between broadleaved and conifer plots (Table 2). In broadleaves plots, the N deposition of both compounds (N-NH_4^+ and N-NO_3^-) was higher in THR than in BOF.

Ammonium and N-NO_3^- depositions were higher in HO than in PO plot, 8.22 meq m^{-2} and 6.27 meq m^{-2}, and 3.81 meq m^{-2} and 3.21 meq m^{-2} respectively. The same was found for N-NH_4^+ for BOF samples (5.29 meq m^{-2} in HO and 3.28 meq m^{-2} in PO). Regarding N-NO_3^- values they were slightly lower in HO plot (2.04 meq m^{-2}) than in PO plot (2.41 meq m^{-2}) (Table 2). On the contrary, on plots with conifer species lower N-NH_4^+ and N-NO_3^- were found in THR than in BOF (Table 2). Deposition of N-NH_4^+ in THR and BOF were higher in BP plot than in AP plot (3.51 meq m^{-2} and 1.43 meq m^{-2}, 3.99 meq m^{-2} and 2.81 meq m^{-2}, respectively).

The same pattern for deposition of N-NO_3^- in THR and BOF samples between BP and AP plot was found. In THR samples, N-NO_3^- deposition on BP plot was 2.43 meq m^{-2} and on AP plot 1.65 meq m^{-2}, and in BOF samples on AP and BP plot 1.96 and 3.05 meq m^{-2}, respectively (Table 2). Considering N-NO_3^- deposition in AP plot, it originates from wet air masses coming from the Adriatic Sea, and the fact that most of this land area is suitable for agricultural production also contributes to its concentration. Regarding N-NH_4^+, highest N-NH_4^+ concentrations were measured on the HO and PO plots (in THR). These plots are also influenced by the intense agricultural activities in its surroundings, and this is highlighted by the high amount of ammonium (Jakovljević et al. 2019).

Considering throughfall N deposition, it reflects both wash-off of the dry deposited particles on tree canopies and the exchange with the leaf surfaces (absorption and leaching) (Balestrini et al. 2007, Jakovljević et al. 2013, Ferretti et al. 2014, Avila et al. 2017). Usually, it is expected to be higher as it was evident in the oak plots. However, N-NO_3^- and N-NH_4^+ in THR samples were lower than in BOF samples on conifer plots (Table 2), indicating possible retention from the canopy (Jakovljević et al. 2019). Forest canopies can intercept the deposited N before it reaches the forest floor. In general, the effectiveness of particle uptake by trees is increased if their leaf and bark surfaces are rough or sticky (Becket et al. 1998). Using the canopy N budget method, Gaige et al. (2007) found that the canopy of the mature conifer forest retained more than 70% of N deposition. Uptake efficiencies by the canopy in the conifer forest was very high, around 90% for N-NH_4^+ and 70–80% for

Table 2. Total amount of precipitation (V), average monthly precipitation (AV), interception between BOF and THR, average monthly deposition of N compounds ($N\text{-}NO_3^-$, $N\text{-}NH_4^+$) in bulk open field (BOF) and throughfall (THR) at the experimental plots during the study period (2017 and 2018).

Plot	Sample type	Study period	V (mm)	AV (mm)	Interception (%)	$N\text{-}NH_4^+$ (meq m^{-2})	$N\text{-}NO_3^-$ (meq m^{-2})
Pubescent oak (PO)	BOF	2017-2018	2013	88	8	3.28± 3.95	2.41±2.14
	THR	2017-2018	1863	81		6.27±5.83	3.21±2.24
Holm oak (HO)	BOF	2017-2018	1969	94	12	5.29±11.6	2.04±1.98
	THR	2017-2018	1742	83		8.22±6.01	3.81±3.31
Aleppo pine (AP)	BOF	2017-2018	1272	85	18	2.81±2.40	1.96±1.83
	THR	2017-2018	1047	70		1.43±1.07	1.65±1.30
Black pine (BP)	BOF	2017-2018	2578	123	15	3.99±8.36	3.05±3.19
	THR	2017-2018	2193	104		3.51±6.84	2.43±2.73

$N\text{-}NO_3^-$, resulting in smaller THR deposition compared to the wet deposition (Sievering et al. 2007).

The Wilcoxon signed test showed that there was a significant level of differences between the average monthly precipitation in BOF and THR samples on the HO and AP plots (Table 3). There are number of reasons affecting the difference between precipitation, such as extreme weather (e.g., rainstorms, hailstorms, etc.) and human activities (e.g., forest management and forest planting) (Cisneros et al. 2018). Processes of rainfall interception of forest canopy depend on the various properties of the rainfall characteristics; especially the rainfall amount and intensity and drop properties such as the number of drops, their velocity, diameter, and median volume diameter. The vegetation periods and leaf area index values can also influence the spatial variability of THR (Zabret et al. 2018, Zabret and Šraj 2018).

In PO and BP plots there were no significant differences between average monthly precipitation of BOF and THR (Table 3).

Although it was expected that a vegetation period would significantly affect the precipitation amount between BOF and THR in the deciduous forest, this was not the case on our PO plot. Our results in PO plot showed slight differences in rainfall amount between leafed and leafless periods (Figure 3). Similar observations were found by Mużyło et al. (2012).

Furthermore, significant differences between BOF and THR deposition of N compounds can be observed at oak plots. In AP plot significant difference for N compounds was not found, while in the BP plot statistical analyses revealed a significant difference in deposition between BOF and THR for $N\text{-}NO_3^-$ (Table 3).

The precipitation volume and monthly deposition of N compounds in BOF and THR in 2017 and 2018 on four selected plots are presented in Figure 3.

In all studied plots precipitation mainly occurred in autumn and winter. The trend could be seen on all plots except on AP plots (Figure 3e, f). This plot also had the smallest amount of precipitation.

It was expected that in the summer months the precipitation would be the lowest, or there would be no precipitation at all that could be observed on PO, AP and BP plots in 2017 (Figure 3a, b, e, f, g, h). These results are not uncommon for the Mediterranean climate that is characterised by seasonal incidence of precipitation (FAO and Plan Bleu 2018). A similar trend was observed in western Mediterranean (Izquieta-Rojano et al. 2016). Moreover, the precipitation amount was identified as an important meteorological factor affecting the amount and annual distribution of N deposition. Changes in the N behaviour of ecosystems are driven by fluctuations of physical drivers (i.e., weather conditions) and biological factors (Shibata et al. 2015).

The results obtained indicated a higher amount of N deposition collected in broadleaved forests than in conifer forests (Figure 3). This fact suggested that the N compounds previously deposited and accumulated in the forest canopy

Table 3. Significant level of the differences between average monthly precipitation bulk and throughfall fluxes according to the Wilcoxon signed test (marked as bold as significant for $p<0.05$).

Plot (BOF-THR)	V	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
Pubescent oak (PO)	0.4654	**0.0043**	**0.0152**
Holm oak (HO)	**0.0021**	**0.0019**	**0.0004**
Aleppo pine (AP)	**0.0277**	0.0546	0.3967
Black pine (BP)	0.0766	0.6051	**0.0276**

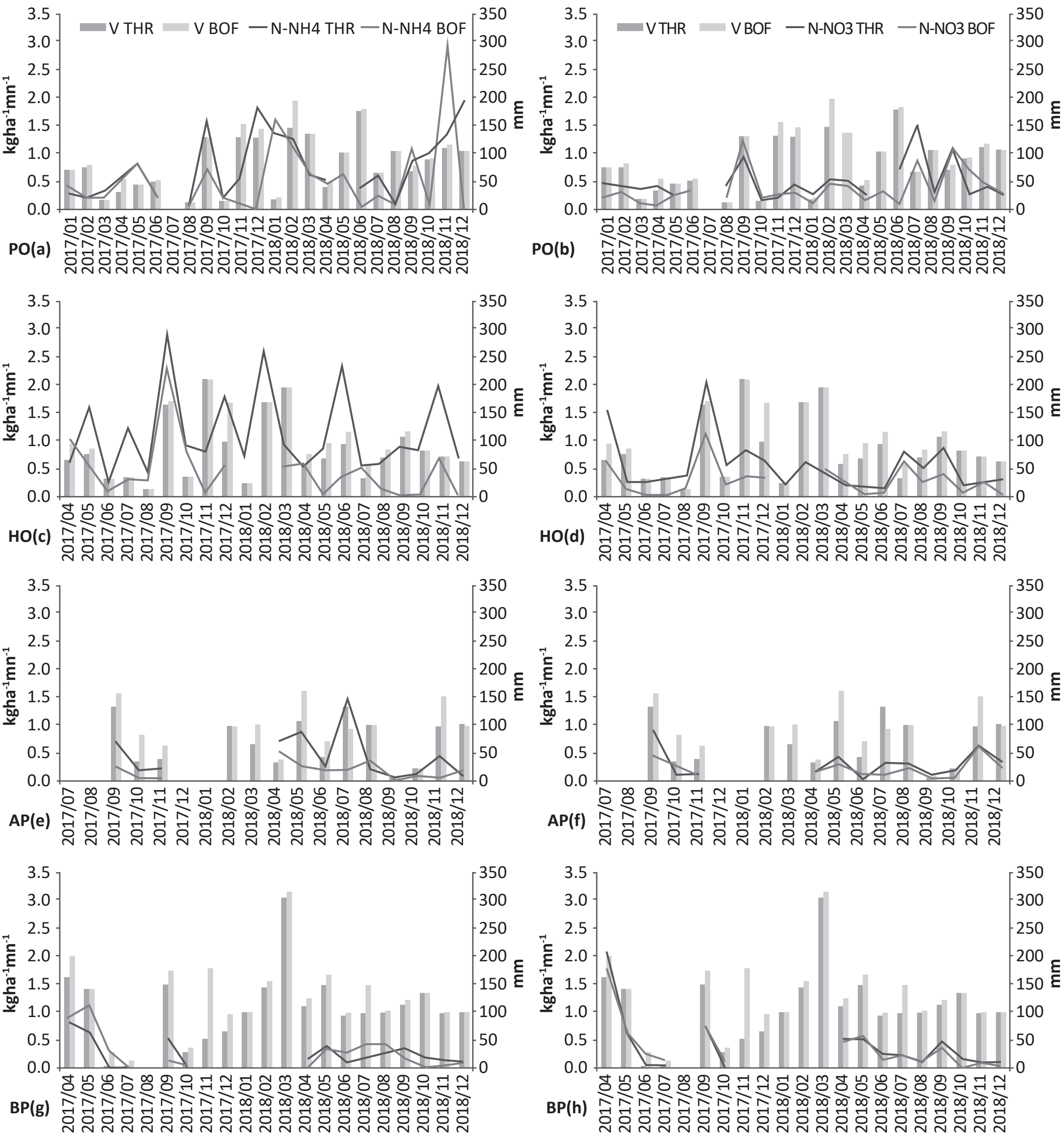

Figure 3. Monthly bulk (BOF) and throughfall (THR) deposition of nitrogenous compounds (kg N ha^{-1} mn^{-1}) and precipitation volume (mm) at the four monitoring plots: PO–pubescent oak **(a, b)**, HO–holm oak **(c, d)**, AP–Aleppo pine **(e, f)** and BP–black pine **(g, h)**.

were washed out in subsequent rain events. Although rainfall amount may affect these peaks, it is likely that other factors were involved, since variations in the size of the peaks are not proportional to the precipitation amount.

In the Mediterranean area, N deposition accumulates on plant surfaces during dry periods, becoming available as high N concentration in pulses with rainfall events (Meixner and Fenn 2004, Ochoa-Hueso et al. 2011, Aguillaume et al. 2016). These pulses could be observed in THR on all plots. They could be explained by a major contribution from dry-deposited particles, washed out after the driest period of the year. It was more evident on PO and HO plots where the collected deposition during August 2017 was washed out in September 2017 (Figure 3a-d).

The highest monthly deposition of N compounds can be observed in THR and BOF throughout the year for PO and HO plots located in Istria (Figure 3a-d) unlike BP and AP plots in Dalmatia (Figure 3e-g). Istria is a region located on the border with Slovenia and Italy. It was expected that the plots on the Istrian peninsula (PO and HO) would have higher N depositions influenced also by urbanistically and industrially developed neighbouring countries.

CONCLUSION

The atmospheric inputs of nitrogen compounds in different Mediterranean forest types along the eastern Adriatic coast were estimated. The results showed that throughfall N deposition was higher in oak forests rather than pine forests, indicating possible wash-off from the oak canopies and possible retention from pine canopies. High N concentration amounts in THR samples were present during the summer period as a result of major contribution from dry-deposited particles washed out after the driest period of the year. Our results revealed in pubescent oak forest that slight differences in rainfall amount between leafed and leafless periods were present. Depending on the study site, different anthropogenic activities and possible influence of neighbouring countries were identified as potential sources of N deposition. Further research is desirable to monitor the potential effects of N deposition on the forests of eastern Adriatic coast.

Author Contributions

TJ and LB conceived and designed the research, LB and IL carried out the field measurements, LL and IL processed the data and performed statistical analysis; project administration TJ and LL, TJ funding acquisition, TJ and LL performed laboratory measurements, TJ secured the research funding, TJ, LB supervised the research, LL and IL wrote the manuscript, TJ and LB helped to draft the manuscript.

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Conflicts of Interest:

The authors declare no conflict of interest.

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Perception and Attitudes of Residents Towards Green Spaces in Croatia – an Exploratory Study

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ABSTRACT

Green spaces are important parts of urban infrastructure. COVID-19 pandemic and lockdown periods around the world have confirmed benefits that people derive from using green spaces for their physical and mental health. Green spaces need to meet the needs of users so that people can use them and benefit over time. It is important to consider users' perceptions and attitudes. User input proves beneficial in improving management practices. We investigated the differences in attitudes and perceptions of respondents from different large settlements in Croatia towards green spaces. Data on the use and perception of green spaces were collected in the first lockdown period in Europe and processed the part of the questionnaire on attitudes and perceptions towards green spaces. People have similar, mostly positive perceptions of green spaces regardless of the size of the settlement. Differences were found in the perception of disadvantages and needs related to the management of green spaces. This is the first study of the attitudes and perceptions on a large spatial scale in Croatia, so the results are exploratory and important. This study contributes to research on the social aspects of green spaces by investigating the influence of environmental context on perceptions and attitudes.

Keywords: perception; attitudes; environment; settlements; questionnaire; cultural ecosystem services; ecosystem services

INTRODUCTION

Green spaces are one of the most important components of infrastructure in cities. The benefits they provide to citizens are numerous and are often referred to as urban ecosystem services to highlight the benefits they provide to the urban environment (Haase et al. 2014). The recent COVID-19 pandemic has shown the importance of urban green spaces for citizens and their mental health, especially during lockdown periods (Poortinga et al. 2021, Pouso et al. 2021), highlighting the importance of green spaces for residents around the world (Derks et al. 2020, Morse et al. 2020, Ugolini et al. 2020, Venter et al. 2020). Therefore, green spaces have become one of the most important components of urban infrastructure in times of crisis (Kleinschroth and Kowarik 2020).

Therefore, it is important to manage green spaces in a way that they continue to provide ecosystem services to urban residents. To plan and manage high quality and appropriate green spaces, it is important to understand their users, which requires conducting empirical social studies (Lo and Jim 2012). In addition, many countries are experiencing rapid urbanization, with more and more people living in cities. The process of urbanization is characterized by pressure on vacant land and its subsequent conversion into construction areas for new housing. This process is particularly evident in cities undergoing transition, such as postsocialist cities. In these cities, many of which can be found in Eastern Europe, there is a significant process of land-use change leading to the loss of green spaces. Furthermore, in such cities, there is often a lack of public participation in decision-making regarding green spaces. This is often because citizens are not interested in participating and have more pressing issues, such as meeting basic household needs, or lack of trust in local authorities or limited opportunities to participate in such issues (Kronenberg et al. 2020). However, public participation in green space planning and management, when perceived as democratic and fair, contributes to improving the quality of environmental decisions (Reed 2008).

Research on public perceptions of green spaces can tell us a lot about how people experience green spaces. Therefore, this research on public perceptions of and attitudes towards green spaces use quantitative, qualitative or mixed methods. Quantitative methods usually involve a survey of a sample of citizens looking at, for example, perceptions of parks (Buchel and Frantzeskaki 2015), urban forests (Larondelle and Haase 2017, Kičić et al. 2020), brownfield sites (Mathey et al. 2018) and visual and auditory perceptions of green spaces (Gunnarsson et al. 2017). Qualitative methods offer an in-depth exploration of perceptions that provide insight into experiences and motivations for using urban parks (Gunnarsson et al. 2017) or perceptions of the cultural ecosystem services provided by different types of urban green space (Maraja et al. 2016, Ostoić et al. 2020b). While there are studies that directly examine the attitudes of different user groups towards green spaces (Baur et al. 2013), there are also studies that understand attitudes and perceptions as synonyms rather than distinct concepts (Mathey et al. 2018). Despite the differences in definitions, these studies examine public opinion on a variety of issues related to urban green spaces. The attitudes and preferences people express towards green spaces are diverse and influenced by numerous factors, and at the same time, the way people use these attitudes is complex (Swanwick 2009). Moreover, the same study emphasizes that attitudes and perceptions are usually location-specific and can only be fully understood in the context of the environment. Other research shows that where people live (e.g., urban or rural areas) can have an impact on their perceptions of a particular environmental issue, and that experiences of nature in different environments influence attitudes and actions toward the environment (Berenguer et al. 2005).

Studies on the perception of urban green spaces are not yet very common in Croatia and are usually conducted in Zagreb, the capital and the largest city in the country (Krajter Ostoić et al. 2020a). Nevertheless, research on the perception of cultural ecosystem services of urban green spaces in Zagreb has shown that people perceive and use/experience different cultural ecosystem services in different types of tree-covered urban green spaces (Ostoić et al. 2020). Besides, there are few studies on the perception and satisfaction of urban green spaces even in southeastern Europe. A recent regional study on this topic was conducted among residents of larger cities in the region (Krajter Ostoić et al. 2017). The study showed that residents of major cities in southeast Europe consider urban forests and green spaces important, but also that they need more such spaces. Moreover, for the respondents in the study, management practices were more important than physical aspects of green spaces, such as size and connectivity. For the residents of Zagreb, vandalism, trash cans, litter, other users and benches were the most frequently perceived problems. The main objective of this article is to investigate the perception and attitude of Croatian citizens towards green spaces. In particular, it will be analysed whether there are differences in attitudes and perceptions of green spaces between people living in large and small settlements. It is hypothesised that there is a difference in perception and attitude based on the size of the place of residence, considering the population size.

MATERIALS AND METHODS

Study Area

The Republic of Croatia is a relatively small country in southeastern Europe. It is 56,594 km² in size and has about 4.3 million inhabitants. Its territory is divided into 21 regional units with a total of 128 cities. Of the total number of cities, only four have a population of 100,000 or more. Zagreb, with about 790,000 inhabitants, is the largest city and also a regional unit. About 75% of all inhabitants in Croatia live in urban areas (Statistical Yearbook of the Republic of Croatia 2018).

The Data Collection

Data for this article were collected using an online questionnaire. The questionnaire was developed in early March 2020 by researchers from the Institute of Bioeconomics of the Italian National Research Council in collaboration with the University of Bari in Italy and Ben-Gurion University of the Negev in Israel. The questionnaire was developed to investigate the use, attitudes and feelings towards urban green spaces during the first closure period in Europe due to the spread of the SARS-CoV-2 virus. The questionnaire was the instrument for a broader international exploratory study conducted simultaneously in Chile, Croatia, Israel, Italy, Lithuania, Slovenia and Spain. The original questionnaire was translated into English and then into local languages before being distributed, including Croatian.

The authors distributed the link to the questionnaire to the general public through their personal and professional networks via email and social media (Facebook, WhatsApp and Messenger). Respondents were kindly asked to share the link with their contacts. Access to the questionnaire in Croatia was granted in the period between 17 April and 4 May 2020. The criteria for respondents were that they were over 18 years old and lived in Croatia during the lockdown period.

Survey Questionnaire

The questionnaire was designed as an online survey at Google Forms. It consisted of nine sections of 30 to 45 questions. Some questions were divided into questions about visiting behaviour before and during the closure period. The questionnaire was semi-structured and consisted of questions with predefined answers and open-ended questions. In the introductory section of the questionnaire, participants were informed about the purpose of the research and their formal consent to participate and consent to the handling of personal data was obtained. Participation in the survey was voluntary, with no incentives offered, and participants had the option to opt-out of the questionnaire at any time.

The questionnaire collected data on the use of green spaces before the lockdown, the use during the lockdown, reflections on the perception and value of green spaces for the respondents, satisfaction with certain services of the green spaces they use most often and suggestions for green spaces in their places of residence in the open-ended question, and, finally, the socio-demographic data of the respondents. Since the focus of this article is to explore the perceptions and attitudes of residents of differently sized settlements, only the results relevant to the main topic are presented here. Therefore, information and results related to the use of green spaces before and during the lockdown period are not included.

Data Sample and Analysis

The sample was not randomly drawn and included 463 respondents. Before the analyses began, three respondents from abroad were excluded from further analyses, so that the total number of respondents whose answers were included in the analyses was 460.

The sample of 460 respondents was used to analyse questions relating to attitudes towards the benefits of green spaces, management and perceived disadvantages, as well as levels of agreement with the various general aspects of green spaces.

Respondents were asked on a 7-point Likert scale (from 1 - "strongly disagree" to 7 - "strongly agree") to express their general level of agreement with statements about the benefits of green spaces, their management and perceived disadvantages. The dataset was split into two subgroups based on place of residence: respondents from larger towns who answered that they lived in a large city with a population of more than 100,000 (N=340), and respondents from smaller towns who answered that they lived in small towns with a population of less than 100,000 and rural areas (N=120). The combination of people living in small towns and villages is possible because in Croatia the local context of the two environments is similar and different from large urban environments.

In the analyses, the percentage of respondents' agreement with each statement was first plotted on a common graph to visually examine the distribution of agreement levels in each group of respondents. The topic was then further analysed using statistics. The data were examined for possible differences in the level of agreement with the statements on the 7-point Likert scale using the Wilcoxon-Mann-Whitney U-test, a nonparametric test that does not assume a normal distribution of the data, with a significance level of $p<0.05$.

To further corroborate the initial results of the Likert scale data, responses to questions about the management of green spaces, the personal importance of public/private green spaces, and what respondents would improve about the green spaces they know or frequently use were also analysed. All these questions had predefined responses that respondents could select. Contingency tables with the frequencies of the selected responses concerning the subdivision into two categories based on the indicated place of residence were created. These tables were then tested for independence using the chi-square test with a significance level of $p<0.05$.

Differences in the level of satisfaction with various aspects of known or frequent green space were analysed using the chi-square test for the frequency of responses given for each aspect between the two groups at a significance level of $p<0.05$.

The responses to the open-ended question about considerations and suggestions for green spaces in their respective places of residence were coded and the codes were presented with the frequency and description of each code.

The socio-demographic data of the respondents were analysed using descriptive statistics on the sample of 460 respondents. The analyses were performed using R v3.6.2 software. For the Likert scale data, the "Likert" package was used.

RESULTS

Sociodemographic Features of the Respondents

About three quarters of the respondents were women (Table 1). More than half of all respondents were between 30 and 49 years old. The fewest respondents were in the age group below 20 years (1%) and the age group between 60 and 79 years (7%). More than three quarters of the respondents reported having a university degree. About the same proportion of the respondents were employed either in public or private companies or worked as freelancers. Almost three quarters of the respondents lived in municipalities with more than 100,000 inhabitants.

Attitudes Toward Green Spaces and Management

As mentioned earlier, before analysis, respondents were divided into two categories based on the number of residents in their locality. The first category includes respondents from small towns and rural areas (Small Settlements) with 120 respondents, and the second category (Large Settlements) includes respondents from large cities, with 360 respondents in the sample. The first group of statements were related to attitudes towards the benefits that green spaces provide to residents, such as improving public health and social cohesion, as well as statements stating that access to green spaces is a primary right for all citizens and that everyone should have access to a green space within 300 meters of their home. People had overwhelmingly positive attitudes towards all statements, regardless of where they lived (Figure 1). There were no statistically significant differences in agreement between residents of the larger and smaller settlements. Therefore it could be concluded that there are differences in the environment, but no differences in attitudes towards the benefits of green space between the two groups of respondents.

The second group of statements were related to the management of green spaces and possible disadvantages. The respondents showed high agreement with the statement that new buildings should be compensated with new green spaces and slightly lower agreement with the provision of more funds for green space management. For other statements, the majority of respondents indicated disagreement that trees should be removed from streets, that they cause practical problems, or that they pose a danger to people (Figure 2). Statistically significant differences between residents of larger and smaller settlements were found for only two statements. These are "The presence of

Table 1. Sociodemographic characteristics of the respondents (N=460).

Variable	Category	Percentage of respondents
Gender	Male	23.7
	Female	76.1
	I do not want to state	0.2
Age	Less than 20 years old	0.9
	Between 20 and 29	16.5
	Between 30 and 39	28.3
	Between 40 and 49	27.2
	Between 50 and 59	20.4
	Between 60 and 69	5.2
	Between 70 and 79	1.5
Education	Primary	0.4
	High school	23.0
	University/college degree	61.1
	Post-graduate degree	15.4
Employment	Employee (public / private)	67.6
	Freelance, private business	10.9
	Retired	5.7
	Unemployed	5.9
	Student	8.7
	Homemaker	1.3
Place of residence	Big town/city (more than 100.000 inhabitants)	73.9
	Small town (less than 100.000 inhabitants)	19.1
	Village/rural area	7.0

green space is a problem because it increases housing costs" (W=18306, p=0.0431) and "Trees along roads pose a risk to people" (W=17779, p=0.0085). Interestingly, the residents of larger settlements were more likely to disagree with both statements than the residents of smaller settlements.

Series of questions with predefined answers from the questionnaire, dealing with different aspects of green spaces and their management, to complement the results of the Likert scale questions were used. These questions allowed the respondents to select the answers they considered important. The frequency of responses between two groups of respondents was examined for possible differences. First, the respondents were asked which area they would prioritize in public administration. The majority of respondents in both groups indicated that they would prioritize "waste management", while "green management" was ranked second in both groups. The chi-square test showed no difference in the frequency of the selected responses between the groups (Table 2).

Moreover, the respondents in both groups found public gardens more important than private ones (Table 2). The chi-square test showed a statistically significant difference between the two groups, indicating that responses were determined by place of residence, with individuals from larger towns finding public gardens much more important than private gardens.

The final question analyzed was about the aspects that the respondents would like to improve in green spaces that

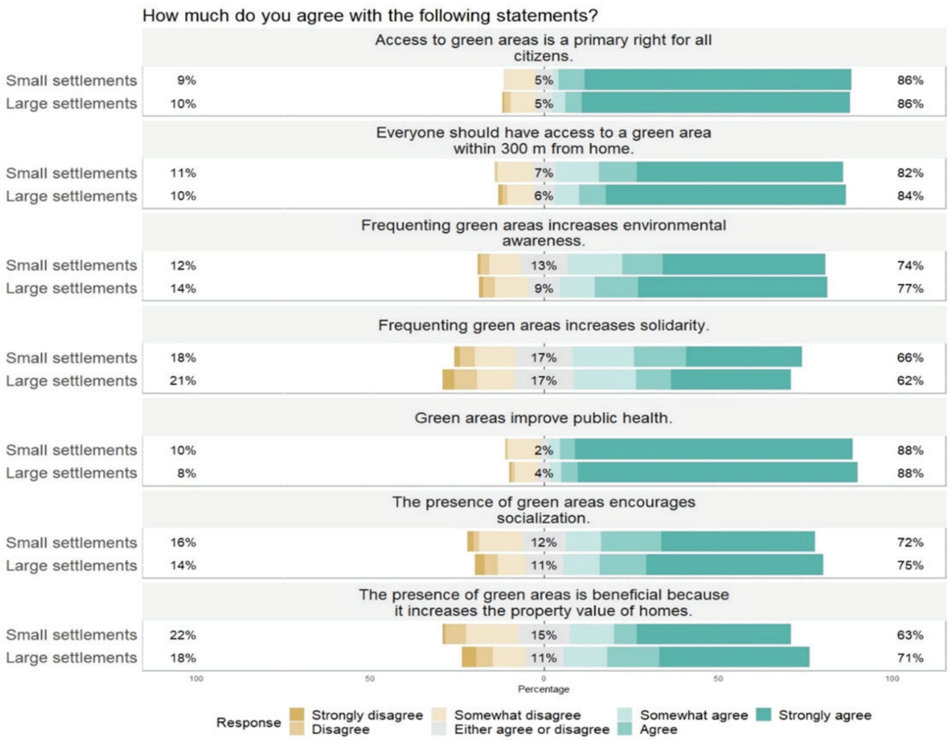

Figure 1. Attitudes toward green space benefits (N= 460).

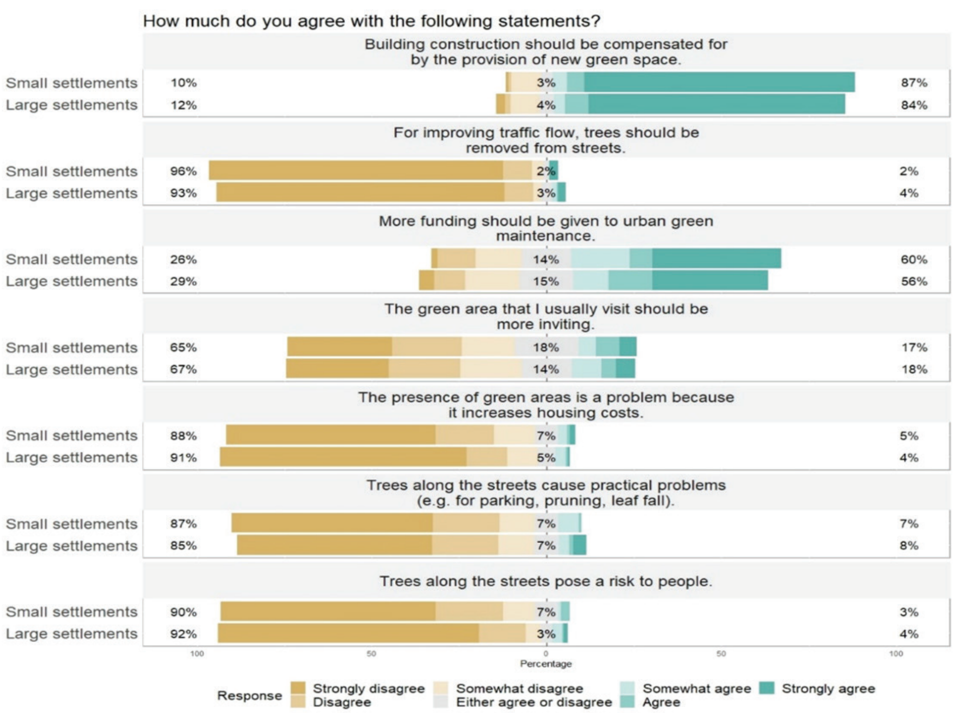

Figure 2. Attitudes toward green space management and perception of potential disservices (N=460).

Table 2. Frequencies of answers to questions regarding green spaces in the place of residence.

Question	Answers	Frequencies		X^2
		Large communities	Small communities	
In the public management of the town, which sector would you prioritize?	Green management	90	27	X^2 = 1,5914 p = 0.6614
	Public transportation	51	16	
	Street maintenance	16	8	
	Waste management	183	69	
What do you consider more important?	Private garden	77	53	X^2 = 19,212 p = 0.0001
	Public garden	263	67	
What would you improve in the green area that you know or frequent?	Aesthetic appearance	22	19	X^2 = 17,763 p = 0.01
	Areas for sports and recreation	7	27	
	Elements for relaxation	90	40	
	Level of noise pollution	4	7	
	Microclimate	62	17	
	Natural value	131	33	
	Visibility with open areas	11	4	
	Waste collection/cleanliness	134	52	

they use frequently or know well. Again, the respondents had a range of preset answers from which they could choose two, with the option to give an open response. For this analysis, the frequencies of the predefined responses that the respondents chose were used. The frequency table contained 564 entries from the respondents from large settlements and 199 entries from the respondents from smaller settlements. Respondents from larger settlements most frequently selected "Waste collection/cleanliness" and "Natural value", while "Elements for relaxation" ranked third in terms of frequency. In addition, respondents from smaller settlements preferred "Waste collection/Cleanliness" and "Elements for relaxation" while "Natural value" ranked third. Respondents from larger communities were least likely to want to improve the "Level of noise pollution", "Areas for sports and recreation" and "Visibility" of the place they know or visit. Even in smaller communities, "Level of noise pollution" and "Visibility" are the elements the respondents are most satisfied with, while "Aesthetic appearance" comes in third. The chi-square test showed that there are differences in the frequency of responses given between two groups of respondents. This means that the respondents indicate a different need for improvement in green spaces depending on where they live.

Satisfaction with Green Spaces

After the statements on the benefits of green spaces, attitudes towards management and perceptions of potential disadvantages, the questionnaire addressed the perceptions of green spaces that respondents know or visit. Respondents indicated their satisfaction with several predefined elements/characteristics of green spaces on a Likert scale ranging from 'Not at all' to 'Very much', with the option to answer 'I am not interested'. More than one-third of the respondents were "Rather satisfied" with the predefined elements of the green space of their choice. One-third of the respondents were "Not at all" or "Little satisfied" (Figure 3). Both groups of respondents were least satisfied with "Equipment for relaxing," "Presence of recreational facilities," and "Presence of wild animals", while they were slightly more satisfied with "Accessibility," "Makes hot days more mild" and "Natural value." In addition, the frequencies of responses to each green space aspect were tested for differences between the respondents from large and small settlements using the chi-square test. A significant difference between the frequencies was only found for "Equipment for relaxing (e.g. picnic tables/benches)" ($\chi2$ = 14.344, p = 0.00627). This means that the respondents from small settlements were significantly less satisfied with the amenities of their green spaces than the respondents from large settlements.

Reflections on Green Spaces – Answers to an Open-Ended Question

In the open-ended question the respondents were asked to share their thoughts and suggestions regarding green spaces in their locality. The responses were coded and the codes and their descriptions are presented below. Responses from 460 people were coded, and a total of 554 codes were assigned, so some of the responses covered multiple topics. Of the total number of responses analysed, 133 people did not make any suggestions (27% of them indicated that they were satisfied with the current state, and 73% indicated that they had no opinion or did not write anything). In the first round of coding, general categories of codes were assigned to each response based on the themes mentioned, while in the second round of coding these codes were further developed to obtain more detailed information. Most respondents' suggestions were related to urban planning (25% of all assigned codes), followed by green space design (19%), management (18%), and least related to governance (5%), visitors (4%), waste (3%), and ecosystem services (2%). The number of codes in each category with major subcategories are shown in Table 3.

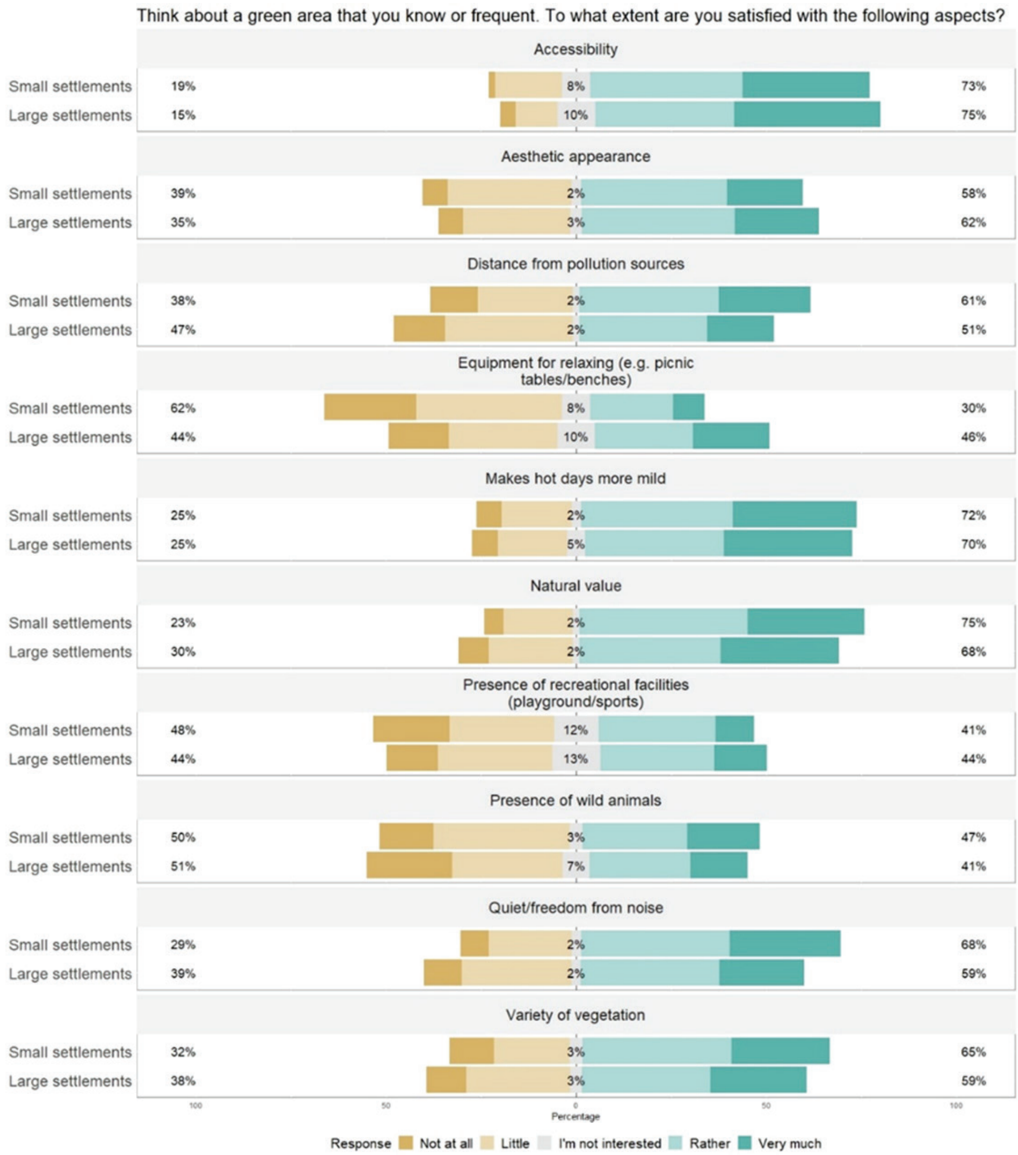

Figure 3. Satisfaction with different elements of green spaces the respondents know or frequent (N=460).

Table 3. Categories and frequencies of codes given in the analysis of the open-ended question.

Category	N of codes	Subcategories	% of codes
Urban planning	140	More green spaces	36
		Lack of green spaces	26
		Better planning	11
		Construction	11
		Other	16
Design	107	Equipment	26
		Trees	22
		Naturalness	13
		Landscaping	7
		Other	32
Management	101	Maintenance	61
		Tree management	12
		Bad management practice	12
		Other	14
Governance	26	Better governance	39
		Participation	23
		Other	38
Visitors	19	Behavior	69
		Visitor control	26
		Information	5
Waste	16	Illegal waste disposal	38
		A lot of waste	31
		Recycling	25
		Less waste	6
Ecosystem services	12	Thermoregulation	42
		Wellbeing	33
		Education	17
		Other	8
Without suggestion	133	Did not share anything	74
		Satisfied	26

DISCUSSION

This study is the first survey of the perceptions and attitudes towards green spaces in Croatia on a large spatial scale, covering cities and rural areas across the country. The survey was disseminated through the researchers' social networks, mailing lists and social media. Even though the sample of the respondents was purposive and small, and therefore not representative of the whole country, the results are exploratory in nature and important. This questionnaire was able to reach respondents from 64 different locations in Croatia (data not shown), thus achieving the first goal of the survey, which was to collect comprehensive data. The significant overrepresentation of women (76.3%) is the result of the personal interest and motivation to participate in the survey by the people contacted and reached via social media, similar to other surveys on the use of and attitudes towards green spaces during the COVID-19 pandemic (da Schio et al. 2020). Based on Croatian census data, there is 51.7% of females in the general population, therefore generalization on gender is not possible in this case (Statistical yearbook of the Republic of Croatia, 2018). This paper presents the first exploratory study of people's perceptions and attitudes towards green spaces in Croatia at the country level. Similar to other studies (Grigoletto et al. 2021), this questionnaire included few young people, i.e. under 20 years old, but 17% of the respondents were in the category of 20-29 years old. As younger people are usually difficult to reach in this type of research, it could be argued that this is related to the lockdown period and the distribution of the questionnaire through social networks, among other factors. Based on data collected in a similar period, people in Croatia reported spending more time looking at screens than usual (Pišot et al. 2020), which could contribute to a higher proportion of younger people and a higher likelihood of participating in the study. On the other hand, schools in Croatia switched to online instruction during the period when data for this study were collected. Therefore, it could be assumed that potential respondents younger than 20 years felt overwhelmed with online classes and were oversaturated with time spent in front of screens for educational purposes, so they were less keen to invest their time for socially and environmentally useful purposes such as our survey. Besides pressing issues of a new type of education, another assumption is that people younger than 20 years are not interested in participating because they do not recognize urban green spaces as personally important, attractive or significant enough, which may explain to some extent the low percentage of the younger people in the sample. In general, the main respondents to the questionnaire were people aged between 30 and 49 years, which is around the average (43.4) in Croatia (Statistical Yearbook of the Republic of Croatia 2018). Although socio-demographic characteristics might have an impact on perceptions and attitudes, these relationships were not examined in this study. However, the differences in attitudes and perceptions of respondents from differently sized settlements were examined. It was hypothesised that there will be differences in attitudes and perceptions towards green spaces in differently sized settlements in Croatia. It was hypothesised that different experiences of nature will shape attitudes and perceptions (Berenguer et al. 2005), but also that perceptions of the environment of green spaces may have an impact on community connectedness, which could promote participation in green space issues (Arnberger and Eder 2012). Given the low to non-existent public participation in green space issues in Croatia, research on the perceptions of green spaces in settlements of different sizes could improve the understanding of the relationship between people and nature and enable better decision-making adapted to community needs.

First, respondents' attitudes toward the benefits of green space were examined. The vast majority of the respondents agreed with the proposed statements about the various benefits of green spaces. Statistically significant differences in the perception of the benefits of green spaces depending on the size of the settlements the respondents come from were not found. This result is consistent with similar research on attitudes towards environmental issues, where no difference was found between urban and rural areas, as concern for the environment was high among residents of both areas (Berenguer et al. 2005). There was also a generally positive attitude towards the benefits of green spaces in our sample.

The second set of Likert scale questions revealed that people have similar perceptions about the management and possible negative impacts. However, this information is important for urban planning as it provides data on the perceived negative aspects of green spaces and their management, which could have consequences for human well-being as well as additional costs for maintenance in the most confined urban environments (von Döhren and Haase 2019). Interviewees from the different large housing estates agreed that trees are an environmental value worth spending money on and that green spaces are an important part of the landscape that needs to be considered during construction. Potential negative impacts of trees were not perceived as such by the respondents. However, statistically significant differences were found between two groups of respondents for two groups of statements. Based on the assumption that people in smaller settlements tend to have a private garden to, they perceive its management as a cost to the household, which may explain why people from smaller settlements reported higher levels of agreement with this issue. As smaller settlements have smaller budgets than larger ones, a possible lack of experts in tree and green space maintenance could also lead to trees being perceived as dangerous. Systematic education in smaller settlements about trees and tree management could improve this negative perception of people. Education is an important resource in green space planning and management (Fischer et al. 2020).

To further develop research on different perceptions and attitudes towards green spaces, it was decided to use another set of questions and investigate possible differences. Further analysis identified differences in perceptions between people from differently sized settlements. This is related to the importance of private or public green spaces and the elements of green spaces they feel could be improved. This suggests that people have similar attitudes but slightly different perceptions of green spaces concerning environmental conditions.

Although people agree with the statements that green spaces are important, that they provide social benefits and are a human right for all citizens, on the other hand, many of the respondents in this survey were not completely satisfied with the benefits that green spaces provide in their neighbourhood. Similar results were found for Zagreb in the study by Krajter Ostoić et al. (2017), where people expressed high importance of urban green spaces and lower satisfaction with their maintenance and management. When asked how satisfied they were with the aspects of known or frequently used green spaces, overall the respondents were slightly more satisfied than dissatisfied; however, there is room for improvement in green spaces in both environments. It must be acknowledged that the respondents were not asked to define the green spaces they were referring to, but researchers took these results to show overall satisfaction, so this is an important finding for green space management, regardless of the size of settlements or the type of green space. In terms of differences in perceptions, it was found that residents of smaller settlements were more dissatisfied with equipment than the respondents from large settlements. Again, a possible explanation could be lower financial resources available for the management of green spaces to provide more equipment.

As mentioned earlier, the data for this study were collected using an international questionnaire. The results and the comparison between countries regarding the use, visitation and perception of green spaces during the first closure period due to COVID-19 can be found in Ugolini et al. (2020). As for the answers to the open questions, they were also reported in the mentioned study, but over a whole sample, while in our study we analysed only the Croatian sample. The different techniques used in the two studies (text mining and coding, respectively) have led to a slightly different presentation of the results, but the main conclusions remain the same. Another important difference between the results is the depth of coding undertaken in the two analyses. While Ugolini et al. use the entire sample collected (including the Croatian one), here we only present the analysis of the entire Croatian sample, which is thus more detailed.

Urban planning is also the most prominent category in our presentation of results, which expresses the reliability of the coding results. The majority of respondents indicated that more green spaces are needed, which highlights the important issue of urbanisation and building development. Croatia as a post-socialist country faces similar problems as described in Kronenberg et al. (2020). The problem of changing land use and the expressed concern about new development are understandable, as the literature provides examples of the loss of large amounts of green spaces due to new development (Iojă et al. 2011). However, the provision of new green spaces, particularly in medium-sized cities, is often influenced by several factors that affect the supply of new green spaces (Boulton et al. 2020).

Insight into the type of green spaces Croatian residents would like to see was provided through proposals coded as designs. The information collected provides a good opportunity to better understand the residents' perceptions and needs, which enables designers and managers to design and redesign green spaces according to the needs of actual users. Respondents expressed a desire for more equipment in green spaces, particularly trees and more biodiversity, naturalness and edible fruit trees in green spaces. Research has shown that people have a very good subjective sense of the level of biodiversity in their urban environment (Gunnarsson et al. 2017). Therefore, those who indicated in the open-ended question that they would like to see more naturalness should be considered. Research also shows that people are generally positive about biodiversity-friendly green space management (Fischer et al. 2020).

Management was the third most frequently mentioned category among the respondents. They expressed an overarching need for better management, while also emphasising that they perceive poor management practices in their neighbourhoods. A recent study with citizens of the city of Zagreb concluded that the residents were more concerned about management practices related to green spaces than the physical component of these areas (Krajter Ostoić et al. 2017). Therefore, management practices that are most easily perceived by visitors and users should take into account their perceptions. This could lead to an improvement in management practices and overall user satisfaction.

Recent examples from Italy have shown how local policies and their programmes can improve the setting and use of urban green spaces (Grigoletto et al. 2021). Therefore, policy and management are important factors in creating not only better green spaces, but also better attitudes towards them among citizens. As urban green spaces are at the heart of a sustainable future, local authorities need to plan green spaces in collaboration with the citizens who will use them most. Public participation is also emphasised by respondents in their consideration of green spaces. Therefore, this result is important for the local context and shows that people need to be more involved in the planning and management of green spaces.

Although the perceived amount of litter, illegal littering, irresponsible visitor behaviour, visitor control and poor behaviour of other users were less frequently cited, these dissatisfactions can have a significant impact on the quality of time spent in green spaces (Ciesielski and Stereńczak 2018). Problems related to litter such as illegal littering or lack of bins, the need for additional equipment essential for spending time in green spaces, and dissatisfaction with the behaviour of other users of green spaces were frequently expressed as problems in a recent survey of visitors in one of Zagreb's forest parks (Krajter Ostoić et al. 2017, Kičić et al. 2020). Research has shown that even a moderate amount of litter can elicit a reaction from green space users (Verlič et al. 2015). In addition, the majority of respondents indicated that they prioritise waste management at their respective residences. Litter affects the aesthetic appearance of green spaces and detracts from the overall experience of contaminated spaces and the services they provide. Therefore, it can be concluded that waste is a problem that needs to be worked on, regardless of the population or size of the settlement in Croatia. The respondents focused more on negative experiences and changes they would like to see in green spaces. Positive impacts on well-being and satisfaction with various ecosystem services were therefore the least mentioned problems.

CONCLUSIONS

Although it was hypothesised that there would be differences in the perceptions and attitudes of respondents from differently sized settlements in Croatia, more similarities than differences were found. This means that people generally have similar attitudes towards green spaces, regardless of the size of the municipality. The differences were related to the aspects of local management rather than to general attitudes towards green spaces as such. Beneficial attitudes towards green spaces have been described in the literature, but in densely built-up areas in Asia (Lo and Jim 2012). In the Croatian context, utilitarian attitudes and dissatisfaction in smaller settlements are most likely the results of uneven funding allocated to green space management than in large settlements. Since attitudes and perceptions are influenced by numerous factors, including the respondents' sociodemographic characteristics, it must be acknowledged that these interactions were not assessed in this study and may explain some of the differences. However, since this is an explanatory study, it is difficult to generalize the results. However, it should be emphasized that the results make a valuable contribution to the academic literature that explores differences in perceptions in the relationship between people and green spaces. The research contributes to a better understanding of the relationship between people and green spaces, especially regarding the different perceptions and needs of residents of different settlements. The results could be used to inform green space management in smaller settlements in Croatia, as well as in large settlements, about the aspects of their work which could be improved according to the needs of actual users.

Author Contributions

Conceptualization: AMM, MK, DV and SKO; methodology: AMM, MK, DV and SKO; software: MK; validation: AMM, MK, DV and SKO; formal analysis: MK; investigation: AMM; data curation: MK; writing - original draft preparation: AMM, MK, DV and SKO; writing - review and editing: AMM, MK, DV and SKO; visualization: MK, AMM; super-vision: DV and SKO; project administration: SKO; funding acquisition: SKO. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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First Results of Monitoring the New Invasive Species *Prunus serotina* Ehrh. Population inside the Regeneration Area of Common Oak-Hornbeam Forest in Western Croatia

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ABSTRACT

Black cherry (*Prunus serotina* Ehrh., Rosaceae) is a widespread invader of the European temperate forests and a significant component of the human-caused part of the global environmental changes. Its successful invasion results from a complex interaction between the species life traits and the recipient ecosystem attributes. While it has been recorded to develop spontaneously in numerous European countries, in Croatia information details on its population distribution, as well as its current status, are still missing. The individuals of *P. serotina* were found in the pedunculate oak (*Quercus robur* L.) forest regeneration area of Jastrebarsko forest management unit in 2018. This alerted us to start to monitor its spreading area, status and impact on the native plant species in a four-year period (2018-2021). In order to investigate the habitat characteristics, phytosociological approach was applied. In addition, the area was surveyed using an unmanned aerial vehicle (UAV) DJI Mavic 2 Pro and DJI Ground Station Pro. The results showed that *P. serotina* spread considerably in the regeneration area, which indicates its invasive character. It also caused alteration in current vegetation. Fast initial expansion of *P. serotina* in 2019 was slowed down in the next 2 years due to performed tending activities, suggesting mechanical measures could help to control its invasive spreading at an early stage of development. This research brought up the first record of the *Prunus serotina* species in pedunculate oak forest regeneration area of western Croatia with a recommendation to continue the monitoring survey in order to help prevent its spread in the future.

Keywords: regeneration area monitoring; invasiveness; Jastrebarsko; spreading control; phytosociology; forest management

INTRODUCTION

Alien invasive species, i.e. the species that are not native to a specific location (an introduced species), are nowadays recognized as the second most important cause of biodiversity loss (just after direct habitat destruction) and may have a strong wide-ranging environmental (on structure, function and stability of the ecosystem) and an economic impact (Starfinger 1991, Simberloff et al. 2013). From an extensive literature on biological invasions (e.g. Starfinger 1991, Starfinger 1997, Vitousek et al. 1997, Everett 2000, Kolar 2001, Vila and Weiner 2004, Godefroid 2005, Verheyen et al. 2007, Vila et al. 2010, Simberloff et al. 2013, Aerts et al. 2017), it can be seen that an organism introduction to areas where they were originally absent may have very different consequences. In the vast majority of cases the introduced species do not survive in the natural or near-natural vegetation and only a small percentage totally naturalizes. In other cases, new species do not only naturalize successfully, but also significantly change the whole ecosystem This happens mostly by establishing high abundance, affecting the regeneration of the native species by suppressing their growth (Huxel 1999, Godefroid 2005, Vanhellemont et al. 2010), indirectly changing the plant community composition and affecting belowground carbon pools (Ehrenfeld 2004, Koutika et al. 2007). They can also have a direct impact on human health, for instance by producing allergenic pollen that exacerbate respiratory diseases or just by serving as a novel habitat for disease vectors (Vitousek et al. 1997). Invasive species often affect larger areas and their impacts on plant communities and soil microbiota may accelerate or decelerate the local nutrient cycles (Ehrenfeld 2003, Vanderhoeven et al. 2005, Liao et al. 2007, Dassonville et al. 2008, Lazzaro et al. 2014), promoting losses or gains in local nutrient stocks and even have an impact on the greenhouse gas emissions from the soil (Wayne et al. 2002, Chen et al. 2015).

American bird cherry, black cherry or rum cherry (*Prunus serotina* Ehrh.) is a deciduous, single-stemmed, native forest tree originating from dry and warm parts of the North America, which was introduced and successfully spread across Europe. It typically forms large and straight branch-free boles and narrow crowns in the forest environment and an irregular crown type with short and broad trunks in the opening area. The bark of the young stems is thin, smooth and reddish-brown to nearly black, while the bark of the large trunks is fissured and scaly but remains thin. It develops simple, elliptic-ovate, thick and glossy leaves with serrated leaf margins, two green glands on the petiole and a brown tomentose center leaf vein. Its small, white and 5-petalled flowers with a pleasant smell form long, cylindrical inflorescences, while the incoming fruits are nearly globular, one-seeded, purplish-black to black, edible drupes (Muys et al. 1992, Starfinger 2010). *Prunus serotina* is highly resistant to some less favorable ecological factors for the majority of the plant species such as drought, frost, lack of light, and excess moisture. It prefers moderately acidic habitats of deep, humid soils with moderate nitrogen concentrations and can also grow on somewhat poorer soils such as sandy or salty ones. *Prunus serotina* shows resistance to various pollutions and even to the pesticide effects of the certain repellents. Its incredibly high hardiness ability and tendency to easily produce larger amount of seeds allows it to successfully expand and have an impact on various types of ecosystems (Muys et al. 1992, Starfinger 2010, Thijs et al. 2012). *P. serotina* disperses by seeds but has a very efficient asexual reproduction by suckering and sprouting. If it is sufficiently exposed to light, it produces an abundant quantity of seeds since the age of seven. Seeds are dispersed by birds and frugivorous mammals (Muys et al. 1992). While its growth rate and/or mass seed production is approximately proportional to light availability, *P. serotina* also holds competitive advantage of enabling its seedlings to persist as ageing juveniles in the dense shade conditions, giving itself the opportunity to disperse again in more favorable, open-gap conditions (Closset-Kopp et al. 2007).

Studies on the invasion of *P. serotina* and its effects have been published by many researchers (Bijak et al. 2014, Halarewicz et al. 2014, Aerts et al. 2017). According to the European alien species checklist database (Klotz 2007), *P. serotina* takes place as an invasive plant species with an existing evidence on various impacts (environmental, social and/or economic) in Europe (Klotz 2007, Kettunen et al. 2009, Sitzia et al. 2016). It covers large parts of the continental European lowlands, reaching high abundance and invasive status in Germany, especially the northern half of the country (Kowarik 1995), the Netherlands (Klotz 2007, Vanhellemont et al. 2010), Denmark (Andersen 1995), Poland (Bijak et al. 2014), Belgium (Godefroid et al. 2005, Vanhellemont 2009, Vanhellemont et al. 2010), Switzerland (Wittenberg 2005), the Czech Republic (Vanhellemont 2009, Pyšek et al. 2012) and Southern England (CABI Undated, EPPO Global Database 2020).

In accordance with the European regulation on Invasive Alien Species (IAS), the black cherry tree has recently been indicated as one of the 96 species proposed for the development of the national list of priority invasive alien species in Italy (Forte et al. 2019). In Slovenia, on the other hand, current status has not been yet extensively studied. As far as it is known, only few places are currently naturalized with an invasive tendencies (LIFE ARTEMIS, Undated).

Furthermore, the existing data from Nikolić 2005 (Flora Croatica Database) indicate the presence of *P. serotina* species in some parts of Croatia (Figure 1). *P. serotina* occurrence has been recorded in Arboretum Lisičine (Idžojtić et al. 2011) as well as in Đurđevački peski Arboretum (Ređep 2017). The data on its distribution within forest complexes and natural habitats are still missing. Unlike in many European countries, in Croatia *P. serotina* is still not on the invasive species list.

Also, according to the EPPO Global Database *P. serotina* observation point, the presence of *P. serotina* in Croatia still lacks the information details (https://gd.eppo.int/taxon/PRNSO/distribution/HR). Lack of national inventories of *P. serotina* populations emphasizes the importance of its further monitoring in our area.

This paper deals with the possible invasiveness of the black cherry in Croatia. Due to its fast growing capability and

Figure 1. Current data of *P. serotina*'s presence in Croatia (https://hirc.botanic.hr/fcd/).

the potential to establish dense shrub layer in sparse forests, it may outcompete some native plant species and become the source or decreasing biodiversity. Its significant spread in pedunculate oak forest regeneration area motivated us to find the most adequate way of tracking its further expansion and development.

The objectives are to determine its spreading area, status and its impact on the native plant species by monitoring over a certain period of time.

MATERIALS AND METHODS

A research area of the *P. serotina* distribution is located in the Jastrebarsko Forest Office as part of the management unit of "Jastrebarske prigorske šume" and subcompartment 19a with the total size of 11.73 ha (Figure 2).

The research area is a former forest culture that consisted of Weymouth pine (*Pinus strobus*) as main species together with Scots pine (*P. sylvestris*) and Norway spruce (*Picea abies*). The area was affected with two mayor windbreaks in 2014 and 2016, resulting with more openings in the canopy layer and degradation of forest structure and habitat. This ended up in 2017 with the replantation of pedunculate oak (*Quercus robur* L.) seedlings inside polypropylene tree shelters in the amount of 8000 seedlings per 4 ha.

According to Köppen climate classification, the area belongs to the "Cfwbx" type of climate. This indicates moderately warm, rainy climate where the mean temperature of the coldest month in the year is between -3°C and 18°C and the warmest is between 10°C and 22°C. The surrounding forest area belongs to *Carpino betuli-Quercetum roboris* (Anić 1959, Rauš 1971) with a typical pseudogley soil type. The first dissemination data of the *P. serotina* in this area date from 15th September 2018.

In order to perform area monitoring we did an areal recording four times in 2019-2021 period (3rd May and 7th June 2019, on 30th June 2020 and on 16th August 2021). It was performed with the use of the unmanned aerial vehicle (UAV) DJI Mavic 2 Pro equipped with standard RGB sensor. These images were used to determine the size of the affected area with *P. serotina* speciments. The mission was planned with DJI Ground Station Pro app for iOS. It was

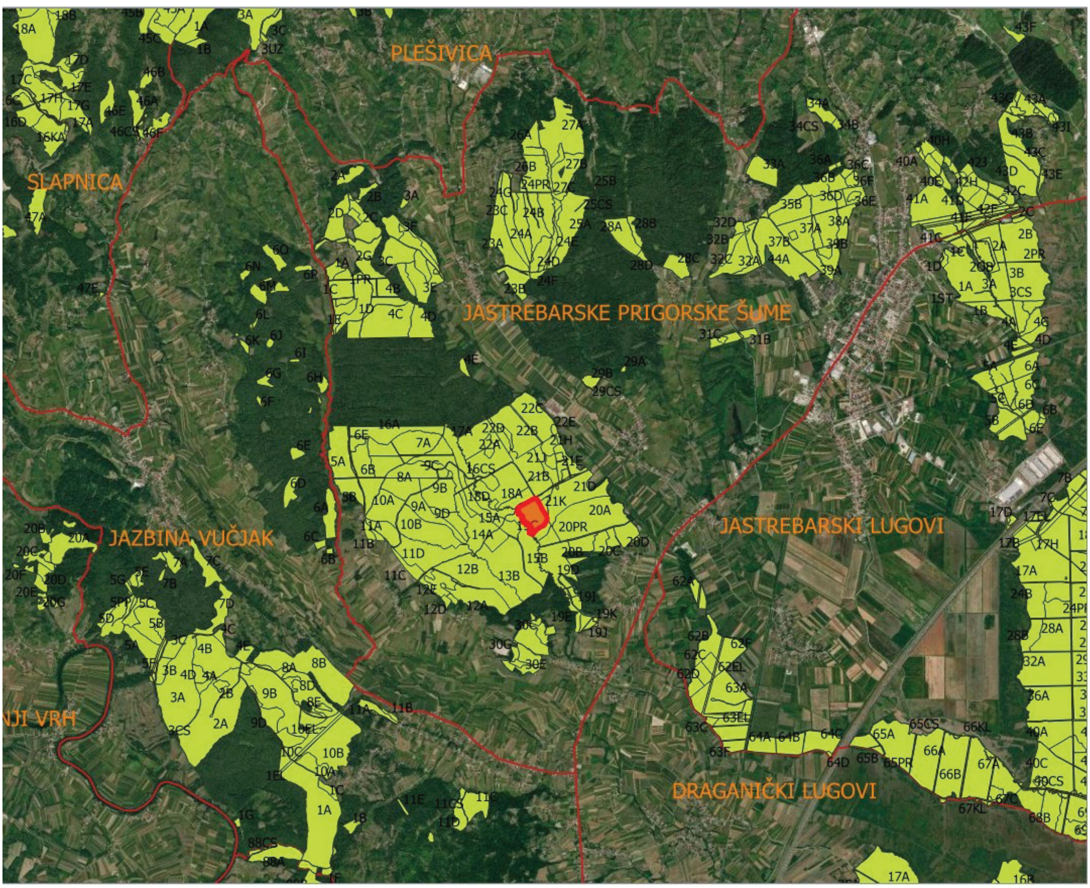

Figure 2. Position of management unit "Jastrebarske prigorske šume".

conducted with 80% front overlap ratio and 75% side overlap which allowed high quality of post flight image processing. The above ground flight was set to 90 meters, resulting with 2.1 cm pixel resolution. Post flight data processing, which included photos alignment, dense cloud build, mesh build and lastly orthomosaic build, was performed using AgiSoft PhotoScan Professional (Version 1.5.5) software. Map of the area was created using QGIS software (QGIS Development Team, http://qgis.osgeo.org). The size of the area affected by black cherry was calculated with QGIS geometry tools.

In order to research habitat characteristics of the area and possible *P. serotina* invasion, we performed vegetation survey according to the standard Brown-Blanquet method (1964) during the high vegetation season on 27th July 2020 and on 2nd August 2021.

RESULTS

Spreading Data

The first report of the *P. serotina* occurrence in forest ecosystem of western Croatia dates from September 2018, when spreading of the "unknown" woody species was detected by local foresters. Herbarium material was collected and brought to Croatian Forest Research Institute where it was identified as *P. serotina* species. The affected area of approximately 200 m^2 in 2018 was reported during the stand tending activities.

Based on the conducted research process, the estimated area of the black cherry expanded to 480.75 m^2 in 2019. It increased its distribution area considerably in comparison to the reported one in 2018.

After this significant spread, the interpretation of aerial images showed no change in the infested area in 2020 and 2021. Even though further spreading of *P. serotina* was successfully prevented by forest tending activities, mechanical measures did not manage to totally remove *P. serotina* off the regeneration area.

Vegetation Data

The results of phytosociological survey in the regeneration area affected with *P. serotina* showed that it mostly consists of pioneer and a fast growing, heliophilic flora. As it can be seen in Table 1, the high shrub is mostly overlaid by *P. serotina* (Figure 5).

The herb layer is mostly covered by *Solidago gigantea*, together with other invasive species such as *Phytolacca americana*, *Ambrosia artemisifolia*, *Erigeron annuus* and other stress-tolerant species: *Eupatorium cannabinum* and *Pteridium aquilinum*. In 2021 some species were missing, such as: *Abies alba, Calluna vulgaris, Angelica sylvestris, Asarum europaeum, Athyrium filix-femina*, *Centaurea jacea, Dryopteris filix-mas, Equisetum aquilinum, Fragaria vesca, Glechoma hederacea, Humulus lupulus, Pinus strobus* and *Pulmonaria officinalis*.

Vegetation survey of the surrounding forest area of *Carpino betuli-Quercetum roboris* community indicates typical floral composition for this community. We detected herbaceous invasive plant species such as *Phytolacca americana* and *Erigeron annuus*, but no presence of *Prunus serotina* specimens.

Table 1. Phytocenological recordings of both regeneration area.

		Regeneration area	
		2 August 2020	27 July 2021
Relevé area (m^2)		400	
Altitude (m)		155	
Slope (degrees)		<10	
Exposure		SW	
Cover tree layer (%)		.	.
Cover shrub layer (%)		70	70
Cover herb layer (%)		70	70
X-coordinate		45.64568	
Y-coordinate		15.58830	
Prunus serotina	s1	4	4
Rubus fructicosus	s1	2	2
Quercus robur	s1	1	1
Carpinus betulus	s1	1	1
Salix caprea	s1	1	1
Frangula alnus	s1	+	1
Populus alba	s1	+	1
Abies alba	s1	+	.
Pinus strobus	s1	+	+
Populus tremula	s1	+	+
Alnus glutinosa	s1	+	+
Solidago gigantea	hl	2	2
Eupatorium cannabinum	hl	2	2
Phytolacca maericana	hl	1	1
Pteridium aquilinum	hl	1	1
Calluna vulgaris	hl	1	.
Genista tinctoria	hl	1	+
Ambrosia artemisifolia	hl	+	+
Angelica sylvestris	hl	+	.
Asarum europaeum	hl	+	.
Athyrium filix-femina	hl	+	.
Calamagrostis epigejos	hl	+	+
Carpinus betulus	hl	.	+
Centaurea jacea	hl	+	.
Cirsium palustre	hl	+	+
Dryopteris filix-mas	hl	+	.
Equisetum sylvaticum	hl	+	.
Erigeron annuus	hl	+	+
Fragaria vesca	hl	+	.
Glechoma hederacea	hl	+	.
Humulus lupulus	hl	+	.
Juncus effusus	hl	+	+
Lycopus europaeus	hl	+	+
Lysimachia vulgaris	hl	+	+
Lythrum salicaria	hl	+	+
Pinus strobus	hl	.	.
Potentilla erecta	hl	+	+
Pulmonaria officinalis	hl	+	.
Salix caprea	hl	.	+
Scrophularia nodosa	hl	+	+
Tanacetum vulgare	hl	+	+
Viola reichenbachiana	hl	+	+

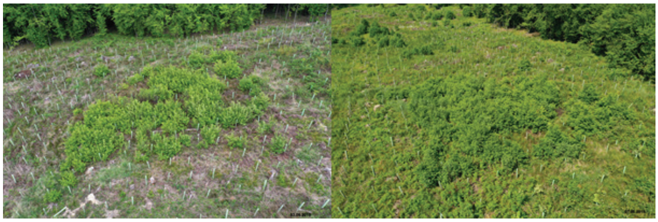

Figure 3. Black cherry group in subcompartment 19a in May and June 2019.

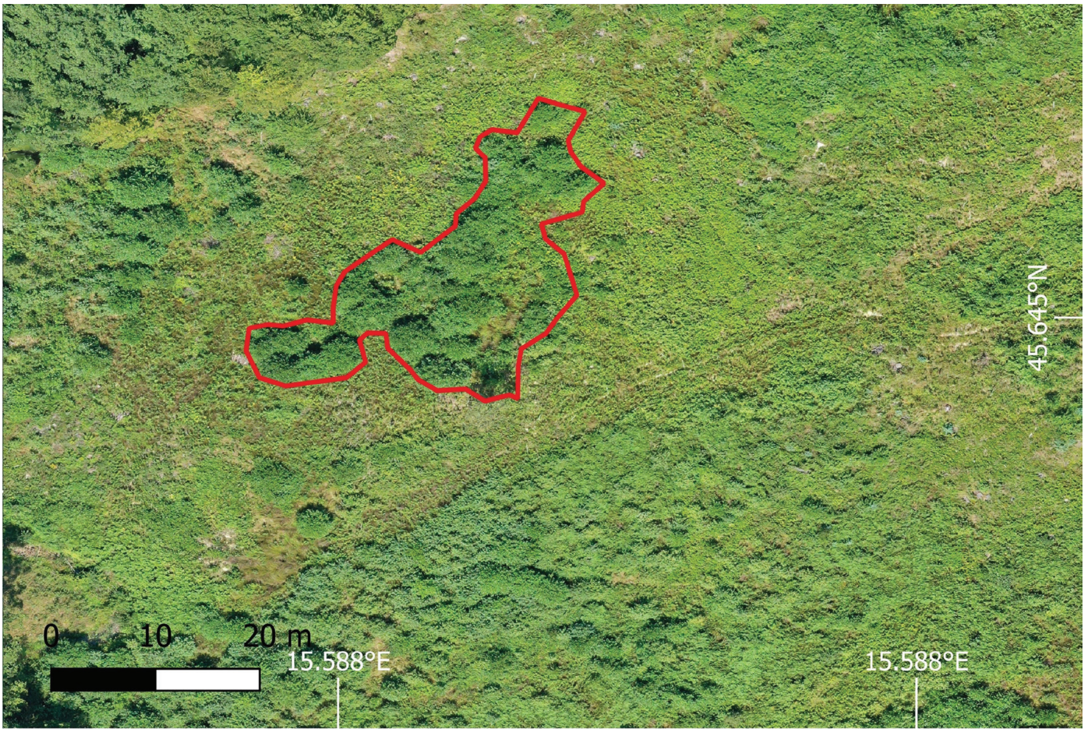

Figure 4. Size of the affected area by *P. serotina*.

Figure 5. Rapid *P. serotina* development suppresses growth of other species.

DISCUSSION

Structural complexity and continuous canopy cover represent one of the main characteristics that insure stability of the forest community. When, at some point, this stability is disrupted, both by anthropogenic and/or natural large-scale disturbances ending with a canopy cover fragmentation, the habitat becomes exposed to potential invasive species' development.

This highlights degradation issue which consequently, in the majority of cases, often leads to vitality disruption and invasive species settlement. Also, the ability of *P. serotina* to naturalize in less favourable environmental conditions, as well as not having direct competitors with a similar life strategy, contributes to its successful expansion and domination upon the native species regeneration process (Starfinger 1997). *P. serotina*'s tendency to easily produce abundant quantity of seed and disperse it by birds and frugivorous mammals can also allow its appearance and successfully expand in various types of ecosystems (Muys et al. 1992, Starfinger 2010), as well as in the regeneration area.

Although the first record of *P. serotina* in this area dates from 2018 we do not know exactly when the first specimen appeared, but we can assume, according to its spreading size, that it happened several years before, as part of the former forest culture. This has been also confirmed by many researches that presume pre-gap patterns in the understorey, rather than postgap partioning, largely determine gap composition. It refers to a fact that species that are present in the understorey at the time of gap creation (chance occupants) are the ones that fill the open area and not the best adapted species (Fraver et al. 1998, Brokaw 2000, Closset-Kopp et al. 2006). According to the Closset-Kopp et al. 2006, this 'sit-and wait' strategy is quite common among co-occurring tree species in *P. serotina*'s native range (e.g. *Fagus grandifolia, Quercus alba, Acer pensylvanicum, Tsuga canadensis*), but it is almost unknown for tree species of European temperate forests. This life plasticity greatly contributes to *P. serotina* invasiveness and explains its rapid spread in the regeneration area in the first year of monitoring.

After its significant spreading progression in the regeneration area in 2019, the use of visual image interpretation elements (Lillesan et al. 2008) in 2020 and 2021 showed no expansion or reduction in size covered with *P. serotina* specimens.

Since *P. serotina* was continuously subjected to the above-ground removal treatments (partial-cutting) of essentially all shrub and herb layer vegetation with a mulcher, twice a year (at the beginning of spring and in the late summer period), it contributed to stopping the spreading of the species in the last 2 years of our monitoring process.

Even though mechanical measures did not manage to totally remove *P. serotina* specimens off the regeneration area, they represent its spreading control method in the regeneration area. If we consider the number of other cases undergone *P. serotina*'s removal (Muys et al. 1992, Van Den Meersschaut et al. 1997, Oosterbann 2005, Annighöfer et al. 2012), when it comes to successful control measures, a combination of often mechanical and chemical methods is used. Mechanical suppression alone, especially by the above-ground biomass removal, has proven inadequate and it is questionable to what extent it would be considered sufficient for its effective suppression in the regeneration area in the future (Muys et al. 1992). Considering such results from different researches, it is also highly important to continue the monitoring of the spreading area in the pedunculate oak regeneration area.

Vegetation survey of the area affected by *P. serotina* showed the expected presence of regeneration area species such as *Rubus fruticosus, Salix caprea, Populus alba, Frangula alnus* and high abundance of *P. serotina* in the shrub layer in both 2020 and 2021. Although invasive species (*Phytolacca americana, Ambrosia artemisifolia, Erigeron annuus, Solidago gigantea*) did not increase their cover significantly, their population became denser and more vigorous after tending activities. Possibly, this lead to repression of some habitat-specific species (*Asarum europaeum, Athyrium filix-femina*, *Dryopteris filix-mas, Equisetum aquilinum, Fragaria vesca, Glechoma hederacea, Pulmonaria officinalis*), in just one year.

Vegetation survey of the surrounding *Carpino betuli-Quercetum roboris* forest community reflects the structural stability regarding canopy cover as well as the floristic composition, without the presence of *P. serotina* specimens. Although some researches suggest possibilities of *P. serotina* to invade the natural forest ecosystems (Closset-Kopp et al. 2007, Bijak et al. 2014), we assume that the stability of the forest ecosystem with continuous canopy cover layer is the first and crucial point in fighting invasive plant species.

CONCLUSIONS

This research brought up the first record of *Prunus serotina* species in pedunculate oak forest regeneration area of western Croatia. Initial significant expansion of the *P. serotina* specimens in the first year of monitoring process indicated its invasive character. *P. serotina* needs to be put on the Croatian National Invasive Species list. The other two-year vegetation survey monitoring showed no change in *P. serotina* spreading. This does not only relate to *P. serotina*, but to other invasive and non-invasive species as well. Mechanical measures, in this case, as a part of a regularly conducted tending activities, represent a potential spreading control method of *P. serotina.* This method of monitoring by using the unmanned aerial vehicle with basic RGB sensors showed the possibility for a fast and easy detection of species. This can also be used for fast on-site inspection of other large areas at a low cost. We recommend to continue the monitoring survey of *P. serotina* in order to prevent and control its spread in the future.

Author Contributions

JM and SP conceived and designed the research. JM, IS and NZ carried out the field activities, NZ processed the data and performed area surveying while JM and IS performed phytosociological approach. JM and SP secured the research funding and JM supervised the research. JM and IS and NZ wrote the manuscript. JM helped to draft the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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First Record of the Saproxylic Beetle *Cossonus parallelepipedus* (Coleoptera, Curculionidae) in Bosnia and Herzegovina

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ABSTRACT

Balkan Peninsula is considered to be a hotspot of beetle biodiversity. Registering occurrence of saproxylic beetles is an important first step for expanding the general knowledge about saproxylic beetles as ecologically important insect species. *Cossonus parallelepipedus* is a European saproxylic species distributed from Iberian Peninsula in the west to Russia in the east, and from the Mediterranean in the south to Fennoscandia in the north. The first, and until now the only find of this species for the Balkan Peninsula is from Croatia. We report the first find of *C. parallelepipedus* in Bosnia and Herzegovina (BiH). In April 2020, larvae, pupae and imagoes were collected, in the central part of BiH, north of Sarajevo, on Zvijezda Mt. near Vareš from decaying moist wood in the lower part of a tree trunk of European silver fir, *Abies alba*. We expect that this species has a wider presence, especially in mountain areas in the central part of the country. Due to the similar environment conditions for other two European *Cossonus* species (*C. cylindrus* and *C. linearis*) their presence is also possible.

Keywords: weevil; wood boring insect; decaying wood; biodiversity; *Abies alba*

INTRODUCTION

The genus *Cossonus* (Coleoptera, Curculionidae) in Europe is represented with three widely distributed species: *Cossonus cylindricus* Sahlberg, 1835, *C. parallelepipedus* (Herbst 1795) and *C. linearis* (Fabricius, 1775) (Löbl and Smetana 2013). *C. parallelepipedus* is a European species distributed from Iberian Peninsula in the west to Russia in the east, and from the Mediterranean in the south to Fennoscandia in the north. The first, and until now the only find of this species for the Balkan Peninsula is from Croatia (Löbl and Smetana 2013, Alonso-Zarazaga 2017, de Jong 2021). In Sweden, the species has been noted on deciduous tree species such as elm, aspen, poplar, oak, beech and willow, and in some cases on spruce (Ehnström and Axelsson 2002). In England, besides of the mentioned hosts it has also been registered on silver fir (https://www.ukbeetles.co.uk/cossonus-parallelepipedus). The status of the species (e.g. in Finland) is critically endangered (https://laji.fi/en/taxon/MX.196213?showTree=true).

The adult beetles of *C. parallelepipedus* are 4.5-6 mm in length, with long dark brown elytrae, the antennae and the legs being usually brighter (Reitter 1916). The larvae live in dead wood, mostly under bark of rotting deciduous trees (Yunakov et al. 2018). They dig tunnels in the tree trunks in various stages of decay for a duration of two years, making winding galleries (Folwaczny 1983). After pupation adult beetles stay in the wood during the winter. Regularly the adults leave the wood during the early summer and can be detected around the exit holes, but they remain hidden under bark by day. Over the years, the species can increase its population in the same trunk.

Decomposition processes is very important in the nutrient cycle of natural ecosystems where saproxylic beetles are irreplaceable (Gotelli and Colwell 2011, Kacprzy and Bilnsk 2017). The knowledge of the biology of saproxylic beetles, for example where they live, what they eat and who eats them is insufficient, so the first step would be to find and identify them. Many saproxylic beetle species remain widely distributed in Europe, although their populations and ranges have suffered significant long-term decline (Gotelli and Colwell 2011).

According to the available data, *Cossonus* spp. have not been registered until now in Bosnia and Herzegovina (Löbl and Smetana 2013, Osella and Zuppa 2013). Our paper provides the first data on the occurrence of this saproxylic species within the territory of the country.

Since basic data on species distribution and population status of saproxylic beetles are limited, there is a clear need for drawing together information providing new data to improve the quality of information, such as in (Nieto and Alexander 2010).

MATERIALS AND METHODS

Material examined: Bosnia and Herzegovina, Zvijezda Mt., Sarić, lat. 44.177174° lon. 18.406838°, 1060 m a.s.l., 5/IV/2020 (Figure 1). The larvae, pupae and the adults of insects were sampled from damp decaying wood of European silver fir, *Abies alba* Mill. Larvae, pupae and adults were collected by hand, stored in 96% ethyl alcohol and deposited in the entomological collection of the Faculty of Science, University of Sarajevo. The identification was done by using identification keys (Jordal 2014) and was confirmed by Gabor Mesaroš from Protego Society (Subotica, Serbia).

RESULTS AND DISCUSSION

The specimens of *C. parallelepipedus* were found at the log warehouse at Šeirići locality (Zvijezda Mt.) (Figure 1) by the first author. They were discovered during inspection of decaying moist wood of tree trunks that were dragged from section 34. Šimin potok to the warehouse. The locality is surrounded by mixed woods of spruce, fir and beech, widely distributed forest community on Zvijezda Mt. (Figure 2). Six specimens of imagoes and larvae (Figure 3 and 4) have been found.

According to the available literature (e.g., Löbl and Smetana 2013, Osella and Zuppa 2013), this is the first finding of the species in Bosnia and Herzegovina, which after Croatia is the second country in the Balkan Peninsula where the species has been recorded. Nevertheless, this finding is not unexpected as *C. parallelepipedus* is widespread in Europe and suitable habitats are widely present in Bosnia and Herzegovina, particularly on Zvijezda Mt. where there are large complexes of preserved forests.

The Balkan Peninsula emerges as a hotspot of beetle biodiversity (Nieto and Alexander 2010) and this is a contribution to knowledge of an up to now unknown species in Bosnia and Herzegovina. There are many possible reasons why this beetle was not found earlier. The secretive life cycle of the species that is nocturnal

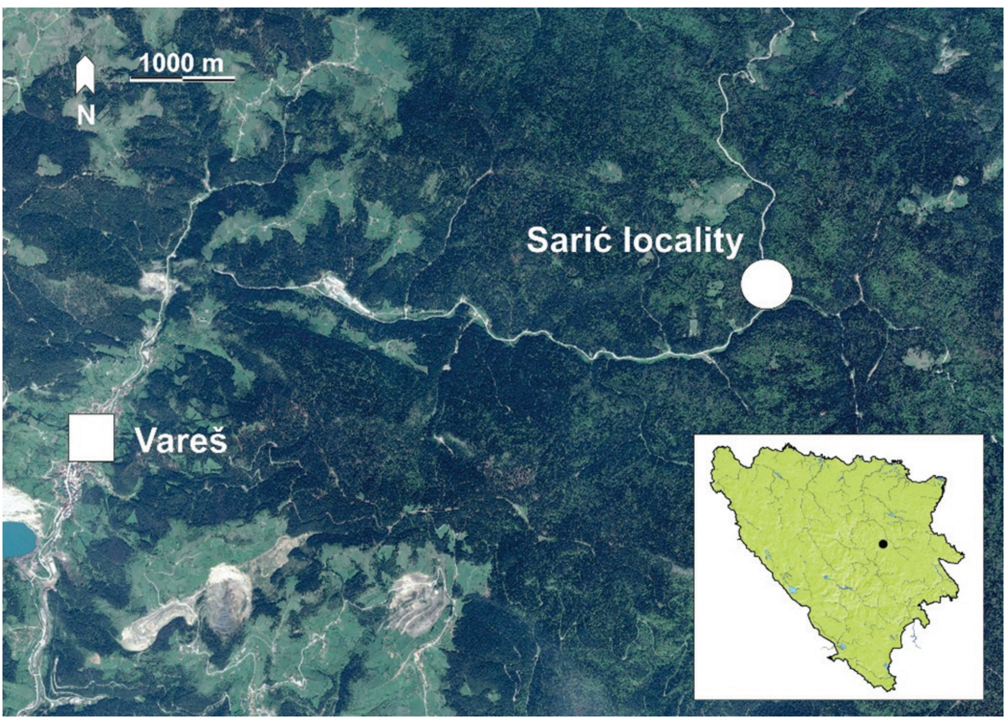

Figure 1. The location of the finding site of *Cossonus parallelepipedus*.

Figure 2. The habitats of mixed woods of spruce, fir and beech on Zvijezda Mt., near Vareš (photo: Adi Vesnić).

Figure 3. Imago of *Cossonus parallelepipedus* (Herbst, 1795) sampled on Mt. Zvijezda near Vareš (photo: Adi Vesnić).

Figure 4. The larva **(a)** and imago **(b)** of *Cossonus parallelepipedus* in a decaying tree stump (photo: Adi Vesnić).

(UK Beetles, 2019) is one possibility or it has not been studied. Saproxylic beetle fauna is insufficiently known in the country and increasingly threatened due to logging and habitat fragmentation and destruction (Kulijer and Miljević 2017), and therefore insufficiently protected. After forest logging, the remaining branches and tree tops on the ground are forming fine wood debris that represents the habitat for many xylobiont beetles, which accelerates the process of organic matter circulation (Gunnarsson et al. 2004, Lindhe and Lindelöw 2004, Jonsell 2008, Zeniauskas and Gedminas 2010). Even under these circumstances logging and wood harvesting in Europe have so far the largest impact on both threatened and non-threatened saproxylic beetles, affecting 35 out of 75 threatened species, and 232 species in total (Nieto and Alexander 2010).

We believe that target research focusing on habitats of this species, particularly in mountain areas in central part of the country will probably result with more records. The occurrence of other two European *Cossonus* (*C. cylindrus* and *C. linearis*) is also possible due to the similar environment conditions and the fact that they are known from neighboring countries (Löbl and Smetana 2013, Osella and Zuppa 2013), and appropriate habitats exist.

Author Contributions

AV, OM, DK, SI conceived and designed the research, AV and OM carried out the field research, AV and OM performed laboratory analysis. DK and SI processed the data and performed the literature review, MD and MP supervised the research and helped to draft the manuscript; all authors wrote the manuscript

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Conflicts of Interest

The authors declare no conflict of interest.

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Insight into Market Supply and Demand of Private Forests in Croatia

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ABSTRACT

Due to their modest 23% share, private forests in Croatia are a resource that is perceived as less important than state-owned forests. One of the basic characteristics of private forests is fragmentation, which is also the biggest obstacle to a successful and, economically speaking, sustainable management of private forests. The cases in which a private forest with its area and integrity can generate a sustainable economic income to its owner are not common. However, from an economic point of view, private forests still have one advantage. Unlike state-owned forests, private forests can be the subject of investment and change hands. Based on this, this paper investigates the supply of private forests on the free market. For private forests that were publicly put for sale in the period from 2010 to 2020, their spatial-temporal distribution and supply dynamics and trends (price and quantity) were analyzed. The data were collected from the leading real estate advertising platform in Croatia (Njuškalo.hr), and a total of 866 advertisements were analyzed, relating exclusively to the sale of raw wood material along with the accompanying forest land. On the other hand, in order to assess the demand, data were collected on the number of potential buyers who viewed the advertisements (period 2020-2021). In the observed ten-year period, a total of 1,890.63 ha of private forests with a total asking value of €32.14 million were offered on the market. The share of advertisements advertised through real estate agencies is 42.1%. The average total annual supply is 170 ha and has a growing trend (in the advertisements in the coastal part of Croatia, the average area is 1.3 ha, while the average area in the continental part is 3 ha). The prices are not constant but rising. According to compound interest, the price increase in the coastal area is 1.57% and 7.49% in the continental area. From the relationship between supply and demand or, more precisely, the relationship between price and the quantity, it was concluded that the market is not well developed and that the price is not affected by the supply/demand quantity of private forests. Furthermore, it was concluded that this market is developing in the direction of a typical real estate market in Croatia due to the fact that forest management and wood processing characteristics of forests do not define the price, but that the price is largely determined by a market with greater financial importance (the market in real estate near the Adriatic coast).

Keywords: asking price; supply; demand; Njuškalo.hr; rural development

INTRODUCTION

The quantity of forests that can potentially be found on the free market is conditioned by two elements. These are the share of private forests and the national forestry strategy of a state. Privately owned forests can themselves be found on the market. At level of the European Union (EU), the share of private forests varies greatly from country to country, ranging from 0.1 to 93% (Živojinović et al. 2015). As the main representatives of a small share of private forests, we can single out Turkey with 0.1% and Macedonia with 10%, a medium share in Estonia, Ireland and Serbia with 47%, Germany and Latvia with 48%, Hungary with 50% and Belgium with 52%. Austria, Sweden, Norway, Spain and Portugal have a large share of privately-owned forests (above 80%). The facts mentioned above point to the connection between the share of private forest ownership of an individual country and the country's economic development. We could say that economically more developed countries have larger shares of private forests and that the forestry's capital mobility is certainly higher than in less-developed countries.

The national forestry strategy can fully determine the perspective of forests in the context of their presence on the free market. Privately owned forests may be bought and sold, but cases in which the state sells its forests are not common. The Republic of Croatia is an example where forest selling is not possible, which is also legally regulated, except in certain cases of disposition (OG, 145/20). However, in other countries, e.g. in New Zealand, Australia and South Africa, there are cases of forest privatization (Cubbage et al. 2020) and cases of successful forest restitution (Nichiforel et al. 2020), which contribute to a larger presence of forests on the free market. Also, the forest restitution is a present and still ongoing process in Croatia (Krajter et al. 2015).

However, in Europe there is a range of different possibilities/obstacles when the private forest is changing the owner as a result of a purchase (Nichiforel et al. 2020). In some cases, the owner can freely decide to whom to sell (without or with some minor obstacles depending on the country's legislation), but in the majority of the countries the authority needs to be informed by the seller. The authority (i.e. Ministry) decides on pre-emption right which goes to the neighbour, municipality or state favour.

Private forests in Croatia are one category of property that can potentially be found on the market. From the point of view that all economically valuable private forests in Croatia can be the subject of purchase, Beljan et al. (2020) explored their investment potential. Furthermore, Beljan et al. (2021) explored their potential as an independent source of timber for the wood-processing industry. In both cases, it had been assumed that all privately-owned forests could be found on the market; however, this is not entirely correct. In other words, only those forests whose owners are interested in selling can be the subject of buying and selling, i.e. in order to adequately investigate their supply, it is necessary to take into account only those cases in which their legitimate owners have expressed their willingness to sell.

Private forests in many cases are obstructed for active forest management and for being sold on the free market. There are two reasons for that: unsolved property rights (Krajter et al. 2015) and their small size. Unsolved property rights are precisely the reason why it is realistic to expect that not all private forests can be the subject of buying and selling, which leads to the assumption that even if the owner is interested in selling, it is not legally possible to do so (the transfer of ownership). Furthermore, it is evident from the literature review that the average sizes of forest parcels are about 0.34 ha, while forest estates on average amount to 1.28 ha (Berta et al. 2017). The small surface area calls into question the economic justification of the purchase because sustainable income and sustainable forest management are not possible in most cases.

Given that information on legal property relations in terms of private plots is not publicly available, the way to evaluate the domestic private forest market is to focus on all private forests that are publicly advertised for sale (Bašić 2021). The private forest market is, figuratively speaking, a 'place' where bidders offer their forests for sale for a certain price and where buyers can buy them. One of the basic insights into market functioning is the relationship between supply and demand, which shows that in the case of higher supply, prices fall and vice versa (Klemperer, 1996). However, there are also cases of the private forest market where this relationship does not necessarily have to be inversely proportional (Bašić, 2021). Knowing the market is important for understanding the relationship between private and state forests, the relationship between supply and demand, and for recording the amount of financial capital present. Furthermore, knowledge about the market, and above all about the supply, is an indicator of past price and quantity trends on the basis of which it is possible to make predictions of market movements.

In this paper we focused on the domestic market in private forests publicly advertised for sale. The primary goal was to gain initial insights into their characteristics, quantity and prices in the last decade through spatial-temporal analysis. The secondary goal was to describe trends in the asking prices that can serve as a basis for further research and for forecasting future market trends.

MATERIALS AND METHODS

Materials

About 49% of Croatia's land area is covered by forests (including bare forest land that has the potential to become a forest in the future), whereas 24% of that area is comprised of privately owned forests (Teslak et al. 2018). Private forests (551,922 ha) are characterized by the average length of forest roads of 13.9 $m \cdot ha^{-1}$ and 36.3 $m \cdot ha^{-1}$ of skid roads and by the growing stock which equals 156 $m^3 \cdot ha^{-1}$. Broadleaved tree species are dominant (common beech 20.9%, sessile oak 13.3%, European hornbeam 10.3%) (Čavlović 2010, Teslak et al. 2018). About one quarter is damaged mostly by negative insect impacts and forests are characterized by poor natural regeneration (Čavlović 2010).

The data sample in this research is predefined by several conditions. The first is the spatial frame which is bounded by Croatia's administrative borders and by the area of private forests respectively. Furthermore, we have focused just on those private forests which are listed on the Croatian free market (which are advertised for sale). According to this, their quantity is taken as market supply.

Characteristics of private forests with regard to the distribution of surface categories and the number of their owners are shown in Table 1. The assumption is that each of the presented forest categories (Table 1) can be subject of buying and selling, or that through advertising for sale they can be found on the free market and thus represent the supply. However, in order to achieve the goal of this research, the material will present only those private forests that have been publicly advertised for sale.

The data source was Njuškalo.hr – the largest advertising platform at the national level, from which data on the location, asking price, forest surface area and advertising method (privately or through real estate agencies) were collected for the period from 2010 to 2020. Only the ads offering a forest with the associated forest land were considered. Furthermore, advertisements that had building land or farmland along with the forest were not taken into account.

Methods

The secondary database (Njuškalo.hr) was the basis for market analysis. We prompted Njuškalo.hr web page

Table 1. The structure of private forests with regard to property size.

Property size (ha)	Surface area (ha)	The number of owners	Share in the total area (%)	Share in the total number of owners (%)
<1	99,948.37	365,301	42.40	87.20
1.01-5	84,525.66	48,553	35,86	11.59
5.01-10	17,320.87	4,300	7.35	1.02
10.01-30	7,654.85	710	3.25	0.17
30.01-100	1,535.26	24	0.65	0.01
>100	23,722.14	27	10.49	0.01
Σ	234,707.15	418,915	100.00	100.00

administrators to list data from their database according to the specific queries which are relevant for this research. Database contains 866 advertisements; however, a part of it refers to the same private forests which have been advertised several times. A representative database, i.e. without repetitive ads, contains 751 advertisements.

In order to analyze the time dynamics through descriptive statistics, the data were categorized by the years when the advertisements were published and according to whether they belong to the continental or coastal part of Croatia. Thus, for the period from 2010 to 2020, the data on the number of advertisements, total area, average area, the largest advertised forest, the smallest advertised forest, average asking prices, minimum price, maximum price and the share of sales through agencies were obtained.

For the purposes of spatial analysis, the advertisements were consolidated by residential areas using QGIS 3.10. The consolidation provided data for a total of 466 residential areas in which all private forests in question are located. Furthermore, the data were spatially displayed and the corresponding variables of private forests were visualized using heat maps (graphic representations of data contained in a matrix presented in shades of red).

In addition to secondary data, primary data were collected in order to assess the market demand for private forests. In the period from April 1, 2020 to March 1, 2021, at the beginning of each month, all active ads were checked and the number of potential buyers' views was recorded.

RESULTS

In the observed period, a total of 1,890.63 ha of private forests (Table 2) with a total asking value of €32.14 million were offered on the market. The share of advertisements advertised for sale through agencies was 42.1%. The minimum price per square meter was 0.09 €·m^{-2} for a plot of 31,000 m^2 in Donji Andrijevci (Brod-Posavina County) in 2019. At a maximum price of 130.07 €·m^{-2}, a plot of 12,058 m^2 in Rovinj (Istria County) was offered in 2020.

Table 2 shows the area categories of private forests that were offered on the market. It is evident that private forests which by their surface area belong to the smallest groups (up to 1 ha or 5 ha) represent the biggest part of the supply on the market. The average asking price is generally lower for those forests that are larger by the surface area. It could be said that the price per square meter, or the total asking price, decreases with the increasing size of the private forest. On average, at the level of the whole of Croatia, the average asking price was 3.90 €·m^{-2}.

The number of private forests in supply, i.e. the number of forest properties, varied from 34 (2010) to 136 (2020) (Figure 1a). During 2012, a significant increase in supply was recorded. It is important to note that this coincided with the time of the greatest interest of the wood industry, which in the absence of raw materials from state-owned forests turned to the private ones. Thus, the private forest market reacted and the supply and increased accordingly. In 2013, after a sharp decline in the demand of the wood industry for raw wood materials from

Table 2. Categories of private forest size offered on the market with the corresponding price (period 2010-2020).

Property size (ha)	Supply surface area (ha)	Share of the forests put up for sale (%)	Average asking price (€·ha^{-1})
<1	214.28	11.33	4.97
1.01-5	603.53	31.92	2.66
5.01-10	165.78	8.87	1.61
10.01-30	236.60	12.51	1.16
30.01-100	145.41	7.69	1.29
>100	525.00	27.77	0.57
Σ	1,890.63	100.00	3.90

private forests, there was a significant decrease in supply, which was increasing slowly since then until the end of the observed period. The number of advertisements in supply in the continental area after 2012 varied around 40, while the supply in the coastal area was significantly lower until 2019, when it increased significantly, and in 2020 the supply in the coastal area was higher than in the continental area.

Also, the supply surface area varied both in the coastal and in the continental areas (Figure 1b). One of the main causes of this unevenness of supply, especially in the continental part of Croatia, is restitution dynamics defined by Croatian law (OG, 92/96). Due to the fact that restitution dynamics and the size of the supply on the market coincide, it is considered that a significant part of the original owners decided to sell, which had an impact on the market (these are forest areas that are often larger than 100 ha).

The average total annual supply was 170 ha, while the average unit area in the advertisements in the coastal part was 1.3 ha, and 3 ha in the continental part. It is obvious that throughout the observed period the surface area share of forests was significantly smaller in the coastal area (Figure 1b). When comparing the supply surface area with the number of advertisements (Figure 1a), the continental and coastal areas were even more divergent.

The asking price time dynamics (Figure 2) shows significant differences between the prices in continental and coastal Croatia. The price in continental Croatia was almost constant, while in coastal Croatia there was a growing trend in average price. As shown by compound interest, the price increase in the coastal area was 1.57%, and in the continental part 7.49%. If at the level of an individual year (2010-2020) the asking price (Figure 2) is compared with the number of advertisements (Figure 1a) and the total and average surface area in the advertisements (Figure 1b), we can see the non-existence of the interaction between basic market principles. Although the supply of forests in the continental part of Croatia varied (total and average surface area and the number of advertisements (Figure 1)), the price remained almost the same (Figure 2). Also, the same applied to the comparison in the coastal part of Croatia.

The spatial analysis (Figure 3) shows the areas where the supply of private forests was most significant. If we take into account all the elements (Figure 3 a-d), it is clear that the area of Istria and Kvarner is somewhat peculiar. Although the central Croatian area, especially northwest of the city of Zagreb (Hrvatsko Zagorje region), is the zone of the largest supply in terms of surface area (Figure 3a), while Istria and Kvarner are in the lead in all the other elements. Namely, in

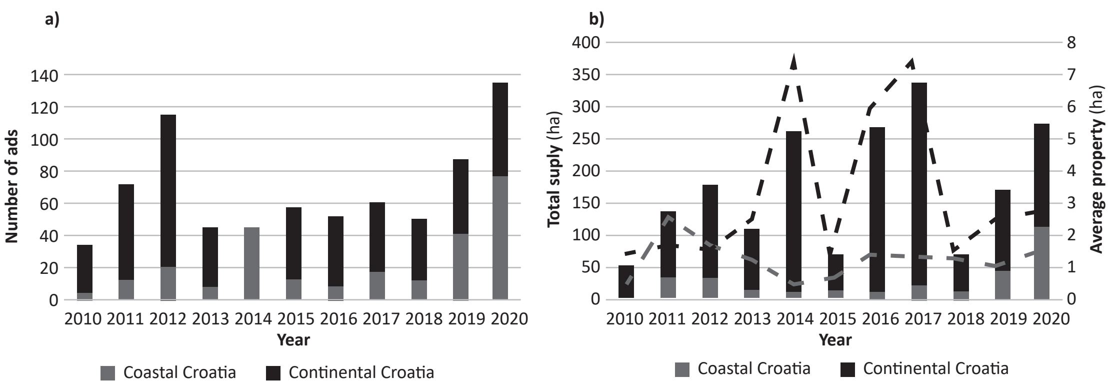

Figure 1. Time dynamics of the basic supply's characteristics. **(a)** The quantity of private forests advertised for sale and **(b)** belonging summarized and average surface.

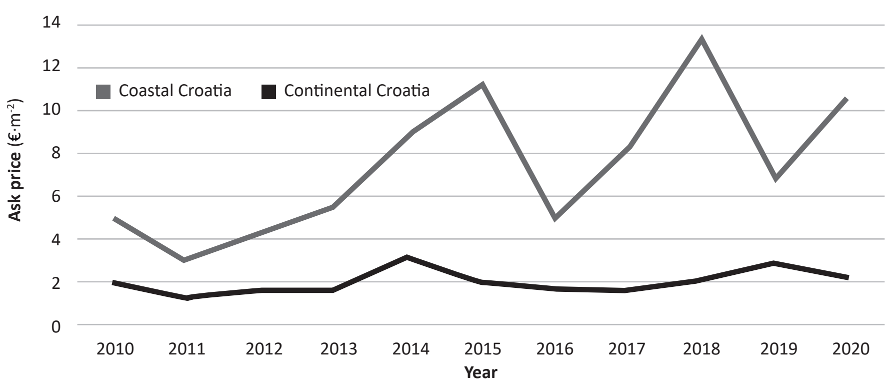

Figure 2. Time dynamics of the asking price.

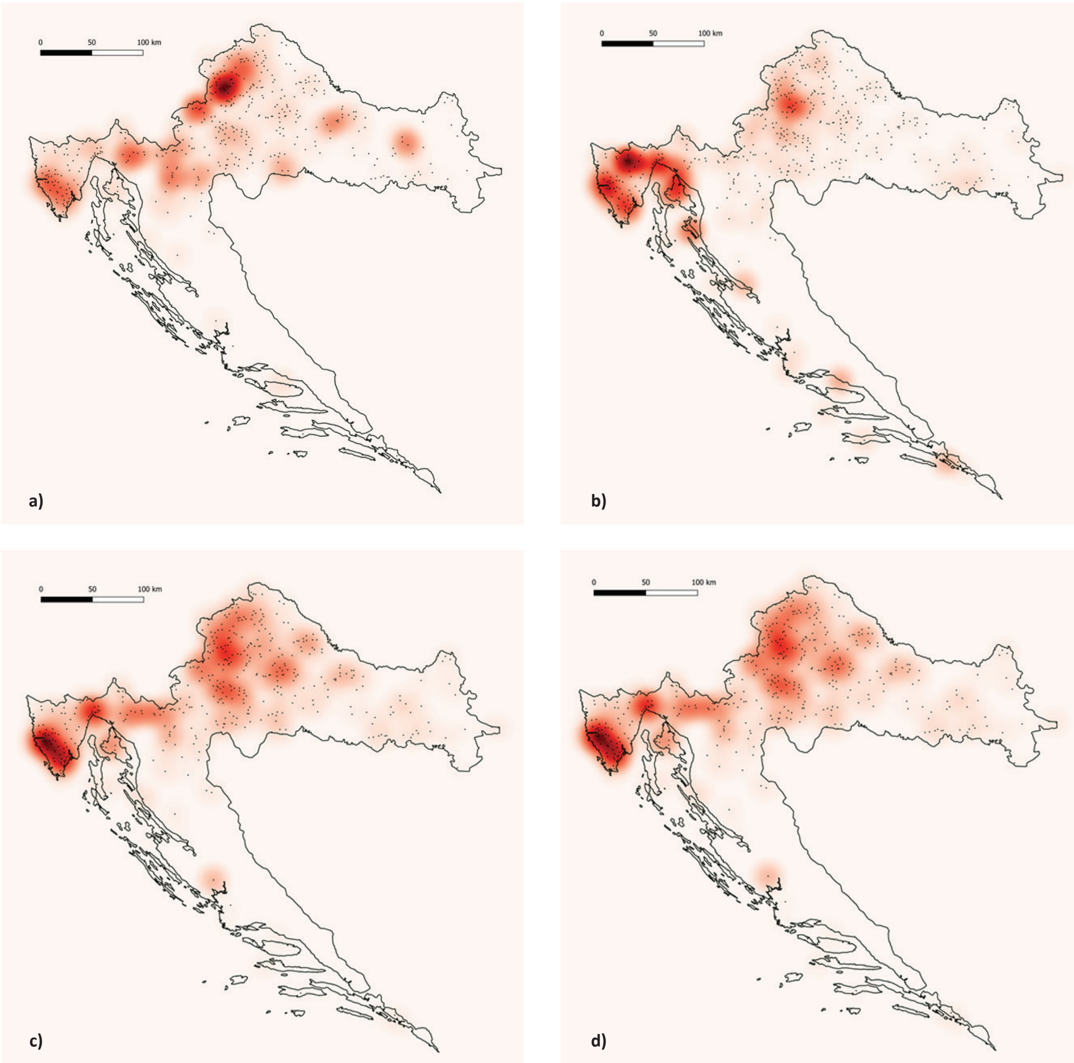

Figure 3. The spatial distribution of private forest supply (2010-2020). **(a)** total surface area, **(b)** average price**, (c)** the number of advertisements, **(d)** the share of sales through real estate agencies.

the last decade, the highest average asking prices and the total number of advertisements were emphasized precisely in that area. In order to determine forest owner sellers' general approach toward the method of finding a buyer, the share of advertising through real estate agencies was analyzed (Figure 3d). This segment is also spatially related to Istria and Kvarner where private advertising, not through real estate agencies, is very rare (just 9% of cases).

DISCUSSION

Previous research on private forests in Croatia provides an overview of the characteristics of the forests themselves and their owners, and their results, e.g. the size of private forests, vary significantly. It is evident from the literature review that the average sizes of forest parcels were about 0.34 ha, while forest estates on average amounted to 1.28 ha (Berta et al. 2017). Our research showed that the average forest property surface area in the advertisements was 2.5 ha, while the median was 0.9 ha.

In this paper, in addition to an overview of the characteristics of private forests, unlike other works so far, an analysis of their market is presented. The data were collected from Njuškalo.hr, which is the leading advertising platform in Croatia but covers only a part of the forests put for sale. Although this online advertising platform is very popular and frequently used in Croatia, it should be considered that some of the estates offered for sale are advertised exclusively via other platforms or by personal advertising. Regarding that, the presented results should be taken with a certain level of uncertainty.

Also, the data we presented refer only to the asking price, but it is not known whether the prices were reduced during the sale itself. One of the possible sources of data for obtaining information on the realized purchase price are the Annual bulletins of the Institute of Economics Zagreb (Vizek et al. 2021), which, among other things, provide the overview of the forest land market. However, it is not certain whether the mentioned data would correspond to the real situation on the market (the situation on the forest site). The fact is that so far it has not been defined what determines the purchase price of private forests and how to collect relevant data on the price agreed upon between the seller and the buyer. However, if we assume that the purchased price is lower than the advertised one, this would be correct, but the difference between those two remains unknown.

On the other side of supply stands demand, which describes the number of products that customers are willing to buy at a certain price. Although a significant number of purchase agreements were not available, estimates were used to describe the demand. Figure 4a and Figure 4b show the relationship between the asking price and the number of views by potential buyers (Njuškalo.hr, April 2020-March 2021). Although shown separately, advertisements in the coastal area and in the continental area very clearly indicate potential buyers' greater interest for on average lower-priced private forests (Figure 4a). However, when looking at demand with respect to the total asking price (Figure 4b), it is not possible to define the link between price and demand. Although this is not usual in terms of supply and demand, we can say that the private forest market is characterized by atypical market laws.

CONCLUSIONS

The supply of private forests on the free market in the last ten years has been marked by changes in all researched variables. Prices have risen (both in the coastal and the continental area, but in the coastal area the rise was multiple), the total and average surface area varied from year to year, and sellers are increasingly abandoning the classic market approach and they are turning to real estate agencies.

From the relationship between supply and demand, more precisely, the relationship between the asking price and the quantity on offer, the absence of basic market laws was observed. The conclusion is that the market is not well developed and that the price is not affected by the ratio of supply or demand, but by some of the hitherto unexplored characteristics of these forests.

The spatial analysis showed which areas are dominant when it comes to the free market of private forests. Although Istria and Kvarner are marked as hotspots according to several researched elements, we can conclude that the market is developing more in the direction of a typical real estate market. From the forest management and wood-processing aspect, the forests which are traded the most do not represent a significant value in traditional forestry concepts – higher timber stock, higher price. It can be concluded that the monetary value and supply of private forests are most likely determined by the high demand for land near the coast. It is necessary to emphasize that similar supply and demand relations are present along the entire coast, but the lands that are listed as forest land (in cadaster) and advertised for sale, are located in Istria and Kvarner.

Author Contributions

KB, AB, conceived and designed the research, AB carried out the data collection, AB processed the data and performed the analysis, JD and MB supervised the research and helped to draft the manuscript, KB and JD wrote the manuscript. All authors have read and agreed to this version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

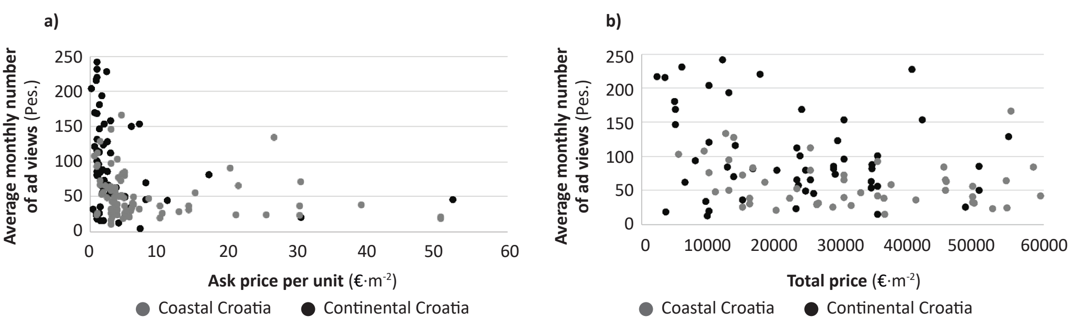

Figure 4. Estimation of market demand for private forests. Comparison between unit **(a)** and the total asking price **(b)** to the average number of monthly views made by the potential buyers

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