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ORIGINAL SCIENTIFIC PAPER

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Accelerated Height Growth Versus Mortality of *Quercus petraea* (Matt.) Liebl. in Hungary

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ABSTRACT

Background and Purpose: Due to climate change, it is important to know to what extent forests will be impacted by atmospheric changes. This study focuses on the height growth response of sessile oak (*Quercus petraea* (Matt.) Liebl.) to counteracting effects of fostering and interfering changes under contrasting climatic conditions with special attention to the xeric limit zone of this species.

Materials and Methods: Twenty-eight sites were selected along a climatic gradient from the humid region in southwest Hungary to the continental-semiarid region in northeast Hungary where neighbouring old and young sessile oak stands were available for pair-wise comparison of height growth. While these young stands developed entirely in the significantly changed atmospheric conditions, the older trees lived only a part of their life time in such changed environment. The Ellenberg quotient (EQ) was used for describing climate aridity. Stand top height in each pair of old and young stands was measured to calculate the relative stand top height using yield tables of sessile oak for Hungary. Additionally, stand densities of old stands were measured. To demonstrate the height growth differences of old and young stands their relative stand top heights were compared as functions of EQ and stand density.

Results: The relative top heights of the young stands were significantly higher than of the older stands, which means that the overall growing conditions were better in the last 30-35 years due to atmospheric changes than the mean conditions during the lifetime of old stands. Although extreme drought events associated with climate change caused reduced stand density due to periodic tree mortality at the xeric limit of sessile oak, the synergetic effect of all atmospheric changes was still sufficient enough to accelerate height growth.

Conclusions: There has been an acceleration of height growth during the last decades despite the increased frequency of droughts. It cannot be concluded that height growth acceleration will continue in the future since climate models show an increasing tendency of dry extremes in Hungary that may overrule the positive fostering effect of atmospheric changes.

Keywords: *Quercus petraea* (Matt.) Liebl., height growth, climate change, xeric limit, stand density, stand top height

INTRODUCTION

Multi-year drought periods since the beginning of the 1980s led to prolonged water deficits during the growing seasons in the Carpathian Basin [1, 2].

Droughts negatively influence the radial growth of trees [3, 4], reduce the vitality of trees [5], increase pest and disease invasions [6], and may lead to mortality [7], resulting in reduced stand density primarily at their xeric distributional limit [8].

Nevertheless, some studies suggest that forests may benefit from higher temperatures due to various compensating effects, such as fertilization through rising atmospheric CO_2 concentration and nitrogen deposition, or improving water use efficiency [9-11]. Data of the ICP Forests plot showed a positive relationship between higher temperature, CO_2 and N deposition, and the increase of volume increment [12]. The results of the project called RECOGNITION (Relationships Between Recent Changes of Growth and Nutrition of Norway

Spruce, Scots Pine and European Beech Forests in Europe) showed that there were significant increases in height growth rates in many parts of Northern Europe. Increasing growth rates were also reported in many forests in Hungary [13] and even beyond its natural range, which is probably related to the changing environments [14, 15].

Sessile oak (*Quercus petraea* (Matt.) Liebl.) forests are among the most important forest communities in the Carpathian Basin and one of the economically most important tree species in Hungary. The distributional area of the species extends from the most humid to arid areas in Hungary. Since the early 1980s, severe drought periods have triggered several mortality events of sessile oak [16, 17], especially in the northeastern part of the country. Therefore, it is a well-suited tree species for the analysis of the climatic background of decline and growth acceleration [18].

The largest 20% of trees, or a fixed number of 100 or 200 of the largest trees from the collective are called stand top height [11]. Among numerous dendrometrical parameters, stand top height is considered to be the most indicative factor for the stand's productivity [11, 19] which is less dependent on stand density and thinning [11]. Moreover, height growth is suitable for examining the effect of climate change [20].

The rate of tree height growth can be most precisely determined by measuring the trees of experimental stands in the frame of a long-term forest yield monitoring. In doing so, the growth rate of the same trees in time can be compared with the growth rate of the specified age found in the yield tables of sessile oak [21].

Any plots of the long-term forest yield monitoring near the xeric limit of sessile oak were affected by tree mortality during the last decades. Therefore, the growth of the same tree stock could not be analysed, but instead the current height of neighbouring old and young stands was compared. This way, we did not try to determine the exact quantity, but the direction of the change in height growth.

The comparison of the height growth performance of neighbouring old and young stands grown on the same site conditions enables the understanding of how the changing climate, the fertilization effect of the CO_2-enriched atmosphere and nitrogen deposition influenced the height growth of trees. Since climate change became more rapid in the 1980s, the growth of young (30-35 years old) stands reflects the effect of atmospheric changes to a great extent. While these young stands developed entirely in the changed atmospheric conditions, the older trees lived only a part of their lifetime (with slower growth potential) in this changed environment. Consequently, the growth of the neighbouring old stands could serve as a comparison of the growth of young stands.

In this approach 28 stands along a climatic gradient were examined using a pair-wise comparison of the height growth of neighbouring old and young stands.

Our research questions were the following:

1) Has the height growth of sessile oak been accelerated or slowed down due to the counteracting effects of fostering and interfering atmospheric changes?
2) Is there a difference in height growth between the humid and more arid areas during the last three decades?
3) Is the height growth suppressed at the xeric limit of sessile oak, where frequent drought periods triggered mortality in the last decades?

MATERIALS AND METHODS

Study Area

The investigated 28 sessile oak sites are situated along the climatic gradient from the humid region in southwest Hungary to the continental-semiarid region in northeast Hungary (Figure 1).

The sites where neighbouring old (>50 old years) and young (<50 old years) stands were available for the pair-wise comparison of growth were selected. The mean age difference of the old and young stands was 61 years. The site

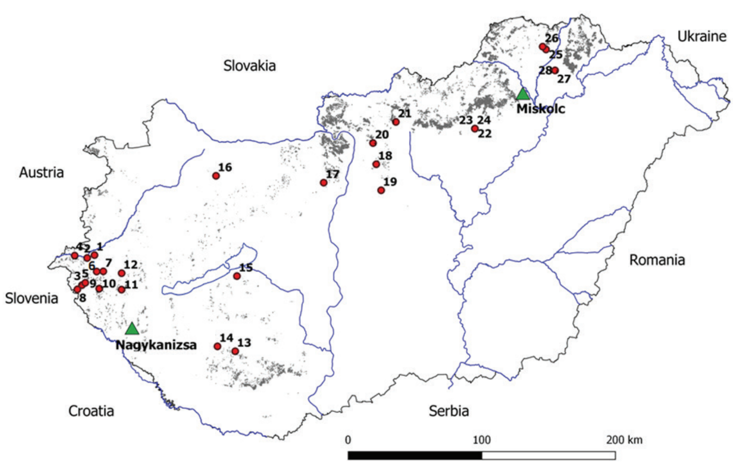

FIGURE 1. Selected sessile oak stands (circles), meteorological stations (triangles) and the distribution of sessile oak (grey) in Hungary.

conditions of the neighbouring stands could be considered similar. All selected stands are in zonal position with low topographic variability, and are situated on deep loamy soils (Table 1).

In Hungary there has been a gradual change from oceanic to continental influence on the climate which is modified by a mediterreanen effect towards the southwest part of the country. This is reflected, for example, in the difference of summer precipitation sums by comparing the meteorological data of two official stations located in the Southwest (Nagykanizsa) and Northeast (Miskolc) of Hungary (Figure 1). A clear warming trend (0.46-0.52°C/decade) during the last three decades can be observed for summer temperatures, whereas contrasting trends (-4.3 mm/decade for Nagykanizsa and +18.8 mm/decade for Miskolc) are visible in the amount of summer precipitation (Figure 2).

Meteorological Data

To analyse the response of growth to climate change, the annual gridded data of the Ellenberg quotient (EQ) were obtained from the CARPATCLIM Database [22] for the period 1961-2010. The EQ has a good potential for describing the aridity limitation of forest stands in Hungary [23] and was thus used to describe the climate of the selected sites with a spatial resolution of 10 km (Equation 1, [24]).

$$EQ = \frac{T_{july}}{P_{anual}} \qquad (1)$$

where T_{july} is mean temperature of July, and P_{annual} is annual precipitation sum.

TABLE 1. Site and stand characteristics.

Stand No.	Ellenberg quotient (EQ)	Soil type	Old stand				Young stand		
			Age (years)	**Top height** (m)	**Relative top height** (%)	**Relative stand density** (%)	**Age** (years)	**Top height** (m)	**Relative top height** (%)
1	28	Gleyic Luvisol	109	31.5	118	94	26	13.5	126
2	27.8	Gleyic Luvisol	62	23.1	109	90	25	13.6	132
3	26.9	Gleyic Luvisol	94	29.1	114	95	27	14.7	132
4	27.6	Gleyic Luvisol	122	30.6	114	92	32	16	122
5	27.2	Gleyic Luvisol	104	32.4	123	85	31	14.9	117
6	26.1	Gleyic Luvisol	94	31.8	125	92	28	15.5	135
7	26.1	Cutanic Luvisol	93	31.3	123	84	35	19.3	137
8	28	Cutanic Luvisol	99	31.7	122	94	26	15.8	148
9	27	Cutanic Luvisol	126	35.4	129	98	31	17.5	138
10	26.8	Cutanic Luvisol	125	34.7	127	101	26	15.7	147
11	26.4	Cutanic Luvisol	114	35.5	132	105	30	18.5	150
12	29.6	Cutanic Luvisol	115	34.6	128	81	32	15.5	119
13	28.6	Cutanic Luvisol	101	31.9	122	89	25	16.7	162
14	29	Cutanic Luvisol	51	25	133	90	26	17	159
15	31.9	Cambisol (Humic)	79	24.3	102	69	45	18.3	106
16	30.3	Cambisol (Humic)	96	26.3	102	98	25	12.8	124
17	35.8	Cambisol (Humic)	98	22.4	87	73	46	17.4	99
18	34.9	Cambisol (Humic)	116	26.2	97	68	25	12.6	122
19	35.6	Cambisol (Humic)	64	21	98	79	30	14.3	116
20	35.1	Cambisol (Humic)	79	20.5	86	62	31	12	92
21	32.5	Cambisol (Humic)	70	22.7	101	77	25	12.7	123
22	36.2	Luvic Chernozem	60	18.7	90	65	34	13.1	95
23	36.6	Luvic Chernozem	98	16.6	64	62	33	12.9	96
24	31.8	Luvic Chernozem	105	22.6	86	80	31	12.5	98
25	34.1	Luvic Chernozem	64	23	107	83	29	15.8	133
26	34.3	Luvic Chernozem	67	20.5	93	89	29	15.5	130
27	38	Luvic Chernozem	77	18.4	78	71	26	12.4	112
28	37	Luvic Chernozem	71	19.9	88	75	41	16.3	102

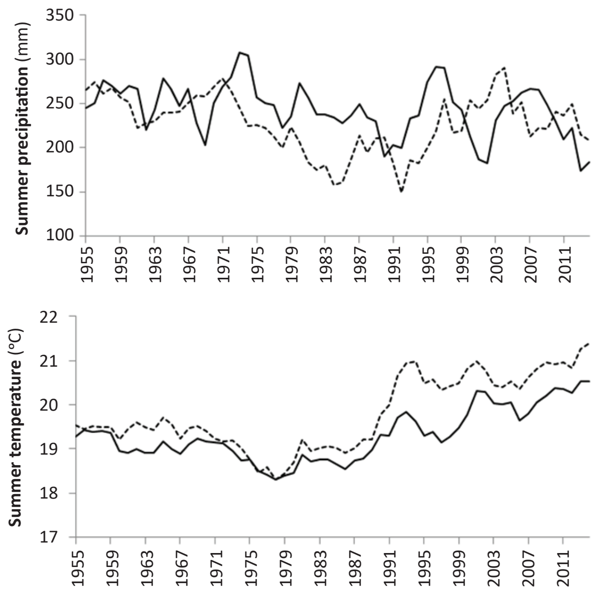

FIGURE 2. Trends in summer (J-J-A) precipitation and temperature for Nagykanizsa (solid line) and Miskolc (dotted line) meteorological stations for 1955-2016; curves are smoothed by 5-years moving average.

Topographical differences may cause differences in micro-climate conditions between the gridded data and the study sites. For that reason, special care was paid to select flat, zonal sites that might help to reduce the bias.

Stand Height Analysis

In each pair of old and young stands stand top height was measured to calculate the relative stand top height using the yield tables of sessile oak in Hungary [21].

The height of the visually highest 25 trees of each stand was measured using a TruPulse 200 laser instrument (Laser Technology, Inc., Colorado 80112 USA), after which the stand top height was considered as the mean value of the highest eight trees. Relative stand top height was calculated as the ratio of the current stand top height and the age-dependent height value of the average yield class (III). This refers to the overall height growth performance of the stands up to the given age [25]. To illustrate the height growth differences of the old and young stands their relative stand top heights were compared as functions of the EQ. To test if the stand top height values differ a one-way t-test was used. Additionally, the ratio of relative top heights was presented to show the differences of height growths of the young and old stands.

Relative Stand Density

Current stand density (trees·ha^{-1}) was estimated for old stands, after which relative stand density (Equation 2, [8]) was calculated to evaluate forest decline as a function of the EQ:

$$D_{rel\%}=\left(\frac{D_{cu}}{D_{fu}}\right) \qquad (2)$$

where: $D_{rel\%}$ is relative stand density, D_{cu} is current stand density, and D_{fu} is fully stocked density (depending on the average stand diameter).

RESULTS AND DISCUSSIONS

Using the average yield class (III) of sessile oak as a referen-ce allowed the analysis of the effect of climate change on the relative stand top heights which are decreasing with increasing aridity, i.e. higher Ellenberg quotient (Figure 3).

While the highest stand top heights are charateristic on areas where the climate is humid and the soil conditions are the most favourable (EQ<30), the lowest top heights can be found in the driest sites (EQ>35) where moisture availability limits growth. Interestingly, the top heights are lower in more humid areas (EQ<29) due to less favourable soil conditions (Gleyic Luvisol) (Table 1).

The pair-wise comparison of the results showed that the relative top heights of the young stands were significantly higher than of the older stands ($t=7.04$, $p<0.01$), which means that the overall growing conditions were better in the last 30-35 years than the mean conditions during the lifetime of the old stands (Figure 3). The ratio of relative stand heights of the young and old stands were above unity in 26 stands with a mean value of 1.15 (Figure 4).

Surprisingly, the height growth of sessile oak has accelera-ted even towards the dry sites. Furthermore, the young stands have an increasing growing tendency (around +15% compared to the old stands). Since the growth of the old stands used as a reference has probably increased in the last decades, the real increase in the height of the young stand is higher than 15% as well.

According to our results, the height growth was accelera-ted even in dry regions although there was significant mortality (mainly middle-aged and old stands) in these regions due to extreme droughts during the last decades [8]. In a recent study (for further details see [18]) we have already determined the relative stand density for 17 old

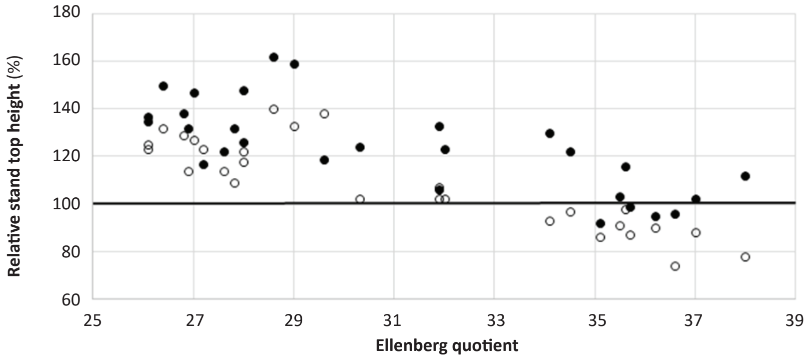

FIGURE 3. Relative stand top height of old (white circles) and young (black circles) stands as a function of Ellenberg quotient.

stands of this present study. We completed the available data with the measurement of the relative stand density in the missing 11 sites applying the same methodology. The comparison of the relative density and relative top height of the stands revealed that a significant difference of the relative stand density of sessile oak has emerged between humid and dry sites (Figure 5).

As a result of forest decline in dry sites, the relative density reduced to 60-70%, while it remained at about 90% in humid regions. The parallel processes of declining relative stand density and accelareted height growth in dry sites are seemingly contradictory but not implausible progressions in forest ecosystems.

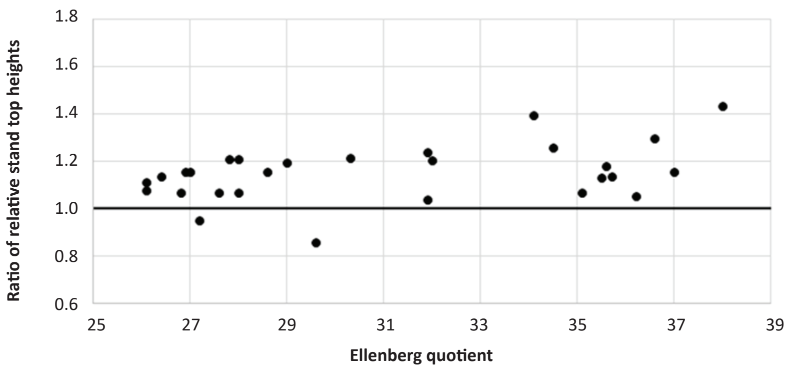

FIGURE 4. The ratio of relative top heights of young and old stands as a function of Ellenberg quotient.

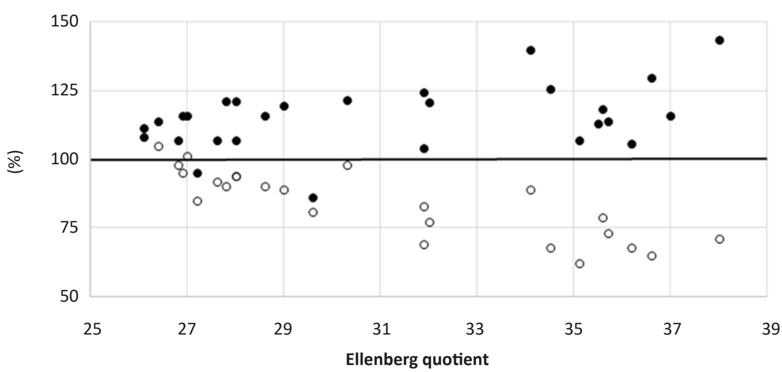

FIGURE 5. The ratio (in %) of relative top heights of young and old stands (black circles) and relative stand density of old stands (white circles) as a function of Ellenberg quotient.

CONCLUSIONS

Although extreme drought events associated with climate change caused periodic mortality at the xeric distributional limit of sessile oak, the effects of all atmospheric changes generated accelerate height growth.

Furthermore, our results do not support the fact that the excess nitrogen deposition fosters growth of trees primarily and only on low nitrogenous soil with sufficient water supply [11], since the height growth of trees on nitrogenous soil in humid climate is not greater than that of on humus-rich soils in drier climate.

Although there was an acceleration of growth in the last decades despite the increased frequency of droughts, this does not mean that growth acceleration will continue to be characteristic in the future since climate models show an increasing tendency of dry extremes in Hungary [26] which may overrule the positive effect of atmospheric changes.

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Which Douglas-Fir (*Pseudotsuga menziesii* (Mirb.) Franco) Provenances Provide the Best Productivity in the Hilly Area of Croatia?

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ABSTRACT

Background and Purpose: Recently raised questions on adaptability of native tree species to climate changes pointed to Douglas-fir as a species suitable for rapid reforestation and increase of stand resistance. The first results on provenance research need to be confirmed in later stages of stand development, so the paper answers the following two questions: (i) are there differences in growth of 14 Douglas-fir provenances still in the fifth decade of stand development, and (ii) which provenances should be used and which omitted from further use in the hilly area of Croatia?

Materials and Methods: Productivity of 14 provenances was evaluated on the basis of height, diameter at breast height and volume in the 46th year after planting. Growth dynamics was also statistically analysed using a repeated measure analysis of variance, for which purpose we partially used published data from the 2010.

Results: The analysis excluded Castle Rock and Shady Cove (Oregon) provenances due to their low values of all analysed growth indicators, as well as Castle Rock, Elma and Hvidilde provenances due to their high values. Average values of tree volume ranged from 0.53 m^3 (Shady Cove) to 2.05 m^3 (Castle Rock), while the tallest trees belonged to Elma provenance (29.6 m).

Conclusions: Different growth dynamics of provenances were confirmed for later development stage, so further monitoring is still required. Clear guidelines for the selection of provenances for practical forestry distinguish provenances from lower altitudes of the State of Washington, Denmark and Bulgaria as the most productive. Shady Cove and Salmon Arm provenances are not advised to be used in the future.

Keywords: Reforestation, diameter at breast height, tree height, tree volume

INTRODUCTION

The management of Croatian forests, as determined by the Forest Law and following a long-lasting forestry tradition, should rest on the principles of sustainable forest management and natural species composition. Climatic disturbances and pest damages raised three questions recently: (i) can native species adapt quickly enough, (ii) to what extent they can adapt to changed conditions, and (iii) what species and provenances can be used for the increase of forest resistance and resilience? Problems in management of autochthonous tree species refer to diverse site conditions and tree species present in all areas of the country. A good example is the decline of artificial Norway spruce forests, as well as close to nature European beech-Silver fir mixed forests in mountain areas. In this case, several strong negative and destructive events took place just in a few years, often affecting already reforested areas. The first significant damages ware caused by strong ice load in 2013, followed by strong bark beetle attacks and consecutive storms. This raised both the need for reforestation efforts in practical forestry and the need for new silvicultural solutions, especially in terms of quick and efficient reforestation techniques and tree species/provenance selection. In addition, studies from the region support the statements that native tree species can decrease their growth as a response to climate changes. For example, in a dendrochronological study Norway spruce decreased its radial growth in relation to the increase of mean annual temperature and mean temperature during growing season, which was significant in the period from 1980 to 2015 [1].

These newly developed problems in management of native tree species underline the use of non-native tree species for reforestation purposes. In that respect Douglas-fir (*Pseudotsuga menziessi* (Mirb.)) has distinguished itself among other non-native tree species. After its introduction from North America more than 150 years ago it has become one of the most economically important exotic tree species of European forests. It has been successfully introduced in almost all areas of the temperate zone (Europe, southern part of South America and Australia) [2]. Its durable, disease-resistant wood, rapid growth, adaptability to a spectrum of site conditions make it well suited for rapid reforestation and flexible forest management options [3-5]. Favourable Douglas-fir features justify the increase of Douglas-fir cultures in the future [6-9]. Countries with the highest coverage of Douglas-fir in Europe are France, Germany, Great Britain and the Netherlands [2], while in Croatia there are only a few localities of Douglas-fir stands. Compared to many tree species, Douglas-fir populations are generally regarded as being closely adapted to their environments with relatively steep clines associated with steep environmental gradients [10]. This is due to its extremely large natural distribution in both horizontal and vertical sense (from California up to British Columbia and from the Pacific coast up to 1500 m a.s.l.) [11]. Differentiation and development of a large number of provenances should be taken into account if the introduction and use of this tree species in areas outside of its natural distribution is aimed.

Even though this species is well-investigated in the countries of its natural distribution [12-18], this kind of knowledge cannot be applied in Europe since it is a poor representation of Douglas-fir growth and development in significantly different growth conditions. To date, European research point to good growth and development of some provenances, while others show mediocre or extremely poor success, highlighting the appropriateness of provenances to specific site conditions [2, 19]. Similar conclusions were obtained through analysis of the first results of Douglas-fir research in Croatia, which was conducted in the frame of the international IUFRO programme for Douglas-fir provenance testing [20]. Early 20th century was the beginning of Douglas-fir introduction in Croatia in forest stands, but more intensive establishment of forest cultures started in the 1970s when experimental plots were established by Forest Research Institute, Jastrebarsko. The goal was to find an appropriate silvicultural solution in terms of suitable species and provenances for afforestation practices. From the results obtained so far Douglas-fir has proved to be one of the most successful coniferous non-native tree species in Croatia and as such should have a more significant role in afforestation and reforestation activities [21-25]. Nevertheless, the same research results also strongly underline the need for further continuous monitoring of the established trials of Douglas-fir provenances to support the first obtained results. The paper answers two basic research questions: (i) are there differences in growth of 14 Douglas-fir provenances still in the fifth decade of stand development, and (ii) which provenances should be used and which omitted from further use in the hilly area of Croatia? The added value of this study is to provide background for active use of Douglas-fir in practical forestry and to implement the obtained results into silvicultural recommendations. This is important from the aspect of climate changes and fast increase of reforestation needs in the future [26]. The paper provides data on productivity of 14 Douglas-fir provenances 46 years (2015) after planting, compared with their productivity in the 41st year (2010) with guidelines for the selection of appropriate provenances.

MATERIALS AND METHODS

Research Area

The experimental plot called Slatki potok is located in the hilly area of the Bjelovar Basin on 140–145 m a. s. l. (45°46′ N, 17°03′ E). The climate of the area is humid (Cfmbx′′ according to Köpen). Thornthwait's index of rainfall effectivity (P/E) amounts to 72. Mean annual air temperature is 10.3°C, while in the warmest part of the year (June–September) it amounts to 16.6°C. Mean annual precipitation is 813 mm, 462 mm in the warmest part of the year (June–September). From the aspect of potential vegetation this is the area naturally dominated by mixed pedunculate oak and European hornbeam forests (*Carpino betuli-Quercetum roboris typicum* Rauš 71). According to Mayer, soil is defined as loess (on the plateau) up to mildly pseudogley (on the slopes) [27]. Mechanical soil properties point to the loam texture in the whole soil depth, while chemical analysis revealed that the soil is very acid. Prior to trial establishment the area was used for agricultural purposes several years in a row (corn production).

Experimental Design

The experiment on Douglas-fir (*Pseudotsuga menziessi* (Mirb.)) provenances was established in the spring of 1969 using a completely randomised block design with four replications. In this field test, eleven American (six from Washington, two from Oregon, three from British Columbia) and three European provenances (from Denmark, Bulgaria, and Croatia) were investigated. More detailed description of the experimental plots and site conditions are provided by Perić *et al*. [28] and Orlić and Perić [29]. For basic information on provenance origin see Table 1 [30].

The overall size of this trial is 3.6 ha and it includes 14 different Douglas-fir provenances, which were established with the aim of determination of best provenance selection for afforestation practices in the hilly area of the country. The experimental plot was established by planting three-year-old Douglas-fir seedlings grown in Jiffy-pots (2+1). In each repetition, 25 seedlings (5×5) were planted, i.e. a total of 100 seedlings per provenance. Planting spacing was 4×4 m, with Norway spruce and European larch planted between rows. These were cut during the first thinning to provide an optimal growth condition of targeted Douglas-fir trees. Diameter at breast height (DBH) and tree height (h) were measured in 2015. All trees on the experimental plots were measured and included in the analysis.

TABLE 1. Origin and codes of Douglas fir provenances tested on Slatki potok locality with some basic information on the origin of provenances.

Code	Provenance	Altitude (m a.s.l.)	Geographic coordinates	
			Width	Length
A	SHELTON, Washington	30 - 150	47°11' N	123°10' W
B	CORVALIS, Oregon	75	44°35' N	123°16' W
C	SHADY COVE, Oregon	1350	42°36' N	122°50' W
D	TENINO, Washington	100 - 200	46°45' N	122°40' W
E	ELMA, Washington	100 - 200	47°00' N	123°30' W
F	ELK RIVER FALLS, British Columbia	-	-	-
I	MERVILLE BLACK, British Columbia	15	-	-
J	HVIDILDE, Denmark	-	-	-
L	SALMON ARM, British Columbia	450 - 600	50°50' N	119°10' W
M	PE ALL, Washington	150 - 300	46°45' N	123°15' W
N	YELM, Washington	0 - 150	46°45' N	122°40' W
R	ŠIPKA, Bulgaria	650 - 780	42°43' N	25°20' W
S	ROVINJ, Croatia	-	-	-
T	CASTLE ROCK, Washington	-	-	-

Field Measurements and Statistical Analysis

For this research we have measured manually DBH and h in the year 2015 (46 years after planting). On the basis of DBH and h, we have calculated wood volume (V) for 2015 for each provenance. Hamilton tables were used while calculating wood volume, so it could be compared to earlier research studies. We have also calculated descriptive statistics for all parameters by provenances for the 46th year after planting (2015). For the purpose of examining growth dynamics of provenances in relation to the five year interval we have partially used published data from 2010 (the 41st year after planting, 30). With a repeated measures analysis of variance (ANOVA) we have tested differences between provenances for all measured variables, which we could apply since the condition of variance homogeneity was proved. In the event where there was a significant statistical difference between provenances, we have determined which provenances differed between others by using the Tukey Post hoc test. Type I error (α) of 5% was considered statistically significant. We have made all analyses and graphs by using the statistical programme STATISTICA [31].

RESULTS

Variations in Diameter at Breast Height among Provenances

The average value of DBH on this experimental plot was 33.61 cm. The lowest DBH values at Slatki potok experimental plot belonged to the provenances from British Columbia, Oregon and Rovinj (Table 2). A 95% confidence interval for DBH for this site is shown in Figure 1. Salmon Arm (23.28±1.93 cm) provenance significantly differed by DBH from all other provenances, except for provenances from Oregon (Shady Cove – 24.27±1.13 cm; and Corvalis – 31.31±1.35 cm), British Columbia (Elk River Falls – 31.78 ±1.14 cm and Merville Black – 30.64 ±1.29 cm) and Croatian provenance Rovinj (31.81±1.46 cm). Castle Rock from Washington had the largest standard deviation (SD=7.28), pointing to the largest differences between DBH of individual trees for this provenance. The smallest differences between individual trees in terms of DBH showed ELMA from Washington (SD=0.91 cm), pointing to the good adaptability to local conditions.

Provenances with the highest average DBH values were Castle Rock (41.38±7.28 cm) and Elma (39.53±0.91 cm) from Washington. Castle Rock provenance from Washington statistically differed from Shady Cove (24.27±1.13 cm), Oregon and Salmon Arm (23.28±1.93 cm) and from British Columbia provenances. Even though it had the largest DBH it did not differ significantly from other provenances, showing that Shady Cove from Oregon and Salmon Arm from British Columbia were provenances with the lowest DBH on this locality. A 95% confidence interval for DBH is shown in Figure 1. The provenance with the largest DBH (Elma) also had the smallest standard deviation (SD=0.91cm), pointing to the lowest differences between individual trees. In terms of the highest DBH values this provenance was followed by Shelton (35.96±1.11 cm), Pe All (36.40±1.06 cm) and Yelm (35.30±1.30 cm) from Washington, Hvidilde (36.19±1.46 cm) from Denmark and Šipka (35.57±1.31 cm) from Bulgaria.

Furthermore, repeated measures ANOVA of DBH in the 46th year after planting in comparison with data from the year 2010 (41st year after planting) confirmed significant difference between DBH ($p<0.05$) both between the values of individual years, but also in relation to *provenance x year* (Table 3). This shows that provenances did not have the same DBH growth.

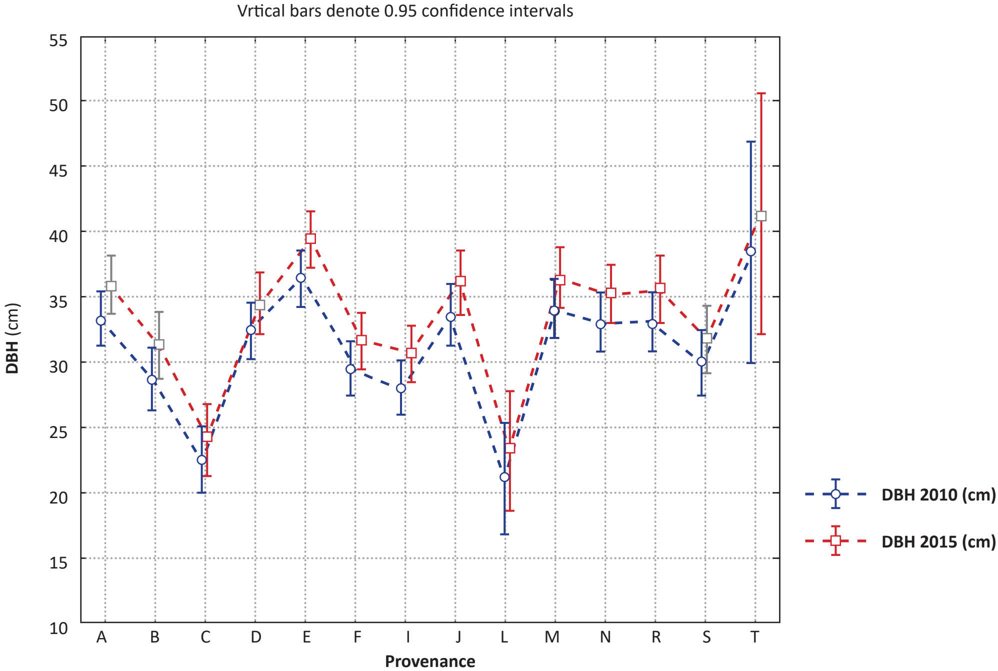

FIGURE 1. 95 % confidence intervals for DBH (in 46th year after planting) compared to data collected in the 41st year after planting [30] for 14 Douglas fir provenances grown on Slatki potok locality. For provenance codes see Table 1.

TABLE 2. Results of descriptive statistics and Tukey post hoc analysis for 14 Douglas-fir provenances (basic growth indicators) in the year 2015 (46th year after planting).

Code	Provenance	DBH (cm)	Height (m)	Volume (m^3)
A	SHELTON, Washington	35.96 ± 1.11 CILS	27.91 ± 0.50 BCILS	1.53 ± 0.10 CL
B	CORVALIS, Oregon	31.31 ± 1.35 CE	25.44 ± 0.64 ACEM	1.15 ± 0.11 CE
C	SHADY COVE, Oregon	24.27 ± 1.13 ABDEFIJMNRST	18.61 ± 0.63 ABDEFIJMNRST	0.53 ± 0.06 ABDEFIJMNRST
D	TENINO, Washington	34.52 ± 1.29 CL	27.04 ± 0.52 CL	1.43 ± 0.11 CL
E	ELMA, Washington	39.53 ± 0.91 BCFILS	29.61 ± 0.34 BCFILS	1.87 ± 0.09 BCFILS
F	ELK RIVER FALLS, Brit. Columbia	31.78 ± 1.14 CE	25.86 ± 0.53 CEL	1.17 ± 0.08 CE
I	MERVILLE BLACK, Brit. Columbia	30.64 ± 1.29 ACEJM	24.77 ± 0.60 ACEMN	1.11 ± 0.10 CE
J	HVIDILDE, Denmark	36.19 ± 1.46 CIL	26.62 ± 0.59 CEL	1.55 ± 0.13 CIL
L	SALMON ARM, Brit. Columbia	23.28 ± 1.93 ADEJMNRT	21.86 ± 1.03 ADEFJMNR	0.57 ± 0.11 ADEJMNRT
M	PE ALL, Washington	36.40 ± 1.06 CIL	28.25 ± 0.45 BCILS	1.56 ± 0.09 CIL
N	YELM, Washington	35.30 ± 1.30 CL	27.11 ± 0.50 CIL	1.49 ± 0.11 CL
R	ŠIPKA, Bulgaria	35.57 ± 1.31 CL	27.12 ±0.58 CL	1.50 ± 0.12 CL
S	ROVINJ, Croatia	31.81 ± 1.46 CE	24.63 ± 0.71 ACEM	1.16 ± 0.10 CE
T	CASTLE ROCK, Washington	41.38 ± 7.28 CL	27.55 ± 1.99 C	2.05 ± 0.69 CL

TABLE 3. Results of ANOVA – comparison of provenances by DBH on Slatki potok locality in the 41st and 46th year after planting (2015) for 14 Douglas-fir provenances.

	Sum of squares	Degrees of Freedom	Mean Square Error	F	p
Provenance	20898.5	13	1607.6	9.825	0.000000
Error	115357.1	705	163.6		
Year	1007.8	1	1007.8	805.181	0.000000
Year*Provenance	43.5	13	3.3	2.675	0.001117
Error	882.4	705	1.3		

Variation in Tree Height among Provenances

The average value of height on this experimental plot was 26.17 m. Elma provenance from Washington was by far the tallest and it was statistically different from other provenances except those from Washington (Castle Rock - 27.55±1.99 m, Shelton - 27.91±0.50 m, Tenino - 27.04±0.52 m, Pe All 28.25± 0.45 m, and Yelm - 27.11±0.50 m) and Bulgaria (Šipka - 27.11±0.58 m). Washington and Bulgarian provenances were the most successful in terms of height (Figure 2). In general, the smallest height values were obtained in Salmon Arm (21.86±1.03 m) from British Columbia and Shady Cove from Oregon (18.61±0.63 m) provenances. Salmon Arm provenance (21.83 m) differed statistically from all other provenances except from Shady Cove (also the lowest height value of 18.61 m), Croatian provenance Rovinj (24.63 m), Elk Falls River (25.86 m) from British Columbia, Corvalis (25.44 m) from Oregon and Castle Rock (27.55 m) from Washington. Regarding DBH, Castle Rock from Washington had the largest standard deviation for height (SD=1.99 m), pointing to the largest differences between heights of individual trees. The smallest differences between individual trees in terms of height again showed ELMA provenance from Washington (SD=0.34 m).

Repeated measures ANOVA for height in the 46th year after planting in comparison with data from 2010 confirmed significant difference between heights ($p<0.05$) for all analysed provenances (Table 4). Differences observed in Figure 2 were confirmed by Tuckey post hoc test ($p<0.05$).

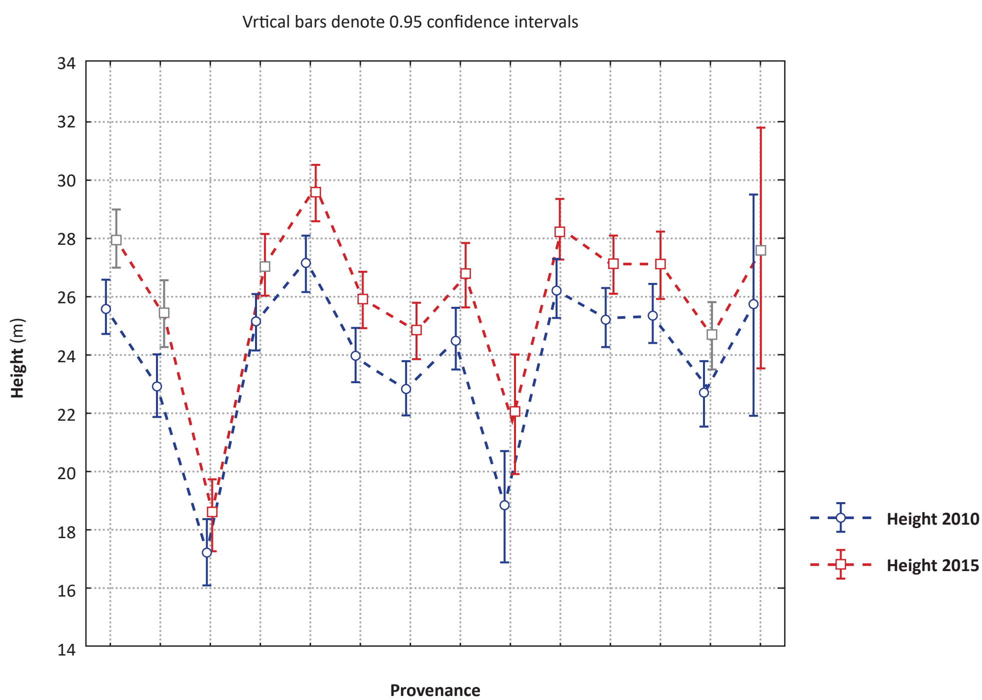

FIGURE 2. 95% confidence intervals for tree height compared to data collected in the 41st year after planting [30] for 14 Douglas-fir provenances on Slatki potok locality. For provenance codes see Table 1.

Variation of Tree Volume among Provenances

Descriptive statistics for V (Table 2) showed a large span from 0.53 m^3 to 2.05 m^3, while the average value for this locality is 1.34 m^3. Statistically significant difference between V in the years 2010 and 2015 points to different volume increment of analysed provenances (Table 5). Tuckey post hoc test ($p<0.05$) for V revealed which provenances differed significantly from others.

The highest average V was recorded in Castle Rock provenance (2.05±0.69 m^3) from Washington (Figure 3). Statistically, it significantly differed from the lowest value for V, which was measured in Shady Cove provenance (0.53±0.06 m^3) from Oregon and Salmon Arm provenance (0.57±0.11 m^3) from British Columbia. These two provenances differed from all other provenances, which isolates them in terms of low growth and proves them to be inadequate for this habitat. There were no statistically significant differences between other provenances. Based on this data it can be concluded that Elma provenance from Washington, and generally the Washington region along with European provenances from Bulgaria, Denmark and Croatia, proved to have the highest V in the hilly area. Castle Rock from Washington had the largest standard deviation for V (SD=0.69 m^3), as in the case of DBH and height. The smallest differences between individuals in terms of V were again obtained in Shady Cove from Oregon (SD=0.06 m^3), and Elma and Pe All from Washington (SD=0.09 m^3, respectively).

TABLE 4. Results of ANOVA – comparison of provenances by tree height on Slatki potok locality in the 41st and 46th year after planting (2015).

	Sum of squares	Degrees of Freedom	Mean Square Error	F	p
Provenance	8678.2	13	667.6	21.23	0.000000
Error	22164.1	705	31.4		
Year	770.8	1	770.8	927.57	0.000000
Year*Provenance	34.9	13	2.7	3.23	0.000092
Error	585.9	705	0.8		

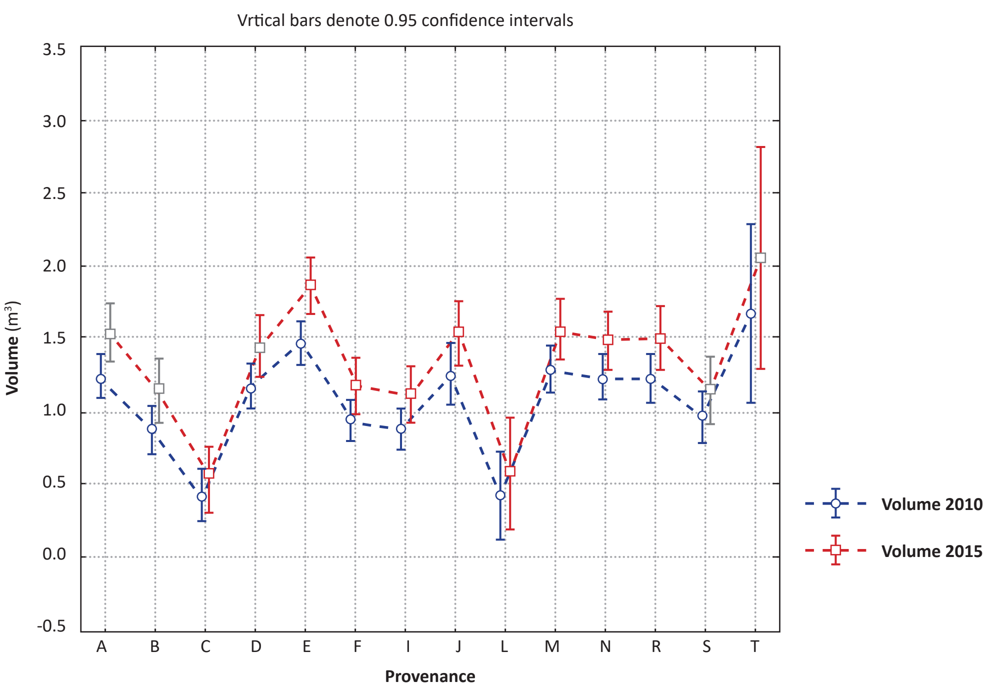

FIGURE 3. 95% confidence intervals for tree volume compared to data collected in the 41st year after planting [30] for 14 Douglas-fir provenances on Slatki potok locality. For provenance codes see Table 1.

TABLE 5. Results of ANOVA – comparison of provenances by volume on Slatki potok locality in the 41st and 46th year after planting for 14 Douglas-fir provenances.

	Sum of squares	Degrees of Freedom	Mean Square Error	F	p
Provenance	130.702	13	10.054	10.336	0.000000
Error	684.822	704	0.973		
Year	12.758	1	12.758	578.622	0.000000
Year*Provenance	1.552	13	0.119	5.415	0.000000
Error	15.523	704	0.022		

DISCUSSION AND CONCLUSIONS

Climate changes, together with the increase of society demands from forests and forestry sector, are predicted to grow constantly and fiercely in the future. The use of NNTS such as Douglas-fir has been in focus of European countries because of their higher adaptive capacities compared to limited ability of some native tree species to cope with climate changes [32]. Recently, this tree species has gained a lot of interest not only due to its high wood production, but also due to its potential use as a new silvicultural option in reforestation and afforestation activities [26]. Even though comparison with native, but highly susceptible Norway spruce was not compared in this research, initial comparative studies had proved Douglas-fir to be good choice both in the lowlands, hilly and coastal parts of the country [27, 33-37]. For Slatki potok locality, Douglas-fir trees were 148% higher, 166% thicker (based on DBH measurements) and had 477% more volume compared to Norway spruce fifteen years after planting [38]. This claim is further supported by international research. For example, in an Austrian research coastal provenances Tenino from Washington and Cascadia from Oregon showed better growth than Norway spruce [39]. Furthermore, the comparison of these two species showed better resistance of Douglas-fir seedlings to drought several years after reforestation [40]. Thus, we conclude that a wisely chosen provenance could present good solution for reforestation after Norway spruce decline, which is a pronounced problem in Croatia at the present.

First of all, the use of Douglas-fir in Croatia has already been advised for four decades, but the amount of Douglas-fir cultures is still small. Former research studies initiated hypotheses that there is a difference among provenances even in the later stages of development [41, 42]. This claim was proven by this research. The research also proved that the selection of appropriate provenances has crucial influence on growth and development of an established forest culture. This research aimed to pinpoint the most productive provenances, so different growth indicators have been used to provide a comprehensive analysis. On the basis of the obtained results, we strongly support coastal provenances, especially those from the State of Washington, for the use in practical forestry in the hilly area of Croatia. This includes Castle Rock, Elma, Pe All, Yelm, Tenino, and Shelton provenances from Washington. Nevertheless, provenances from Europe (Hvidilde from Denmark and Šipka from Bulgaria) also showed good productivity and are advised to be used in reforestation and afforestation activities. Castle Rock and Elma clearly distinguish themselves among all other provenances by their superior growth, which has been observed for all measured parameters. The results are supported by international research as well [43, 44]. On the other hand, we do not support provenances from Oregon and British Columbia to be used in the hilly area since they have shown poor growth results for all analysed parameters. Low values of growth parameters, especially tree volume in the case of Castle Rock and Shady Cove provenances are derived from the low number of survived trees in the trial, which is evident in all four repetitions. Already from the first years after planting strong abiotic influences caused the decline of trees of Castle Rock provenance [22]. Thus, the survival during the first years after planting is an important parameter to be taken into account.

Secondly, the survival of provenances should be considered as well. Even though the survival of tested provenances is a basic trait to assess when adaptation to climate change is considered, especially for provenances moved over long distances, it cannot provide sound conclusions in this late stage of development. The survival of individual trees is strongly influenced by silvicultural measures, which were needed in this late in tree development since the growing space was far below the needed (due to high tree dimensions). On the studied trial, thinning from below was conducted, leaving only the most suited trees from each provenance. Nevertheless, this way the survival of provenances as a basic indicator was not taken into account, leaving the published data from earlier developmental stages as the more reliable ones. Thus, the survival data were not included into the analysis. The satisfactory survival of the selected provenances based on productivity data is supported by earlier research [20, 30, 38], further highlighting the use of Washington provenances for forest culture establishment. It should also be noted that, if regarded from the aspect of survival of young generation after plating, Douglas-fir provenances growing quickly are also the ones with better quality and less prone to frost and low temperatures; conversely, the ones growing slowly are of lower quality and are more sensitive to low temperatures [22].

Finally, if research results should be applied in practical forestry, nursery production has to be harmonised with silvicultural needs in practice and should anticipate the forthcoming needs for reforestation purposes [45]. Nevertheless, the data on nursery production of Douglas-fir [45-47] show insufficient amount of produced Douglas-fir seedlings. Thus, we strongly propose to include that research results into nursery production plans locally, but on the national level as well. Regarding the significance of Norway spruce in Croatia and the scale of its decline [48, 49], it can be concluded that the use of Douglas-fir research should be continued in the hilly area, but also broadened to other areas of Croatia, especially mountain areas.

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Outbreak of *Orthotomicus erosus* (Coleoptera, Curculionidae) on Aleppo Pine in the Mediterranean Region in Croatia

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ABSTRACT

Background and Purpose: *Orthotomicus erosus*, Mediterranean pine engraver, is widely distributed across the Mediterranean and southern Europe, Asia and North Africa. It is considered as secondary pest found on recently dead or felled trees, but can also attack weakened living trees. In high population levels this species can attack healthy trees and cause their dieback. Severe outbreaks occur after dry periods, or after fire in adjoining stands in warmer parts of the Mediterranean region, while this scenario has never happened in Croatia up to now. Bark beetles are important forest pests which have already been researched and discussed in relation to climate change, indicating that the predicted increase in temperature would lead to higher survival rates and faster development, thus directly influencing their population dynamics. Increase in temperature may stimulate changes in insects' rate of development, voltinism, population density, size, genetic composition, extent of host plant exploitation, longitudinal and latitudinal distribution. Since climate conditions might have changed in the last few years as predicted in the Mediterranean region, the aim of our research is to document the first outbreak with high population levels of *O. erosus* in Croatia.

Materials and Methods: The extent of dieback was evaluated by counting trees with dieback symptoms on diagonal transects plotted through each of 33 forest management sections of Marjan Forest Park (Split). Trunk sections from several trees with early stage symptoms were collected for further laboratory analysis, which consisted of incubation phase and subsequent morphological identification. During regular yearly surveys in forests of Croatia, the pest was observed on several sites and damages were recorded for both years 2017 and 2018. The records were entered into a map using QGIS version 3.2.1-Bonn. Spatial data was downloaded from DIVA-GIS server. Monitoring efforts were initiated in affected areas where 13 flight barrier pheromone traps (Theyson®) equipped with pheromone lure Erosowit® (Witasek, Austria) were set-up in late March in state-owned and privately owned forests across Dalmatia. Catches in the traps were collected and *O. erosus* adults were counted on a weekly basis in order to identify the abundance of the pest in monitored sites, as well as to obtain the first information about population dynamics and to assess voltinism.

Results: On-site survey and the evaluation of dieback extent included sampling of 5% of all trees in Marjan Forest Park ,and the results showed that 23% of all trees in the forest park were affected by dieback symptoms. Visual examination of trunks, branches and bark showed symptoms of bark beetle infestation, while preliminary on-site examination of the observed adults pointed out to *O. erosus*. After two weeks in controlled conditions, bark beetle adults started to emerge from trunk sections which were placed in several mesh cages for incubation. Morphological identification by using stereomicroscope and the key for European bark beetles resulted in identification of *O. erosus* species. Over the course of the year 2017 one more site was reported to be infested with *O. erosus*, and eight additional sites were reported over the course of year 2018. In total, 446 ha were reported as infested, varying in intensity, in several different management units of state-owned and privately owned forests. The total number of trapped beetles in pheromone traps varied largely among sites. Our data indicate that several generations (at least 5 generations per year) were present in the year 2018.

Conclusions: Sudden surge in observed damages, as well as the number of beetles trapped during monitoring, in years 2017 and 2018 throughout Aleppo pine forests in Dalmatia are the first record of *O. erosus* outbreak in Croatia. *O. erosus* is native to Croatia and so far it has been considered only as a minor pest whose outbreaks have never been recorded.

Drought intensity and frequency and aridification trends in the research area (Dalmatia, Croatia) cause cumulative stress to trees and have increased *O. erosus* occurrence. *O. erosus* is expected to exhibit increased voltinism, better overwintering performance and earlier spring flights. Our first results confirm this epidemic stage of *O. erosus* with high abundances in Dalmatia in 2018 and at least 5 generations per year, which alter the population level of this pest. Finally, with high dispersal abilities of *O. erosus* through active flight and easy transportation with infested material (logs and branches with bark), *O. erosus* has the potential to become an important forest pest in Croatia. Thus, extensive studies on its biology, ecology, natural enemies and interaction with ophiostomatoid fungal species are needed in order to predict further spread and suggest viable and effective management measures.

Keywords: Mediterranean pine engraver, climate change, *Pinus halepensis*, *Pityogenes calcaratus, Tomicus destruens*

INTRODUCTION

Bark beetles (Coleoptera; Curculionidae; Scolytinae) have been documented as a relevant ecological and economic factor in ecosystem functioning and their activity can indicate the health condition and vitality of forests [1]. They are also very important forest pests that can cause serious dieback of forests on huge areas [2-4] and enormous wood volume loss [5]. Out of many species only a few are able of causing tree dieback, and usually they have fluctuations from low abundance for lengthy periods when they are limited to stressed trees [6]. However, their populations can rise suddenly and spread over large areas, sometimes killing huge numbers of healthy trees as well.

There are 42 bark beetle species recorded living on Mediterranean conifers and usually they have been registered on weakened trees only [1, 7]. According to Pfeffer [8] and Knižek [9], 11 bark beetle species have been listed for Croatia, developing on Aleppo pine trees (*Pinus halepensis* Mill.), out of which only 3 species have the potential to behave like a pest (*Tomicus destruens* Woll., *Orthotomicus erosus* Woll. and *Pityogenes calcaratus* Eich.).

Orthotomicus erosus, Mediterranean pine engraver, is widely distributed across the Mediterranean and southern Europe, Asia and North Africa. It has been introduced to Fiji, South Africa, Swaziland [10] and the USA [11]. It can occur in association with other bark beetle species (*Pityogenes calcaratus, Tomicus destruens* [12]) and in symbiotic relationship with blue stain fungi (Ophiostomatidae) [13]. It is considered as a secondary pest found on recently dead or felled trees, but can also attack weakened living trees (e.g. under drought stress). In high population levels this species can attack healthy trees and cause their dieback [14]. Severe outbreaks occur after dry periods, or after fire in adjoining stands in warmer parts of the Mediterranean region [15, 16].

Mediterranean forests are one of the world's biodiversity hotspots characterized by a variety of environmental conditions with an array of plant and animal species diversity. As such, they represent a major socio-economic component for tourists that visit the Mediterranean every year, with their unique biological richness and multiple values [17]. However, today they are under severe threat from climate change and it is predicted that Mediterranean forest ecosystems will suffer from its impacts by 2050 [17]. Mediterranean forests composed mostly of drought-tolerant Mediterranean oak species [18] have been over-used for their multiple resources. Huge amount (75%) of these ecosystems has been destroyed by humans already in the 19th century [19]. Aleppo pine has been widely planted in reforestation of the degraded areas as a fast-growing pioneer species. First reforestation efforts in Croatia were documented in 18th century [20]. Aleppo pine was chosen as the most suitable species because of its drought tolerance [18] and it was widely distributed on the coast of Croatia [21]. Today, Aleppo pine plays an important role in edaphic preparation for other native species (e.g. *Quercus ilex* L.) [22]. This pine species is also very important in preservation of multiple environmental services provided by Mediterranean forests (e.g. carbon sequestration, biodiversity, landscape quality, soil and water protection, landscape and recreational role). However, this widely growing species is endangered by prolonged drought periods that cause water deficit and weaken the trees, as well as by forest fires, pests and diseases [23-25]. New examples of climate change induced pest occurrences give rise to special concerns since these changes could have long-term effects on the vitality and health status of Aleppo pine forests in the coastal region of Croatia [25, 26]. Bark beetles have already been researched and discussed in relation to climate change, indicating that predicted increase in temperature would lead to higher survival rates and faster development, thus directly influencing their population dynamics [27].

Climate change could indirectly negatively influence forest ecosystems through range expansion and changing of seasonal phenology of insect pests, resulting in faster development and higher feeding rates of phytophagous insects [27]. This negative influence is likely to be accelerated with increased temperatures and frequency and intensity of droughts with extended growth period of vegetation predicted for Mediterranean forests [28]. Other negative influences of climate change on forests might be seen in physiological changes in tree defense mechanisms and indirect effects through changes in abundances of natural enemies and competitors [29]. Temperature may stimulate changes in insects' rate of development, voltinism, population density, size, genetic composition, extent of host plant exploitation, longitudinal and latitudinal distribution [14, 30].

Among bark beetles, *O. erosus* is considered as a secondary pest which infests already fallen and/or stressed trees [31]. Attacks of *O. erosus* and *P. calcaratus* have already been recorded in warmer Mediterranean regions such as Israel [32], Iran [33], Morocco [34], Turkey [35] and Tunis [36]. According to written records, this species has not yet been observed in Croatia [25, 37]. When it comes to bark beetles in the Mediteranean part of Croatia, only very local outbreaks of *T. piniperda* L. or *T. destruens* have been recorded [24, 38, 39]. However, it was predicted that climate change increases the possibility that the outbreaks will spread and increase in frequency, and that Mediterranean forests could become more vulnerable to their attacks than temperate and boreal regions [1]. In outbreaks of pests correlated to climatic change outside their historical ranges, northwards spreading or elevation expanding have already been well documented [e.g. 36, 41-42].

According to Lieutier *et al.* [1], *O. erosus* infesting Aleppo pine may develop up to 4 generations per year or even up to 7 generations [15, 40], while in Croatia only 2 to 3 generations have been described [43]. Males of *O. erosus* bore through the bark into the cambium where they mate with several females. Females construct egg galleries and can oviposit up to 75 eggs in the niches along the galleries [12]. Larvae pass through three instars and gnaw their galleries perpendicularly to maternal ones. The adults perform maturation feeding beneath the still moist bark and if the bark is too dry, they move to another tree [12]. Insect overwinters as an adult and beetles fly in spring at temperatures of 12-14 °C [15, 41]. The beetles choose rough-barked tree trunk and branches larger than 5 cm in diameter for breeding. Smooth barked sections of the trunk are used for maturation feeding, while lower trunk parts of old trees with too thick bark are not suitable for attack [12].

Considering that climate conditions for multiple generations of *O. erosus* described by Mendel [15, 40] were not fulfilled could be the reason why outbreaks of this insect have never been documented in Croatia [24]. Though, these conditions might have changed in the last few years as predicted [28].

The aim of our research is to document the first outbreak with high population levels of *O. erosus* in Croatia.

MATERIALS AND METHODS

First Record of Symptoms and Identification of the Pest

In 2017, unusual wilting and drying of Aleppo pine trees was reported in Marjan Forest Park, Split (43°30′33″N; 16°24′38″E). The report triggered intensive on-site survey in order to determine the extent and cause(s) of dieback of Aleppo pine trees. The extent of dieback was evaluated by counting trees with dieback symptoms on the diagonal transects plotted through each of 33 forest management sections of the forest park. The identification of dieback causative agent was performed by visual examination of trunks and branches (Figure 1). Trunk sections from several trees with early stage symptoms were collected for further laboratory analysis. Samples were taken to entomological laboratory of Croatian Forest Research Institute, Jastrebarsko, Croatia.

Laboratory analysis consisted of incubation phase and subsequent morphological identification. Incubation was performed by distributing trunk sections (collected during field survey) into mesh cages and subjecting them to controlled temperature of 20(±2)°C and L:D=16:8. Trunk sections were sprayed with distilled water across the entire surface once per day in order to maintain bark moisture. Upon emergence, adult beetles were collected from mesh cages and morphologically identified. Identification was performed by visual examination, using stereoscopic light microscope Olympus SZX7 and the key for bark beetle identification [8, 9].

Localities and Years of Record

Similar symptoms were observed also in other Aleppo pine forests in Dalmatia, and on-site training was organized

FIGURE 1. a) Green crown of freshly infested Aleppo pine tree; **b)** Examination of the trunk and branches for infestation symptoms.

in the summer of 2017 in Biograd Forestry Office in order to familiarize regional foresters with new threats posed by the potential outbreak of *O. erosus* and to teach them how to identify damages caused by this bark beetle. During regular yearly surveys in forests of Croatia, the pest was observed on several sites and damages were recorded for both years 2017 and 2018. The records were entered into a map using QGIS version 3.2.1-Bonn. Spatial data was downloaded from DIVA-GIS server.

Monitoring of *O. erosus* in Dalmatia

After surprising record of damage done by *O. erosus* in 2017, monitoring efforts have been initiated. Thirteen flight barrier pheromone traps (Theyson®) equipped with pheromone lure Erosowit® (Witasek, Austria) were set up in late March in state-owned and privately owned forests across Dalmatia. Catches in the traps were collected and *O. erosus* adults were counted on a weekly basis in order to identify the abundance of the pest in monitored sites, as well as to obtain the first information about population dynamics and to assess voltinism.

RESULTS

First Report of Symptoms and Identification of the Pest

On-site survey and evaluation of dieback extent included sampling of 5% of all trees in Marjan Forest Park , and the results showed that 23% of all trees in the forest park were affected by dieback symptoms by the end of 2018. Visual examination of trunks, branches and bark showed symptoms of bark beetle infestation, while preliminary on-site examination of the observed adults pointed out to *O. erosus* (Figure 2).

After two weeks in controlled conditions, bark beetle adults started to emerge from trunk sections which were placed in 10 mesh cages for incubation. Morphological identification by using stereomicroscope and the key for European bark beetles resulted in positive identification of the species as *O. erosus*.

Localities and Years of Record

Over the course of the year 2017, aside from Marjan, one more site was reported to be infested with *O. erosus*, and eight additional sites were reported over the course of the year 2018 (Figure 3). In total, 446 ha and about 9.000 m^3 of wood mass were reported as infested, varying in intensity, in several different management units of state-owned and privately owned forests in Šibenik-Knin County in 2018 (Table 1).

Monitoring of *O. erosus* in Dalmatia

Pheromone traps for monitoring the abundance of *O. erosus* in Aleppo pine forests in Dalmatia were set up on 13 sites in total (both in state-owned and privately owned forests). The total number of trapped beetles varied largely among sites (from 21,442 specimens to 140,448 specimens trapped in Šibenik) and fluctuated substantially over the course of the year (Figure 4 and 5). Our data indicate that several generations (at least 5 generations per year) were present in the year 2018. These data need further validation in the years that follow.

FIGURE 2. *O. erosus* bark beetle, observed on the bark of Aleppo pines in Marjan Forest Park: **a)** Bark beetle galleries and **b)** Adult stage of beetles.

TABLE 1. Area and wood mass infested by *O. erosus* reported for private, protected and state-managed forests in 2018.

Forest Office	Forestry	Management unit	WGS coordinates		Infestation		
			N	E	Area (ha)	Wood mass (m^3)	Intensity (%)
Private forests	Šibenik-Knin County	Šibenske šume	43.7448	15.9695	10.5	n/a	1-20
State-protected forests	Split	Marjan	43.5139	16.4092	196.0	5,900	21-40
	Korčula	Ošjak	42.9606	16.6794	18.0	1,800	21-40
	Makarska	Osejava	43.2886	17.0138	70.0	150	1-20
	Dubrovnik	Lokrum	42.6276	18.1112	70.0	100	1-20
State-managed forests Split	Biograd	Biograd	43.9308	15.4802	25.0	400	21-40
		Pašman-Vrgada	43.9540	15.3494	31.0	250	41-60
		Turanj	43.9978	15.4266	3.0	25	1-20
	Korčula	Šaknja Rat	42.9438	16.7932	17.5	200	1-20
	Zadar	Nin-Kožino	44.1996	15.2144	2.0	10	1-20
		Starigrad	44.3499	15.3502	3.0	20	1-20
Totals					**446.0**	**8855.0**	**1-60**

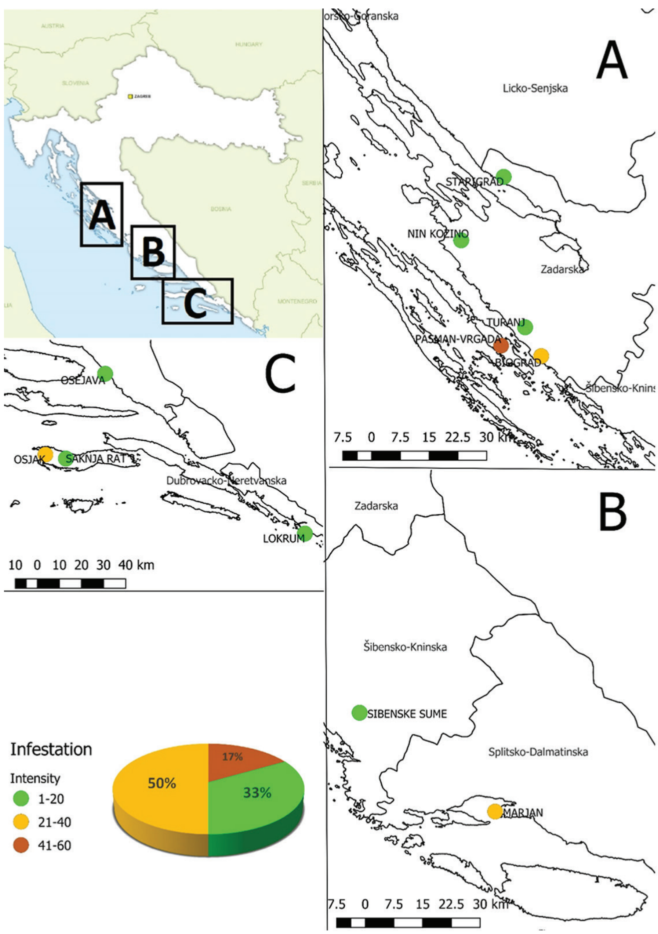

FIGURE 3. Map of management units reported as infested by *O. erosus* in 2018. Coloration according to the reported infestation intensity. The pie chart represents area ratios of the reported infestation intensities.

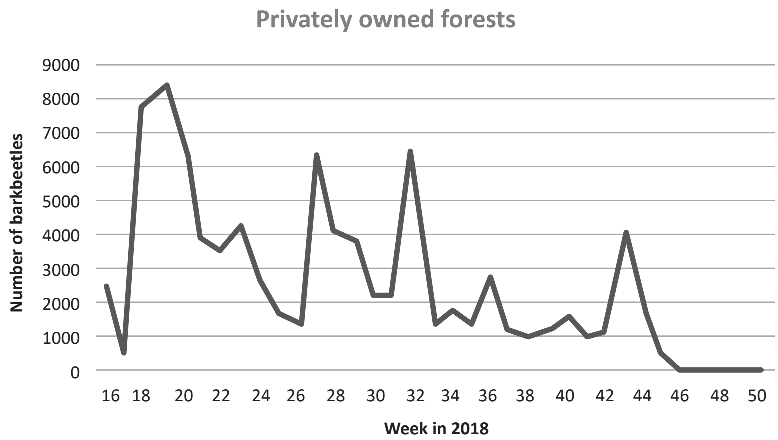

FIGURE 4. Weekly distribution of the total number of trapped *O. erosus* beetles per trap in 2018 in privately owned forests.

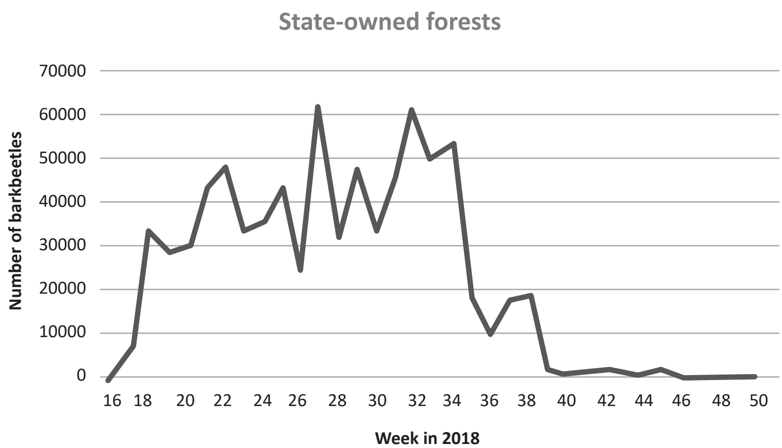

FIGURE 5. Weekly distribution of the average number of trapped *O. erosus* beetles per trap in 2018 in state-owned forests.

DISCUSSION

Sudden surge in the observed damages, as well as the number of beetles trapped during monitoring, in years 2017 and 2018 throughout Aleppo pine forests in Dalmatia, as presented in this paper, is the first record of *O. erosus* outbreak in Croatia. *O. erosus* is native to Croatia and so far it has been considered only as a minor pest and its outbreaks have never been recorded [23, 24, 39, 43, 44]. Thus, the outbreak came as a surprise, rising questions about causes of this phenomenon, predictions of further expansions, as well as the availability and efficacy of control measures. Drought intensity and frequency have increased in the region of *O. erosus* occurrence (Dalmatia, Croatia) and aridification trends cause cumulative stress to trees [43]. More evidence shows that population dynamics of forest insects have already been affected by climate change [14, 26, 44, 46, 47]. Temperature is the primary climatic factor affecting insects since they are poikilothermic organisms and respond quickly to temperature changes [29]. The responses manifest through changes in population density and distribution range of the affected species [48]. Generally, in mid-latitude regions temperature increases associated with climatic changes could result in changes of beetle ecology, such as extension of geographical range, increased overwintering, increased number of generations, extension of development season and so on [49]. It seems to be very important that the beetles jointly overcome tree defense mechanisms, and temperature positively influences such synchronization [50]. Furthermore, reduced production of active defenses could reduce tree resistance to bark beetle attacks [51].

According to IPCC [28], intensity, duration and frequency of drought have increased in semi-arid areas, e.g. in the Mediterranean region, which manifests as aridification process capable to trigger forest diebacks [52]. Trees stressed by aridification processes are becoming more prone to insect infestations, which leads to an increase of injury and eventually to tree death [53, 54]. On the other hand, longitudinal and altitudinal range shifts caused by climate change have already been documented for various species of forest insects (as reviewed in [14]). Furthermore, temperature increase has been predicted to influence the distribution of Mediterranean species of bark beetles (e.g. *T. destruens*), enabling them to spread northwards and feed on new hosts in new areas [54].

O. erosus can establish up to 7 generations per year [40] and it exhibits accelerated development at high temperatures with no thermic limitations for mass production, which enables it to pass from endemic to epidemic stage within months [12, 15, 40]. With predictions for temperature change in the Mediterranean region towards warmer winters and warmer and drier summers [14, 28], *O. erosus* is expected to exhibit increased voltinism, better overwintering performance and earlier spring flights. This might probably ultimately increase its population size, resulting in more severe and widespread damages as reported for other bark beetle species [56, 57]. Our first results confirm this epidemic stage of *O. erosus* with high abundances in Dalmatia in 2018 and at least 5 generations per year, which alter the population significance of this pest.

It is very hard to discriminate direct from indirect events of climate change [30], which is why the overall impact of all interacting factors should be considered. With this in mind, natural enemies are also influenced by climate change as the host and parasitoid synchronization may be disrupted under altered climate conditions [27]. Unexpected events, e.g. storms which are more frequent and are predicted to increase (as reviewed in [14]), can provide an abundant source of fresh food for bark beetles, increasing the build-up of populations. High availability of food source (stressed trees, freshly felled trees) together with increased voltinism can lead to permanently high bark beetle populations that are able to attack healthy trees, enabling them to become primary pests [58].

Furthermore, *O. erosus* is associated with several ophiostomatoid species [13, 59]. Some ophiostomatoid fungal species in association with bark beetles show increased virulence and it is assumed that they help their vectors, bark beetles, to break the defensive mechanisms of the host plant. This is a successful strategy for weakening the host plant and plays an important role in the attack strategy of bark beetles [60, 61]. How and to what extent could the temperature increase affect fungal species remains unknown, making this issue one of the questions that should be addressed in future studies. Our first preliminary research has shown several species of ophiostomatoid fungal species (Pernek and Matek, unpublished data) isolated from samples taken from the same localities shown in Table 1.

Finally, with high dispersal abilities of *O. erosus* through active flight and easy transportation with infested material (logs and branches with bark), *O. erosus* has the potential to become a serious forest pest in Croatia. Thus, extensive studies on its biology, ecology, natural enemies and interaction with ophiostomatoid fungi are needed in order to predict its further spread and to suggest viable and effective management measures.

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Assessment and Comparison of Machine Operators' Working Posture in Forest Thinning

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ABSTRACT

Background and Purpose: Due to technological progress and improvement of working processes, significant changes in the field of health protection and safety at work have occurred in the forestry sector. Accordingly, this paper presents the assessment and comparison of the working posture for operators of three different types of forest machines: chainsaw, forwarder and harvester.

Materials and Methods: The analysis was carried out from an ergonomic point of view using ErgoFellow 3.0 software, i.e. two ergonomic methods: Ovako Working Posture Analyzing System (OWAS) and Rapid Entire Body Assessment (REBA). Field measurements and data collection were carried out during the summer of 2017, when different wood harvesting technologies were applied within the same forest stand. The operators' body posture was recorded during effective work by a video camera and was taken as a relevant comparison factor of different types of forest machines and three observed operators. From the video recordings, the working body postures were defined in accordance with the snapshot method with the aim of obtaining an equal number of observations for all three operators of forest machines.

Results and Conclusions: The results of the analysis of the working posture for operators of all three types of forest machines show that, in terms of the level and type of their impact on the worker, the work of the chainsaw operator is more demanding and much more risky than that of the harvester or forwarder operators. The comparison of the two risk categorization methods, from the aspect of the working posture, shows that the REBA method has higher risk ratings than the OWAS method for all three types of forest machines. The need to implement preventive measures established in Scandinavian countries and to define the guidelines for future research of the working postures of forest machine operators is presented in the discussion of this paper.

Keywords: Croatia, forest thinning, machine operators, OWAS, REBA, working posture

INTRODUCTION

In today's dynamic market environment, due to the need for competitiveness and constant pressure to reduce production costs and the duration of the production cycle, industries increasingly tend to automate specific aspects of work and production processes. Many industries, however, still rely on motor-manual or manual work, either as a consequence of a low technological level or because of the unavailability of modern technologies in underdeveloped countries. The forestry sector, i.e. the operations in the harvesting process, is also characterized by a large share of manual and motor-manual work. The reason for such a situation is the level of mechanization of forestry production, which largely depends on factors such as stand type, mode of management, field and climatic conditions [1]. Today, globally, a large number of wood harvesting systems/technologies are currently used in forestry [2], and most of them still use a lot of manual work in the production process. In these work processes in forestry, workers are exposed to a high level of physiological [2] and physical stress and to possible musculoskeletal disorders [3].

Musculoskeletal Disorder (MSD), i.e. cumulative Work-Related Musculoskeletal Disorders (WMSD) of the neck and upper limbs, usually occur due to repetition of the same movements, prolonged use of vibrating tools and non-ergonomic working posture. These disorders represent an important occupational problem that reduces workers' productivity and increases costs in terms of remuneration, medical expenses, etc. [4]. In forestry practice, there are many conditions due to which forest loggers are exposed to WMSD: tough field conditions (low temperatures, slippage and uneven terrain), hard physical work and non-ergonomic body posture (load handling, hunched back), and dangerous tools and machines such as chainsaws [3]. With the development of machine cutting and processing, the work is transferred from the outside work environment into the cabin, which reduces the physical strain of work and the exposure to most of the risk factors within the working site. On the other hand, with machine cutting and processing (harvester and forwarder), new types of injuries and diseases, such as repetitive movement syndrome [5], occur as a result of the musculoskeletal disorder, along with new cognitive risk factors that are increasingly present. Harvester and forwarder operators often suffer WMSD-related pains in the area of the neck, lower back and shoulders [6-8], while Østensvik *et al.* [9] conclude that the occurrence of WMSD in machine cutting and processing largely depends on the organization of work. Therefore, the old ergonomic paradigm "less is better" for traditional wood harvesting systems/technologies should be replaced with "more can be better", where reduced physical activity in modern wood harvesting technologies can also have adverse impact on workers' health [10].

Furthermore, ergonomic research is most often carried out with the purpose of evaluating, classifying and, if necessary, implementing corrective measures related to the working posture of workers throughout the day, all with the aim of finding the optimal balance of the two basic components of the working system - human ability and working conditions. Therefore, the ergonomic assessment of the worker's posture during work may provide valuable information aimed at designing or redesigning workplaces and work tools, which can ultimately help to improve work performance, while at the same time meeting the safety level important for the musculoskeletal stress. Bearing in mind the above, the survey carried out in the area of Forest Office Bjelovar covered the assessment and comparison of the body posture for the operators of three different types of forest machines (chainsaw, forwarder, harvester), for which two ergonomic observation techniques were applied: Ovako Working Posture Analyzing System (OWAS) and Rapid Entire Body Assessment (REBA). An additional benefit of this work is the presentation of examples of good practice of the Western countries in relation to the implementation of measures to reduce overtime and workload with the application of modern technologies (e.g. harvesters, forwarders) in forestry.

MATERIALS AND METHODS

Research Area

Field research, i.e. the main experiment of the use of machine cutting and processing in thinning of deciduous forest stands, was carried out in compartments 14b and 14c of the Management Unit (MU) Bjelovar-Bilogora managed by Forest Office (FO) Bjelovar, Bjelovar branch of the company Hrvatske šume d.o.o. Zagreb (Figure 1). As part of the main experiment of measuring the productivity of harvester and forwarder operations, the video camera was used to record the postures of the harvester and forwarder operators and forest chainsaw operator (Figure 2). The aim was to evaluate and compare the working risk of forest machine operators based on the analysis of the working postures, and the type and level of their impact on the worker.

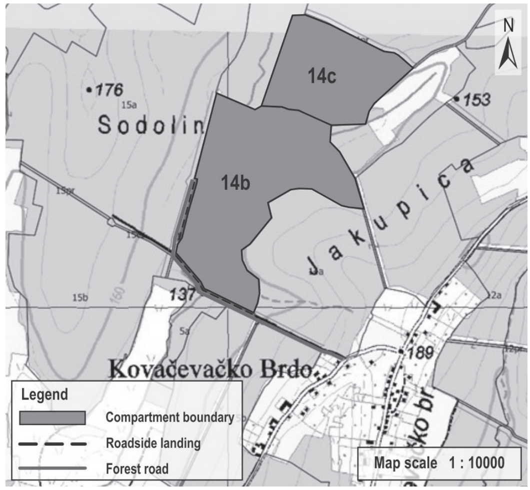

FIGURE 1. Test sites of the main research in MU Bjelovar-Bilogora.

Compartment 14b represents a mixed stand of European hornbeam (84%), common beech, pedunculate oak, black alder and sessile oak, with an area of 18.28 ha and 79 years old. The compartment belongs to the management class of European hornbeam seedlings. The growing stock is 5.330 m^3, i.e. 291.58 $m^3 \cdot ha^{-1}$, and the management plan prescribes thinning intensity of 11.67% in the first semi-period. During marking for motor-manual cutting and processing, a total of 1,455 trees were marked with the total volume of 741.81 m^3. Subsequently, by marking trees on "harvester lines" and by correcting the previous markings, the total number of trees marked for machine cutting was 1,782 with the total volume of 731.24 m^3. For compartment 14b average breast height diameter of felled trees is 21.7 cm.

Compartment 14c is a mixture of common beech (50%), European hornbeam (44%), sessile oak and pedunculate oak, with an area of 9.07 ha and 79 years old. The compartment belongs to the management class of common beech seedlings managed on a 100-year rotation. The growing stock is 3.681 m^3, or 405.84 $m^3 \cdot ha^{-1}$, and the management plan prescribes thinning intensity of 11.08% in the first semi-period. During marking for motor-manual cutting and processing, a total of 423 trees were marked with the total volume of 407.02 m^3. Subsequently, by marking trees on skid trails and by correcting the previous markings, the total number of trees marked for machine cutting was 559 with the total volume of 446.3 m^3. For compartment 14c average breast height diameter of felled trees is 26.4 cm.

Applied Machines and Workplace Organization

Mechanized harvesting system for cut-to-length logs, i.e.

FIGURE 2. Three types of forest machines used for the main experiment.

the parallel work of harvester and forwarder, was used in leaf forest thinning. Six-wheel (6WD) Timberjack 1470D harvester (Figure 2) was used for cut-to-length logging operations. The dimensions of the machine used are: 7700 mm long, 3050 mm high, 3000 mm width and weighs 18800 kg. Timberjack 1470D harvester uses a parallel hydraulic crane model TJ 200 H 97 with a built-in harvester head. The crane reaches 10 m and the angle of rotation is 220°. The machine does not have a rotating cabin, i.e. the harvester's cabin does not simultaneously move when changing direction of the crane to left or right.

For extracting logs an eight-wheel (8WD) Timberjack 1710D forwarder was used (Figure 2). The length of the machine used is 10,900 mm, while its width is 3050 mm. The height of the forwarder to the top of the crane is 3900 mm, and its weight depends on the degree of equipment and can range from 18,500 to 19,500 kg. The Timberjack 1710D forwarder is equipped with a Boom CF885 hydraulic crane, which has a grasper. Maximum reach of the crane is 8500 mm. The machine used does not have a rotating cabin, but it has a rotating seat with commands.

On the field site harvester trails, with appropriate spacing (20 m) and spatial distribution, were marked vertically to the existing main skid trails in compartments 14b and 14c. Larger diameter trees, which the harvester could not cut down, were felled and processed by a chainsaw operator.

Methods

The available literature describes a large number of developed and used ergonomic methods/observation techniques for assessing working body postures, with numerous methods intentionally developed for specific research objectives [11, 12]. Observation techniques include: OWAS [13], Task Recording and Analysis on Computer (TRAC) [14], Posture, Activity, Tools and Handling (PATH) [15], Rapid Upper Limb Assessment (RULA) [16], REBA [17], Loading on the Upper Body Assessment (LUBA) [18], etc. The main advantage of these methods is that they can easily adapt to the needs of a specific industry, depending on the scope of ergonomic assessment. As part of the research carried out in the area of FO Bjelovar, the assessment of the strain of the harvester and forwarder operators and loggers was carried out by assessing the operators' working posture using the ErgoFellow 3.0 software (Figure 3). Within the aforementioned software, two observation techniques (Figure 3) were applied: OWAS and REBA.

The OWAS was developed by a Finnish steel company (Figure 3). The OWAS method allows estimating the degree of static load of the workers at the workplace by analysing their posture, thus identifying four work postures for the back, three for the arms, seven for the legs, and three categories for the weight of load handled [19]. Each of these factors have an attributed code value. The technique classifies combinations of these four categories by the degree of their impact on the musculoskeletal system for all posture combinations. According to the OWAS method, the degrees of the assessed harmfulness of these posture–load combinations are grouped into four action categories which indicate the urgency for workplace intervention [4, 20]:

- Action category 1: normal and natural postures with no harmful effect on the musculoskeletal system – no action required;
- Action category 2: slightly harmful postures – corrective action required in the near future;
- Action category 3: distinctly harmful postures – corrective action should be taken as soon as possible;
- Action category 4: extremely harmful postures – corrective action for improvement is required immediately.

FIGURE 3. Software interface and two techniques for observing body postures.

The REBA is a postural analysis system sensitive to musculoskeletal risks in a variety of tasks, especially for the assessment of working postures found in health care and other service industries [17]. The basic idea of REBA is to assess positions of individual body segments which are observed. Postural scores increase when postures deviate from the neutral position. The posture classification system, which includes upper arms, lower arms, wrist, trunk, neck, and legs, is based on body part diagrams. Group A includes trunk, neck, and legs, while group B includes upper and lower arms and wrists. These groups are combined into one of 144 possible posture combinations that are transformed to a general postural code [21]. The method reflects the extent of external load/forces exerted, muscle activity caused by static, dynamic, rapid changing or unstable postures, and the coupling effect. These scores are summed up to give one score for each observation [21]. This technique provides five action levels for evaluating the level of corrective actions:

- Action level 0: corrective action including further assessment is not necessary;
- Action level 1: corrective action including further assessment may be necessary;
- Action level 2: corrective action including further assessment is necessary;
- Action level 3: corrective action including further assessment is necessary soon;
- Action level 4: corrective action including further assessment is necessary now.

OWAS classifies postural load for the urgency of corrective actions into four action categories, while REBA groups postural loads into five action levels, which have slightly different meaning from the action levels of OWAS. To enable a comparison of REBA and OWAS, the risk levels of REBA had to be reclassified into four levels with consideration of the meaning of action categories for both techniques [4]. The new four action levels of REBA are classified in Table 1.

Research Design and Data Analysis

Field measurements and data collection were carried out during the summer of 2017, when different wood harvesting technologies were applied within the same forest stand. Details of the field research, i.e. the work of harvester, forwarder and chainsaw operators, were recorded using a video camera. In the field work of the harvester operator, 9 h and 29 minutes of effective time recorded was related to machine cutting and processing, in the field work of the forwarder operator, 8 h and 29 minutes of effective time was related to timber extraction, while in the field work of the chainsaw operator, 45 minutes of effective time was related to motor-manual cutting and processing. Body postures were determined from video recordings in accordance with the snapshot method. When using a harvester for machine cutting and processing, the defined interval of observation is 6 minutes, which makes a total of 88 sampled working postures of the operator during effective work. When using a forwarder for timber extraction, the defined interval of observation is also 6 minutes, which makes a total of 79 sampled working postures of the operator during effective work. On the other hand, due to the shortness of video recording, in the case of motor-manual cutting and processing, the defined interval of observation is 0.5 minutes, which makes a total of 88 sampled working postures of loggers. All sampled postures were evaluated using the ErgoFellow 3.0 software through two observation techniques: OWAS and REBA methods, which ultimately results in two posture loads of the operator's body by each applied technology. Table 2 shows the planned and achieved number of sampled working postures for all three operators.

Processing of the sampled and assessed postures of operators of three different types of forest machines was made by the method of analysis and synthesis, and comparison. The method of analysis and synthesis was used in the process of work, where various sources were ultimately summarized in a single text. The method of comparison was applied in the practical part of the work when showing and comparing the risk category of body postures with respect to the machine used in the process of wood harvesting.

TABLE 1. Reclassified risk levels of REBA.

Regrouped action level	Original action level	Meaning
1	0	Normal posture
2	1 and 2	Low risk posture
3	3	Medium risk posture
4	4	High risk posture

TABLE 2. Structure of sampled working postures for all three operators.

Means of work	Working posture		
	Defined by calculation, N	Sampled from video recording, N	Efficiency, %
Chainsaw	88	88	100.00
Harvester	88	84	95.45
Forwarder	79	76	96.20

RESULTS

The analysis of the working postures of the operators of three machines against the action category (Figures 4 and 5) showed that the work of the chainsaw operator was more demanding and much more risky than the work of the harvester and forwarder operators. According to the OWAS method (Figure 4), 40.91% of the sampled body postures were classified in the normal posture category, 37.50% were classified in the category of low risk posture, 20.45% in the category of medium risk posture, and 1.14% in the high risk category. On the other hand, 82.14% of the sampled postures of the harvester operator (Figure 4, N=84) were classified into the category of normal posture and 17.86% in the category of low risk posture during work. According to the OWAS method (Figures 4, N=76), 97.37% of the sampled body postures of the forwarder operator were classified in the category of normal posture and 2.63% in the category of low risk posture during effective work. The rating of the action category of the posture according to the REBA method (Figure 5) for the chainsaw operator was as follows: 60.23% of the sampled postures were classified in the category of low risk posture, 21.59% in the category of medium risk posture and 18.18% in the category of high risk posture. For the harvester operator (Figure 5), 98.81% of the sampled postures were classified in the category of low risk posture and 1.19% in medium risk category, while for the forwarder operator all sampled postures (100%) were classified in the category of low risk posture. The comparison of the two risk categorization methods, from the point of view of the working posture, shows that the REBA method gives sharper results in relation to the OWAS method for all three sampled machines (Figures 4 and 5).

A more detailed comparison of the sampled operator postures, according to the OWAS and REBA methods, for all three machines was performed according to groups of work operations. In the analysis of the posture of the chainsaw operator (Figures 6 and 7), there were three groups of work operations: felling elements (N=29; they included clearing of the working site, root collar clearing, making the undercut and back cut), processing elements (N=38; they included delimbing, cross-cutting, bucking and sorting, etc.) and other activities (N=21; they included determining and checking the felling direction, retreating from the tree/trunk and choking activities). According to the OWAS method (Figure 6), the results of the analysis show that the highest share of medium risk posture (19.32%) and high risk posture (1.14%) are present in the felling elements. According to the OWAS method (Figure 6), the largest share of the medium risk posture (26.14%) is present in the processing elements, and the largest share of normal working posture is present in other activities. On the other hand, the more severe categorization of the working posture risk according to the REBA method (Figure 7) shows a higher share of high-risk posture (17.05%) in the felling elements and a slightly lower share of medium-risk posture (11.36%). With the processing elements, the category of low risk posture accounts for 31.82%, while the category of the medium risk posture accounts for 10.23% (Figure 7). In other activities (Figure 7), all sampled postures are classified in the category of low risk posture.

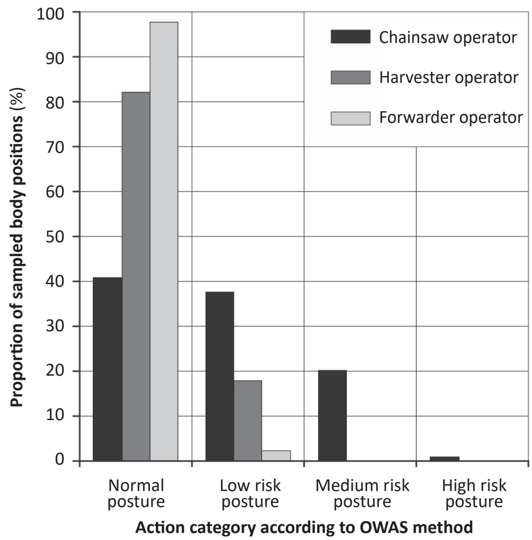

FIGURE 4. The share of sampled operator postures according to OWAS method.

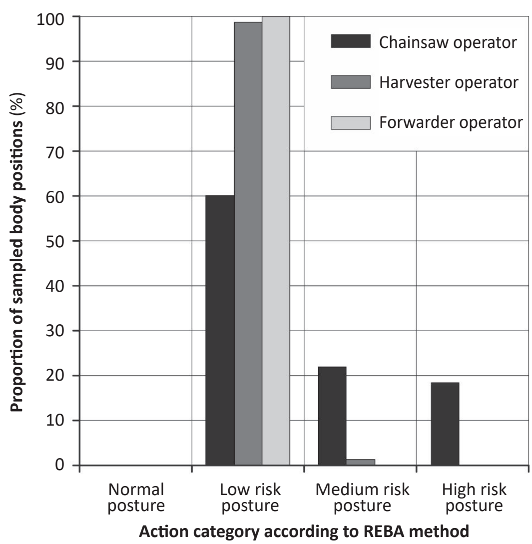

FIGURE 5. The share of sampled operator postures according to REBA method.

A more detailed analysis of the harvester operator posture (Figures 8 and 9) was performed within three groups of work operations: operations related to harvesting head (N=56), forward and reveres drive (N=23) and other activities (N=5; they included cooler cleaning, discussion of work issues with colleagues via cell phone, etc.). The results of the analysis according to the OWAS method (Figure 8) show that the largest share of low risk posture (10.71%) is present in forward and reverse drive because

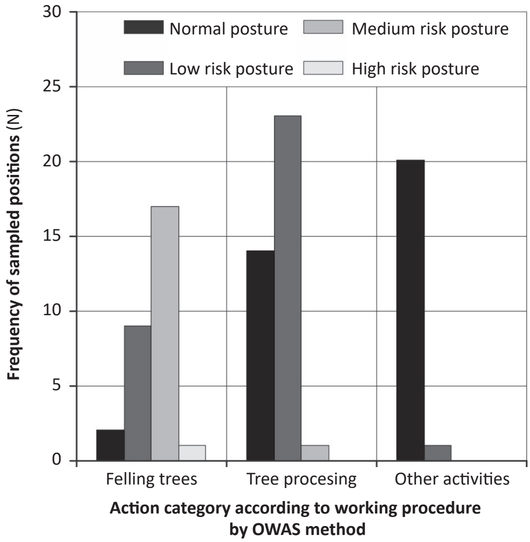

FIGURE 6. The number of sampled postures of chainsaw operator according to OWAS method.

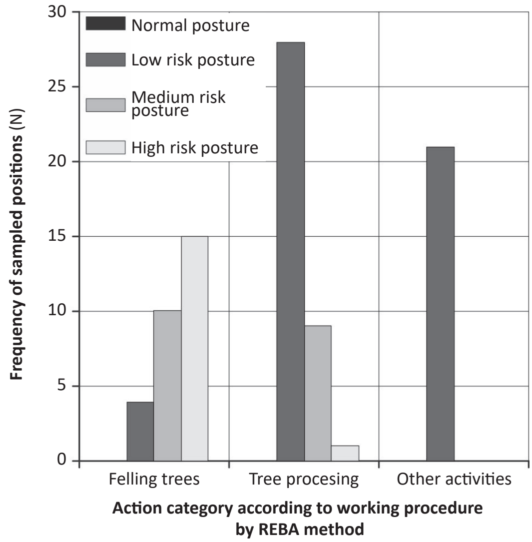

FIGURE 7. The number of sampled postures of chainsaw operator according to REBA method.

the operator's seat cannot rotate 360°, i.e. during reverse drive, the operator's working posture is physiologically quite unfavorable. When working with the harvester head (Figure 8), the normal working posture accounts for 63.10% and medium risk posture for 3.57%. In other activities (Figure 8), low risk posture accounts for 3.57% because this category includes the cleaning of the cooler from leaves, etc. The categorization of body posture risk according to the REBA method (Figure 9) showed sharper results in all three groups of work operations. The category of medium risk posture of the operator working with the harvester head accounts for 66.67% (Figure 9), and when driving, it accounts for 27.38%. The category of medium-risk posture of the harvester operator with the share of 1.19% is included in other activities.

The analysis of the forwarder operator postures (Figures 10 and 11) was carried out within three groups of work operations: work with crane (N=39), driving and/or moving backwards and forwards (N=36), and other activities (N=1; stopping at roadside landing for truck loading). The results of the analysis according to the OWAS method (Figure 10) show

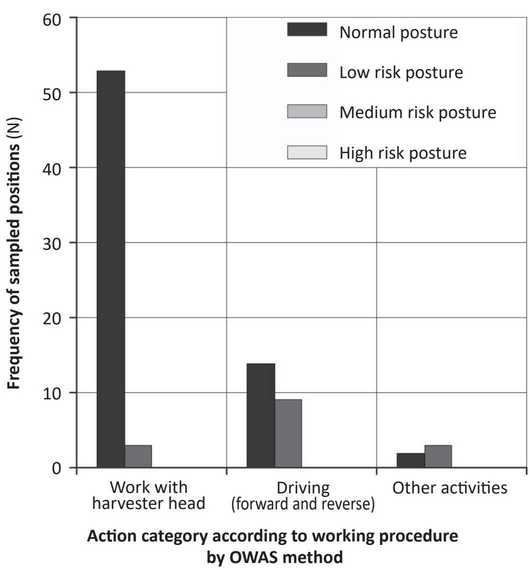

FIGURE 8. The number of sampled postures of the harvester operator according to OWAS method.

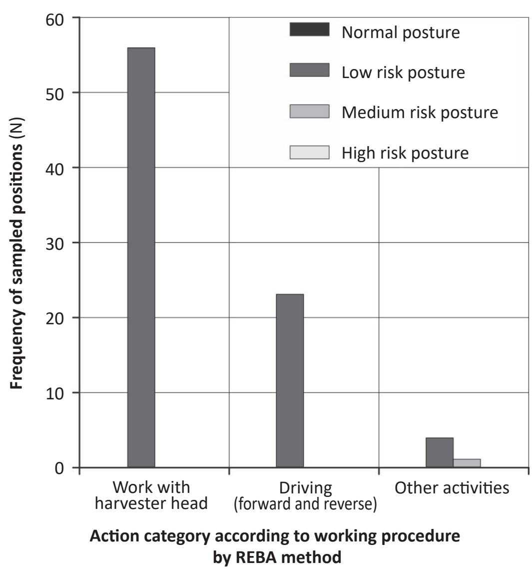

FIGURE 9. The number of sampled postures of the harvester operator according to REBA method.

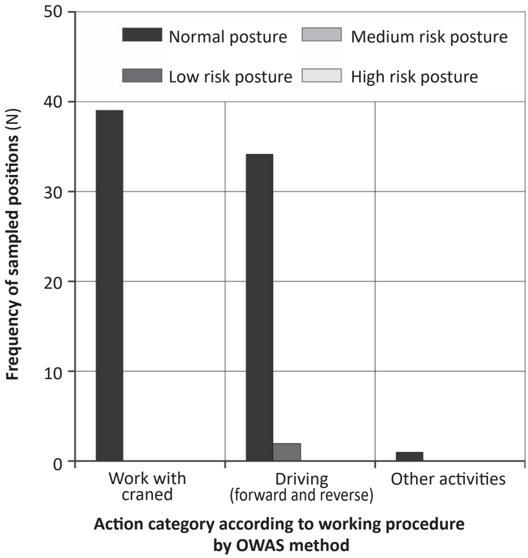

FIGURE 10. The number of sampled postures of the forwarder operator according to OWAS method.

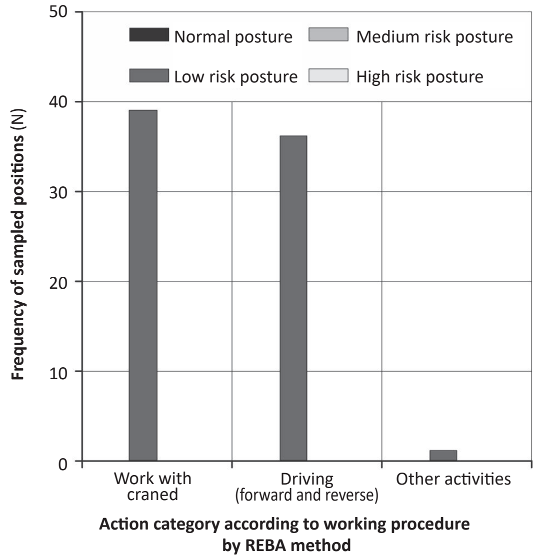

FIGURE 11. The number of sampled postures of the forwarder operator according to REBA method.

that the only portion of the low risk posture (2.63%) is present when driving or moving backwards and forwards because with the combination of loading and moving, the operator does not turn the seat, which is possible. When working with the crane (Figure 10), the normal posture accounts for 51.32% and when driving or moving backwards and forwards for 44.74%. Categorization of the forwarder operator's risk posture according to the REBA method (Figure 11) showed a low risk posture within all three groups of work operations.

DISCUSSION

The categorization of work risk depending on body posture, according to the OWAS and REBA method, was performed on the example of motor-manual work (chainsaw logger), and on the example of machine cutting, processing and extracting (harvester-forwarder) of wood assortments in timber harvesting. During the field survey, and the assessment and comparison of the posture, only the effective working time of the forest machine operator was analyzed. The results of the research showed that, regardless of the group of work operations and work equipment, the OWAS method underestimated the work risk associated with the operator's posture compared to the REBA method. Considering summarily the work equipment, the OWAS method rated the majority of chainsaw operator postures as low postural load in action category 1 and 2 (78.41%), while the REBA method rated 39.77% of the postures as action category 3 and 4 (Figure 4 and 5). In machine cutting and processing (using a harvester) and extracting (using a forwarder), the OWAS method rated the operator's posture of both machines as 100% low postural load in action category 1 and 2 (Figure 4). With the REBA method, only 1.19% of the operator's posture was rated as action category 3 (Figure 5). Considering the assessment and comparison of postural loads regarding the group of work operations, the results showed that the elements of tree felling were significantly more risky than the elements of wood assortment processing according to both assessment methods (Figures 6 and 7). Data analysis showed that, during tree felling, the logger's body was mostly bent and crooked, and his legs were unstable, i.e. the weight of the body relied on one leg or on a bent knee. Consequently, the work risk in tree felling is considered high. The categorization of the risk of the harvester and forwarder operators' working posture, according to the REBA method (Figures 9 and 11), showed slightly sharper results in all three groups of work operations compared to the OWAS method (Figures 8 and 10).

A visible difference in the assessment of occupational risk based on the postural load of forest machine operators, especially those working with the chainsaw, can be explained by higher sensitivity of the REBA method in detecting the working risk, as it has several more rating degrees for the assessment of the position of individual body parts than the OWAS method. The second reason is related to an extended work risk assessment using the REBA method in terms of activity type, work dynamics, etc. The third reason is related to the technological structure of the working time considered (effective working time), which also limits the research. This limitation is particularly important for machine cutting and processing as well as extracting, where the greatest part of postural load is within the additional time, which includes maintenance and repair activities during field work, such as hydraulic hose replacement, chain repair on the harvester bar, etc. Both observation techniques have been developed for a different purpose and need to cover different types of risks. When selecting the most appropriate techniques/methods in specific working conditions, the researcher should clearly define the needs and the impact of the information obtained on the decision-making process [21]. Along with choosing the most appropriate method, the sampling strategy is very important if the results are generalized outside the observed sample.

The new ergonomic paradigm "more can be better" in machine cutting, processing and extracting can have an adverse effect on the health of forest machine operators. An example of such effect comes from Swedish forestry, where many research results and organizational measures have been implemented in practice with the aim of reducing work safety problems for forest machine operators. Research shows that the average weekly working time in hours of the forest machine operator is 61 hours [22], and the 8-hour daily work load of an operator working in a harvester and/or forwarder for the whole time is considered too high and causes excessive strain and stress [23]. The Swedish Authority for Occupational Health and Safety, as an example of a corrective mechanism, has introduced a legal measure where forest machine operators must spend daily at least two hours engaged in some other activities that do not include mechanized work [24]. Another example is related to designing a worker list within a work shift, which includes exchanging jobs and enriching the work with additional tasks. This example of good work practice uses the method of workload points (WLP) for the identification of workload and for the substitution of work activities [24] if more points than allowed are accumulated during the working day, which means excessive fatigue for the machine operator.

CONCLUSIONS

The most acceptable way of increasing the aspect of health and safety for forest machine operators in the Croatian forestry is the application and implementation of the achievements of the international best practice. Considering all the above, most important conclusions are:

- regardless of the work task and work equipment in forestry, the OWAS method underestimated the work risk associated with the operator's posture compared to the REBA method;
- from the aspect of working posture, motor-manual working risk in tree felling is considerably higher than mechanized work with a forwarder or harvester;
- at motor-manual work the elements of tree felling are significantly riskier than the elements of wood assortment processing according to both assessment methods;
- at mechanized work the REBA method showed slightly sharper results in all three groups of work operations compared to the OWAS method;
- mechanized work, carried out in particular by private contractors in Croatian forestry, should be subject to legal measures, i.e. organizational measures in accordance with the Swedish example of good practice.

In conclusion, a small share of the research of work risk of forest machine operators with respect to postural load in Croatian forestry, especially in the field of machine work, implies the need to conduct systematic research of the above-mentioned issues that should comprehensively cover the technological structure of working time.

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Forest Estates/Organisational Units Ranking Model - The MRG Model

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ABSTRACT

Background and Purpose: The fact that new organizational concepts require comparison and ranking of some business entities, implies the analogy that, in forestry, ranking should create the basis for differentiation of Forest Estates (FE) (seen as profit centers) according to their capability to allocate funds from rent for the utilization of forests and forest land. In this sense, it was necessary to determine the basic criteria and variables, and then to create the model for FE ranking on the basis of ecological and production potentials, and business results (economic indicators). The main idea was to create a model that can be used primarily by forest owners (which are, in certain countries such as Bosnia and Herzegovina, Croatia, Serbia, and Montenegro, mainly governments) and by public forest enterprises. The proposed models may serve to all other scientific, professional, research and other institutions, as the starting point for further research and as suggestions for possible improvements of the proposed solutions.

Materials and Methods: The research was carried out within the project "Differential rent in the Republic of Srpska forestry". Total sample for the survey was 44 interviewed parties, with 118 questionnaires filled in. The methods of classification, content analysis, desk research, analysis, synthesis and comparison were used. In the concrete application of the Forest Estates/Organisational Units Ranking Model (hereinafter MRG Model; Model rangiranja šumskih gazdinstava, in Bosnian), the following methods were used: brainstorming, focus groups, survey, desk research method, Pareto analysis, modelling and induction. The statistical methods used were descriptive statistics and rank correlation. By using these methods and by combining them, a new model for forest estates ranking was created. Different input data and variables that refer to economic and natural indicators were used for ranking, all in accordance with the values for areas for which the ranking was carried out.

Results: The main results are used for defining and proposal of the new model for forests estates ranking, i.e. the MRG Model. This model includes the following steps: (1) Survey, (2) Selection and scoring of specific variables, (3) Determining the intervals for specific variables, (4) Ranking of forest estates, and (5) Validation and rank correlation. This paper presented the algorithm of implementation of specific steps within the MRG Model, together with all activities that need to be implemented in order to perform forest estates ranking. It is necessary to emphasize that forest estates ranking was performed in accordance with the following three ranks: (1) for all analyzed variables, (2) for economic variables, and (3) for natural variables. Additionally, three modules for the calculation of scores for individual forest estates are the result of this research.

Conclusions: The MRG Model is based on FE ranking according to deviation from the average value of the selected variables. The quality of the model lies in the fact that it is relatively simple (there are no complex statistical or other methods, necessary data can be collected easily), and that it can be applied again for similar surveys. Implementation of the MRG Model involves 5 basic steps with 7 phases to be performed in the order specified in this paper. The selection of variables which will be part of the MRG Model is crucial. The survey sample must include representatives that are directly or indirectly involved in the forestry sector. Although it might seem that all selected variables are significant, it is always necessary to give each variable the importance in accordance with the survey results. It is necessary to validate the defined model, data and final ranks on a pilot sample. Since there are three ranks, it is necessary to consider their mutual correlation, by performing statistical analysis rank correlation.

Keywords: MRG Model, ranking of forest estates, differential rent in forestry

INTRODUCTION

Research results presented in this paper resulted from the project "Differential rent in the Republic of Srpska forestry". The main objective of this project was to, through the analysis of various variables, define the methodology for forest estates ranking (including 26 forest estates) within the Public Forest Enterprise (hereinafter, PFE) Forests f the Republic of Srpska, according to their real capabilities to allocate differential rent funds. In that sense, it was necessary to determine the basic criteria and variables for forest estates ranking, on the basis of natural and production potentials and business results (economic indicators).

The initial idea for this research is related to the allegations stated in paragraph 6 of the Republic of Srpska Government's Proposal [1] of the measures for redefining the organizational, economic and personnel positions within PFE Forests of The Republic of Srpska, where it was pointed out that "the rent as well as the classification of forest estates were not determined, which prevents realistic planning". This was precisely the reason for project activities, and one of its results is the defining of the Forest Estates/Organisational Units Ranking Model (hereinafter MRG Model; Model rangiranja šumskih gazdinstava, in Bosnian) described in this paper. The fact that new organizational concepts require comparison and ranking of some business entities [2], implies the analogy that, in forestry, ranking should create the basis for differentiation of Forest Estates (FE) (seen as profit centers) according to their capability to allocate funds from rent for the utilization of forests and forest land. A review of the previous research [1, 3-19] identified the basic problem, which was the lack of clearly defined methodology which would be, in accordance with certain ecological and business conditions, applied in forestry enterprises in order to rank forest estates, thus creating the basis for their differentiation for allocating funds for forest rent. In this sense, the subject of the research was focused on defining a simpler, scientifically based model, which would be, in more or less altered form, applicable for the periodical ranking of forest estates. The purpose of all the above mentioned requirements is to establish a more operative, more flexible and more profitable system, as well as to create a realistic basis for allocating funds from rent for utilization of forests and forest land. The main idea was to create a model that can be used primarily by forest owners (which are, in certain countries such as Bosnia and Herzegovina, Croatia, Serbia, and Montenegro, mainly governments) and by public forest enterprises [20]. Through research, it was concluded that the issues related to the ranking of enterprises are more present in economic literature sources than in those dealing with the forestry sector. For example, in the publication published by the Institute of Professional Financial Managers [21], there is a statement that the economic potential of an enterprise is used for comparison of the scope of enterprise operations with other enterprises, and for ranking the enterprise at local and international levels. In the same publication, it is also stated that the "comparison of the enterprise ratios with the own indicators only allows identification of the area of development of the enterprise itself and does not provide any information about the ranking of the enterprise within the industry, and does not compare it with its competitor". The logic of these facts was also applied when creating the MRG Model.

Babić and Plazibat [22] pointed out the need for ranking enterprises by using multiple criteria, stating that "since multi-criteria analysis provides enterprise ranking in terms of various criteria simultaneously, it is one of the most suitable tools for total approach to the problem of business efficiency analysis". The authors emphasize the need to use the relative efficiency approach, stating that "the value of relative efficiency will provide one with the information about the 'better' enterprise and will have greater importance than just the information about partial efficiency achieved by an observed enterprise".

Even Ivanić [23], as an economist, emphasized the issues of the instruments for renting annuity, stating that "the state must force enterprises to pay rent in order to limit the cuts and make it more expensive, as well as to provide money that would stimulate afforestation and protection of forests". His statement that "some plots in the forestry sector differ, which is a consequence of natural circumstances or social investments" indirectly suggests the need for the ranking of enterprises to which these plots are allocated, in order to create an assumption for more or less allocation of rent annuities, depending on business conditions.

When considering research conducted by forestry economists, research by Šporčić *et al.* is usually pointed out. Their long-term research [14-18], which was conducted in 2007, 2008, 2009 and 2014, is in its essence very similar to the research conducted for the needs of this paper, and was thus one of the basic prerequisites for the MRG Model development. This research assesses the efficiency of basic organizational units in the Croatian forestry, i.e. forest offices, by applying Data Envelopment Analysis (DEA). The authors state that in forestry, due to numerous forest management objectives, it is very difficult to apply classical economic methods for estimating the efficiency of forest enterprises, which was the reason they had decided to use the DEA. This methodology represents a methodology suitable for the efficiency and productivity analysis of numerous production units, but is not traditionally used in forestry [18]. This method was used for the comparison of organizations [24], regions and countries [25], as well as in various other fields, such as agriculture [26]. One of the foreign authors who used this method for the comparison of enterprises in forestry and paper sectors is Lee [11]. DEA is based on linear programming [27], which may have a potentially complex application, and the selection of variables may be subjective, with subsequent ranking of business units according to individual variables, not according to all business conditions. The MRG Model is aimed at overcoming these issues, with a strict focus on the forestry sector.

Economic performance analysis of forest enterprises, aimed at their ranking according to the achieved profitability indicator, was conducted in 2017 by Hajduchova *et al.* [6]. The authors stated that performance may serve as a tool for the competitiveness assessment and, in a broader context, for the assessment of its vitality and further development. The research sample consisted of all forest enterprises and thus aggregated data of revenues, costs and profit of all forest enterprises in Slovakia as provided by the Green Reports on Forestry from 2011 to 2015. Creating an operational tool for measuring the performance of forest estates was also one of the basic ideas applied when defining the MRG Model. Further on, the research was based on classical economic indicators which may not be comprehensive since multi-criteria approach must certainly be applied, with respect to both economic and natural criteria.

Balážová and Luptáková [3] aimed at pointing to the possibilities of using the Economic Value Added index in evaluating forest enterprises' performance. When calculating the index, they took only the financial statements of a selected forest enterprise for their starting point, and there was no multi-criteria analysis which includes both economic and natural variables.

Certain authors, such as Wolfslehner *et al.* [19], have used Analytic Hierarchy Process (AHP) method in the forestry sector, which is actually based on ratio scales for the analysis of multiple-criteria decision-making problems [28]. As Wolfslehner stated, Mendoza and Sprouse [29] were the first to apply AHP in forest-management planning, and more recent applications of AHP in multiobjective forest management and land-use planning included Kangas and Kuusipalo [30], Mendoza *et al.* [31], Vacik and Lexer [32], Vacik *et al.* [33], Schmoldt *et al.* [34], and Ananda and Herath [35]. The application of AHP Method can be considered as one of the methods for forest estates ranking, but no papers dealing with that issue have been found.

Pears [36], in addition to other issues, addressed economic issues of tenure systems. He stated that "many forms of using fructuary rights for forests not only provide their holders with rights to use resources, but also assign them management responsibilities". This claim indirectly points to the need for ranking of certain forest users or owners aimed at various obligations in managing this good. The author further states that: "(…) it is important to distinguish the issue of who is responsible for resources management from the question of who will pay for it. This is because licensees who assume such contractual responsibilities are often reimbursed, directly or indirectly, for the cost. The ultimate impact of resource rents thus depends on these financing arrangements as well as more direct fiscal measures".

Oesten and Roeder [37] addressed the issues of classification of enterprises according to economically relevant criteria, for the purpose of comparing the enterprises. It is stated that if the business results (balance and/or calculated profit, net turnover, etc.) differ in spite of the same preconditions for success, the reasons must be sought in differences in operational management, i.e. in creating the factors relevant to the success on which enterprise management can have a short-term influence as well. The authors indicated different variables, favoring one type of variables (the economic one). This research had similar logic and approach to the problem. Speidel [38] suggested variables for the classification of enterprises, which he considers relevant for success and on which enterprise management cannot have a short-term influence, such as: legal form, the size of the enterprise, natural location, the distribution of plant types, the structure of age groups (height and structure of the stock). These variables were considered to a greater or lesser extent when selecting the MRG Model.

For a quality analysis of the presented problems, especially in the Western Balkans region, the research of regional forest economists has to be included. The issues of forest rent and creating equal conditions for the operating of organizational units/estates within forest enterprises, have been addressed by several regional authors which are retrospectively listed as follows.

Potočić [12] suggested that it is necessary that all work collectives are in the same position, with equal or approximately equal prospects for success. Therefore, he defines the problem of determining business results arising from the real merits of a work collective, i.e. from the separation of results which are the consequence of more favorable natural conditions.

Kraljić [13] also referred to the variables on which the forest rent depends, stating that the rent should definitely be separated into two parts, the one which depends on natural conditions and which would, if not necessary for the forestry sector, be allocated to a society (municipality, government), and the other one intended for the development of forestry. The same author [7] had previously addressed the issues of determining organizational units as such and of the distribution of income within an enterprise or at the level of certain units, as well as with the technique of separation of the part of funds, depreciation of forests from a specific organizational unit to the benefit of the entire enterprise and vice versa. The paper focuses on the organization of individual organizational units, and the distribution of financial resources between them. As a continuation, the author refers to stimulating the distribution of income (or profit) between specific organizational units within the enterprise, as well as to financial norms of biological reproduction of forests, analyzed in several papers [9, 39-43]. Methods and criteria for the distribution of income and profit, i.e. the sources of funding for equal development of all organizational units, are as follows. In its modified form, the assumption that an equal or at least continuous development of forest areas (managed by certain forest estates) cannot be provided, can be considered as one of the basic purposes of using the results obtained through the MRG Model.

In his further studies, Kraljić [10] referred to the issue of forest rent, i.e. the separation of a part of income which depends on extremely favorable conditions for some forest estates, dividing them into natural, market and other conditions. This classification was used as a guideline for the division of variables when defining the MRG Model.

Golubović [5] raised the question of how to bring work units into an equal starting position in a variety of economic conditions. The paper identifies the differences between the conditions of certain organizational units, which are the result of different average fertilities (classes) of habitats and different average distance from the consumers (market). The variables were given and the amounts of differential rent for specific organizational units were determined.

Ranković [13] addressed the economic function of forest rent and the methods of its calculation. The author points out the problem of active and passive areas, i.e. those areas where a higher amount may be allocated for forest rent, but where there is no need for investing in cultivation and protection, and on the other hand, the areas that do not provide such high amounts for the rent, but where there is a great need for silvicutrure and protection activities. The method of separation, i.e. the ranking of active and passive areas is not defined, which indicates the need to define the methodology presented in this paper.

Delić [44] and Delić *et al.* [45], in addition to the issues of differential rent as extraordinary profit which might be generated, put a special emphasis on rent in forestry, where the graphic presentation well represents the role of the rent within the structure of the market price of forestry products.

Sabadi [46] is one of the regional authors who referred to the rent issues within the economic aspect of the rent calculation, with no detailed analysis of the forestry rent issues and forest estates ranking in accordance with the possibilities of allocating funds for rent.

The research results can primarily be used by forest owners (which are, in certain countries, mainly governments) and public forest enterprises. The proposed models may serve to all other scientific, professional, research and other organizations/institutions, as the starting point for further research and as suggestions for possible improvements of the proposed solutions.

MATERIALS AND METHODS

Study Area

The survey which defined the MRG Model was carried out within the project "Differential rent in the Republic of Srpska forestry". The project was financed by the Republic of Srpska Government, Agreement no. 113-4/16 as of 04 February 2016. The research was conducted in the period between April and October 2017. The subject of the survey was PFE Forests of The Republic of Srpska, i.e. 26 forest estates operating within the PFE, which utilizes public forests and forest lands in the Republic of Srpska, Bosnia and Herzegovina.

Field research included a 40-day survey, during June and July 2017. The total sample for the survey was 44 parties, with 118 questionnaires filled in. In addition, the official data issued by the Department of Forestry within the Ministry of Agriculture, Forestry and Water Management, as well as the data contained in the Cadastre of forests and forest land in the Republic of Srpska, production and financial statements of PFE Forests of The Republic of Srpska, and current forest management plans were used. The analyzed data refer to the five-year period, from 2012 to 2016.

Research Methods

Research methods can be classified into those used during the research for drafting this paper and those used as a part of the MRG Model.

The following research methods were used during the research for drafting this paper [47]: classification, the method of content analysis, desk method, method of analysis, method of synthesis and method of comparison.

Classification, which is used when defining the problem and determining the cause and effect of the problem. This method was primarily used for classification of variables, sources of relevant data and forest estates. The definition of theoretical framework was carried out based on the application of the method of content analysis, within which the identification and analysis of regional and foreign bibliography based on the issues of forest rent and forest estates ranking were carried out as well. Desk method was conducted in order to collect the existing data, that refer to a wide range of identified problems related to the differential rent and conditions for the operating of forest estates. Method of analysis was used for a clear disaggregation of the research subject into components, i.e. factors of structure, function, connections and relationships of the model for forest estates ranking according to more favourable or less favourable business conditions. Method of synthesis was used after description and disaggregation, for interpretation of the obtained data. After the classification and finding the influence factors, the data were linked. On the basis of interpretation and linking, the data were combined into meaningful units, which could be further used within the entire research. Method of comparison was used to determine the identity, similarities and differences between values of the selected variables for different time periods.

The following methods were used as part of the MRG Model: brainstorming, focus groups, survey and Pareto analyses. The statistical methods used were descriptive statistics and rank correlation. Brainstorming technique was used to determine variables that should be taken into consideration when creating the Model. Due to biological, technical and economic specificities in the forestry sector, the identification of all (or the largest number of) variables that may have direct or indirect impact on a particular problem was crucial. The project team identified a total of 106 possible variables. Focus groups were used to collect and isolate certain variables defined through brainstorming and to enable effectiveness during the survey. A total of 106 defined variables were collected and isolated for the survey, thus determining a total of 50 variables that had formed the basis for this research. Through the survey, the validity of variables to be included in the final model was provided.

Following the defined principles for the sample selection, the survey was used as a basis for scoring and ranking of the selected variables. For this concrete research, the survey lasted 40 days, during June and July 2017. The total survey sample included 44 interviewed parties, with 118 questionnaires filled in. Desk method was used for the collection of historical and current data for specific variables specified for the analysis within the MRG Model.

According to the Pareto principle [48], it is claimed that roughly 80% of the effects come from 20% of the causes, which means that this principle indicates that, in each population, certain phenomena are significantly more important than the others. This method was used after the survey for the selection of corresponding variables to be included in the final model.

Modelling was used to define the final models for forest estates ranking according to business conditions. Models were defined for three groups of variables: all of the selected ones, natural and economic.

Statistical method applied includes simple descriptive statistics. The option of using regression analysis to define certain statistical methods was considered. However, it was concluded that, due to a large number of variables that are the subject of analysis and that do not have to be necessarily the same in every subsequent research, the application of regression and probably any other more complex multivariate statistical analysis (such as factor analysis) is difficult to apply. It was important to establish a scientifically based and representative model for forest estates ranking, which would at the same time be practical, applicable, reproducible and simple for use, as well as easily used by different stakeholders – from academic community representatives to representatives of forest enterprises. Rank correlation is applied within the MRG Model, which is more thoroughly presented in the chapter referring to research results.

RESULTS

As the result of the project "Differential rent in the Republic of Srpska forestry, 26 forest estates within PFE Forests of The Republic of Srpska", were ranked in accordance with ecological/natural and production potentials and their business results (economic indicators). As previously stated, the MRG Model was used for the ranking, and its basic characteristics are given below.

Five basic steps of the MRG Model (also known under its full name The ranking of forest estates according to deviation from the avearge value of the selected variables) are classified into seven basic phases, as follows: (1) Selection of variables, (2) Survey designing and determination of the survey sample, (3) Survey with the processing, analysis of the collected data, and evaluation of certain variables, (4) Determination of the intervals for certain variables, (5) Validation of the defined model, (6) Ranking of forest estates, and (7) Rank correlation.

It is necessary to form an expert team that will conduct all the activities. It is suggested that the team consists of a minimum of 6 members, preferably involving the representatives of various stakeholders (scientific-research institutions, higher education institutions, public forest enterprises, relevant ministries, representatives of the local community, and non-governmental sector).

Selection of Variables

In the initial phase, it is necessary to identify as many variables that may have direct or indirect impact on the forest estates operation as possible. For the successful implementation of the first research phase, the methods of brainstorming and focus groups are combined. Expert team members, primarily in brainstorming sessions, propose as many variables as possible, which would (in their opinion) have an impact on more favourable or less favourable business conditions for certain forest estates. After the compilation of all suggestions, focus group meetings are organized (expert team members and the representatives of other stakeholders – the number of up to 12 participants is recommended), where all submitted proposals are compiled and the most important variables to be included into the survey questionnaire are selected. For easier reference, it is necessary to sort all variables into three categories, as follows:

1. Economic - which basically includes the following fields: economics, politics, organization, utilization, communication, safety at work, etc. Within this research economic variables which were selected are as follows: cost-effectiveness, volume of realized wood assortments (conifers and broadleaves), productivity (natural and value method), openness of forests.
2. Ecological - which basically includes the following fields: dendrology, pedology, climatology, phytocenology, etc. Within this research none of the offered ecological variables were selected within the top ten.
3. Planning - forest management - which basically includes the following fields: increment, forest management, silviculture, seed growing, etc. Within this research economic variables which were selected are as follows: total and average wood stock, total wood stock of conifers and broadleaves, planned annual cut of conifers and broadleaves, total and average volume increment, site class, and the surface and structure of forest areas according to forest categories.

All variables are considered individually and in the final selection of variables there does not have to be an equal number of variables from the listed categories (economic, ecological and forest management). It is necessary to randomly group the variables in the survey questionnaire, without grouping them into the above mentioned groups.

The importance of each variable may be evaluated by grades 0 to 5 (0 – with no impact; 1 – very small impact; 2 - small impact; 3 – medium impact; 4 – large impact; 5 – very large impact), and there should be a 'with no opinion' option (I do not have an opinion/sufficient information) for those variables for which the participants are not sure or competent for or have no sufficient information. When analyzing the data, the answers 'with no opinion' should not be included in the calculation of the average grade.

Survey Designing and Determination of the Survey Sample

After preparation of the final version of the survey questionnaire, the sample for the survey is determined. In order to define a quality model, it is necessary to include as many stakeholders as possible (recommended minimum is 50 respondents/filled questionnaires), primarily in the field of forestry, as well as in the fields that are directly or indirectly related to forestry. The survey refers to individuals, and does not reflect official attitudes of certain organizations or institutions. In this regard, the following criteria for the group of respondents were set:

- The questionnaire has to be filled in only by a person with BSc in Forestry (or those with higher level of education);
- The questionnaire may be filled in by experts in other fields as well (with a high level of education), who are directly or indirectly involved in forestry activities (for example, economic experts who are in charge of commercial activities in forest enterprises);
- In each forest estate and other organizational units (such as Directorate) within Public Forest Enterprise, at least one respondent must fill in the questionnaire, preferably the most experienced one;
- The survey should be conducted in as many higher education and scientific-research institutions, organizations and institutions in the field of forestry or related activities as possible.

The total survey sample was 44 interviewed parties, with 118 questionnaires filled in.

Survey, Processing, Analysis of the Collected Data, and Evaluation of Certain Variables

After collecting and processing the data obtained from the questionnaires, all variables had to be ranked in accordance with the number of points won, i.e. based on the average importance of a certain variable as evaluated by the participants in the survey. Based on all analyzed questionnaires, the average grade for each variable was determined.

For creating a practical and applicable model, it is not possible to consider all variables included in the questionnaire. Therefore, in accordance with the Pareto principle (80/20) [48], it is necessary to select 20% of the most important variables, i.e. those which after the conducted survey, data processing and analyzing, have the highest number of points.

The average value was determined (simple arithmetic mean) for all variables included in the model (20% of the selected variables from the questionnaire), after which a percentage deviation of the average grade of each variable from the average value of all variables was determined. Deviation (if any) can, naturally, be positive or negative. For this specific research, it is presented in Table 1.

Although in some cases (as noted above) average grades for certain variables do not differ much (3.70% maximum), it is always necessary to give each variable the importance in accordance with the survey results. This is achieved by defining the adjusted scale of points for each individual variable, as described below.

Scale from 0 to 5 is determined for the initial scoring of all variables, and the number of points for certain variables is determined according to the percentage deviation of the average grade of certain variables from the average grade of all selected variables. This implies that the initial scale from 0 to 5 is multiplied by the percentage deviation of the average value of certain variables from the average grade of all variables (4.21 in this case). For example, in the first variable presented in Table 2, deviation of the average grade of certain variables from the average grade of all variables is 3.70%. This further means that the scale of points for this variable is as shown in Table 2.

The scoring of specific variables is in accordance with Equation 1.

$$B_v = P_s + \% \text{ of deviation from the average grade} \quad (1)$$

where B_v is points for a single variable, and P_s is the initial scale defined (0 to 5).

Determining the Intervals for Certain Variables

In accordance with the specifics of each research area, it is necessary to determine the interval of the value for each variable, which was evaluated by the defined number of points in the previous step. This implies that for certain points (as in the previous example, 0 to 5.185), it is necessary to determine the interval (i.e. intervals) for the observed variable. An example of variables and average wood stock is given in Table 3.

TABLE 1. Selected variables for creating the model, ranked according to the average grades.

No.	Variable	Average grade	Deviation from the average value of all selected variables (%)
1.	Total and average wood stock	4.37	+3.70
2.	Total wood stock of conifers and broadleaves	4.27	+1.33
3.	Cost-effectiveness	4.26	+1.09
4.	The volume of realized wood assortments (conifers and broadleaves)	4.25	+0.85
5.	The planned annual cut of conifers and broadleaves	4.23	+0.38
6.	Total and average volume increment	4.21	-0.09
7.	Site class	4.17	-1.04
8.	Openness of forests	4.15	-1.52
9.	Productivity (natural and value method)	4.13	-1.99
10.	Surface and structure of forest areas according to forest categories	4.10	-2.71
	Average value of all grades	4.21	0.00

TABLE 2. An example of determining the scale of points for a specific variable.

Initial scale (A)	Percentage difference between the average grade of the subject variable and the average grade of all variables (B)	Absolute value of the deviation from the average grade (C=A*B)	Score scale for the subject variable (D=A+C)
0	+3.70%	0	0
1	+3.70%	0.037	1.037
2	+3.70%	0.074	2.074
3	+3.70%	0.111	3.111
4	+3.70%	0.148	4.148
5	+3.70%	0.185	5.185

The intervals were determined after collecting, processing and analysis of the data on the observed variable, which refer to the current condition of that variable in a certain forest estate. For each variable, maximum and minimum values were determined. Then the difference between the maximum and minimum values was divided by 5 (according to the fact that it is necessary to determine the intervals for 5 scores), and thus the value of one interval was obtained. Furthermore, one value of the interval for each point was added to the minimum value for the observed variable. Value between 0 to the minimum is always scored with 0 points. The specified procedure for determining the intervals for some points is presented in Equation 2 and Table 4.

$$I_v = \frac{V_{max} - V_{min}}{5} \quad (2)$$

where I_v is the value of one interval, V_{max} is the maximum value of the observed variable, V_{min} is the minimum value of the observed variable.

On the basis of concrete values in the field (for example, real total and average wood stock), each forest estate has a certain number of points per individual variable. Thus, all forest estates that are subject to analysis are scored by each of the selected variables. Based on the sum of the scores per each variable, the ranking list of forest estates in accordance with realistic business conditions is obtained.

Validation of the Defined Model

It is necessary to validate the defined model on a pilot sample through a direct contact with the representatives of forest estates, by organizing workshops with representatives of small, medium and large forest estates within the PFE. Through a direct presentation of the method of determining and the selection of variables, as well as the defined model, it is necessary to obtain feedback from the representatives of forest estates on possible suggestions for corrections and amendments of the defined model.

The Ranking of Certain Forest Estates

Certain forest estates are ranked in accordance with the sum of points for all analyzed variables. On the basis of the total number of scores for each forest estate, they were ranked according to more favourable or less favourable conditions and possibilities to achieve (among other things) positive business results.

In that sense, forest estates are primarily ranked in accordance with the total number of scores for all analyzed variables. In addition, in order to separate and analyze "all the rents together" [9], besides the ranking in accordance with the scoring for all variables, it is also necessary to additionally analyze those variables that refer to natural conditions (mostly variables that represent natural conditions for performing business activities), as well as those with an economic component of business operations (caused mainly by anthropogenic, i.e. economic and organizational factors). The first group of variables is determined by general natural (habitual) potential, as well as by the condition of basic factors affecting forest estates ranking, which are quantitatively presented in the forest management plan. The other group of variables is the result of strong human influence on their values, and thus on forest estates ranking. The ranking of forest estates on the basis of these analyses provides the definition of their rank with regard to overall forest management conditions.

TABLE 3. Example of intervals for a variable: total and average wood stock.

Total and average wood stock		
Scoring points for a variable	Scoring points for a variable total wood stock (m^3)	Scoring points for a variable average wood stock ($m^3 \cdot ha^{-1}$)
0	Up to 1,264,000	Up to 190
1.037	1,264,001 – 3,506,922	190.10 – 255.21
2.074	3,506,923 – 5,749,844	255.22 – 320.42
3.111	5,749,845 – 7,992,766	320.43 – 385.63
4.148	7,992,767 – 10,235,688	385.64 – 450.84
5.185	10,235,689 - 12,479,449	450.85 – 517.04

TABLE 4. The specified procedure for determining the intervals for points from 0 to 5.

Number of points	Values
0 (previous example 0)	From 0 to V_{min}
1 (previous example 1.037)	$V_{min} + I_v = I_1$
2 (previous example 2.074)	$I_1 + I_v = I_2$
3 (previous example 3.111)	$I_2 + I_v = I_3$
4 (previous example 4.148)	$I_3 + I_v = I_4$
5 (previous example 5.185)	$I_4 + I_v = I_5$

I_v – value of one interval; V_{max} - maximum value of the observed variable; V_{min} - minimum value of the observed variable;
$I_{1, 2, 3, 4, 5}$ - intervals for some scores between 1 and 5

After the ranking, it is necessary to divide all forest estates into 5 groups, according to more favourable or less favourable business conditions. The groups of forest estates are as follows:

- A group of forest estates (the most favourable business conditions),
- B group of forest estates (favourable business conditions),
- C group of forest estates (medium favourable business conditions),
- D group of forest estates (satisfactory business conditions),
- E group of forest estates (the least favourable business conditions).

Each group includes 20% of forest estates. If it is not possible to divide forest estates into 5 equal groups through calculation, the grouping is done in accordance with a bottom-up principle (first, one forest estate is added into the group E, and if necessary, another forest estate is added into the group D, and so on to the group B).

It must be emphasized that the ranking within certain groups is important, since the higher rank implies a better position within the group. In that sense, after the ranking, all forest estates are labelled as, for example, A-3, B-5, C-1 and so on.

Forest estates are divided into 5 groups, primarily in order to give the decision-makers the opportunity for a possible differentiation of forest estates into more groups according to the possibility of allocating funds for the use of forests and forest land.

Within this research, the following models were defined:

MODULE 1. Calculation of scores for one forest estate by all analyzed variables.

B_g = (1,037 to 5,185 for **V_u**) + (1,037 to 5,185 for **V_p**) + (1,013 to 5,067 for **V_{cu}**) + (1,013 to 5,067 for **V_{cp}**) + (1,011 to 5,055 for **E**) + (1,009 to 5,043 for **SDS_c**) + (1,009 to 5,043 for **SDS_l**) + (1,004 to 5,019 for **ET_c**) + (1,004 to 5,019 for **ET_l**) + (0,999 to 4,996 for **I_u**) + (0,999 to 4,996 for **I_p**) + (0,990 to 4,948 for **B_c**) + (0,990 to 4,948 for **B_l**) + (0,985 to 4,924 for **O**) + (0,980 to 4,901 for **P_n**) + (0,980 to 4,901 for **P_v**) + (0,973 to 4,865 for **P_{vs}**)

MODULE 2. Calculation of scores for one forest estate by natural variables.

B_g = (1,037 to 5,185 for **V_u**) + (1,037 to 5,185 for **V_p**) + (1,013 to 5,067 for **V_{cu}**) + (1,013 to 5,067 for **V_{cp}**) + (1,009 to 5,043 for **SDS_c**) + (1,009 to 5,043 for **SDS_l**) + (1,004 to 5,019 for **ET_c**) + (1,004 to 5,019 for **ET_l**)+ (0,999 to 4,996 for **I_u**) + (0,999 to 4,996 for **I_p**) + (0,990 to 4,948 for **B_c**) + (0,990 to 4,948 for **B_l**) + (0,973 to 4,865 for **P_{vs}**)

MODULE 3. Calculation of scores for one forest estate by economic variables.

B_g = (1,011 to 5,055 for **E**) + (0,985 to 4,924 for **O**) + (0,980 to 4,901 for **P_n**) + (0,980 to 4,901 for **P_v**)

where B_g is total number of scores for one forest management unit, V_u is total wood stock, V_p is average wood stock, V_{cu} is total stock (conifers), V_{lu} is total stock (broadleaves), E is effectiveness, SDS_c is forest assortment (conifers), SDS_l is forest assortment (broadleaves), ET_c is annual cut (conifers), ET_l is annual cut (broadleaf), I_u is total increase I_p is average increase, B_c is site class (conifers), B_l is site class (broadleaves), O is forest openness, P_n is productivity (natural method), P_v is productivity (value method), and P_{vs} is area of high forests.

These modules are the result of this concrete survey and serve for the ranking of forest etates operating within PFE Forests of The Republic of Srpska. In such form, the moduls cannot be applied to other areas, and it is necessary to form new moduls according to specific business conditions.

The results of this research, i.e. the ranking and division (into five groups) of all forest estates operating within PFE Forests of The Republic of Srpska, based on natural, economic and unified (natural and economic) variables, is shown in Tables 5 to 7.

Rank Correlation

As stated in the previous chapter, the MRG Model application defines three ranks of forest estates, as follows:

1. Rank for all variables,
2. Rank for variables for natural conditions,
3. Rank for variables for economic conditions.

Since there are three ranks, it is necessary to consider their mutual correlation. If we want to determine the degree of correlation of the features whose values have been ranked, it is necesssary to perform a statistical analysis that represents a special form of simple correlation, which is called a rank correlation [3, 45]. Rank correlation is performed for all rank combinations, as follows: (1) Rank of all variables and natural variables, (2) Rank of all variables and economic variables, (3) Rank of natural variables and economic variables.

In order to determine the degree of correlation (compliance) between the specified ranks of forest estates according to the grouped variables, it is necessary to determine Spearman's rank correlation coefficient [49-51] as follows:

$$r_s = 1 - \frac{6\,\Sigma d_i^2}{n^3 - n} \tag{3}$$

where r_s is Spearman's rank correlation coefficient, d_i is difference between the ranks, n is number of forest estates.

In this way, for this specific research, correlation between the specific ranks was determined, i.e. it was determined whether the ranking of all variables complies with the rank for natural variables or the rank for economic variables. In this research, Spearman's rank correlation coefficient for all variables and natural variables was 0.94, for all variables and economic variables was 0.48, and for natural variables and economic variables it was only 0.19. Naturally, for each new research, new variables would probably be used (depending on the results of the survey). Although the rank correlation indicates a lower or higher connection, the rank for all variables is considered to be the final result of forest estates ranking.

Algorithm for the MRG Model

On the basis of all the above, and for greater transparency, algorithms for the MRG Model are given in Figure 1.

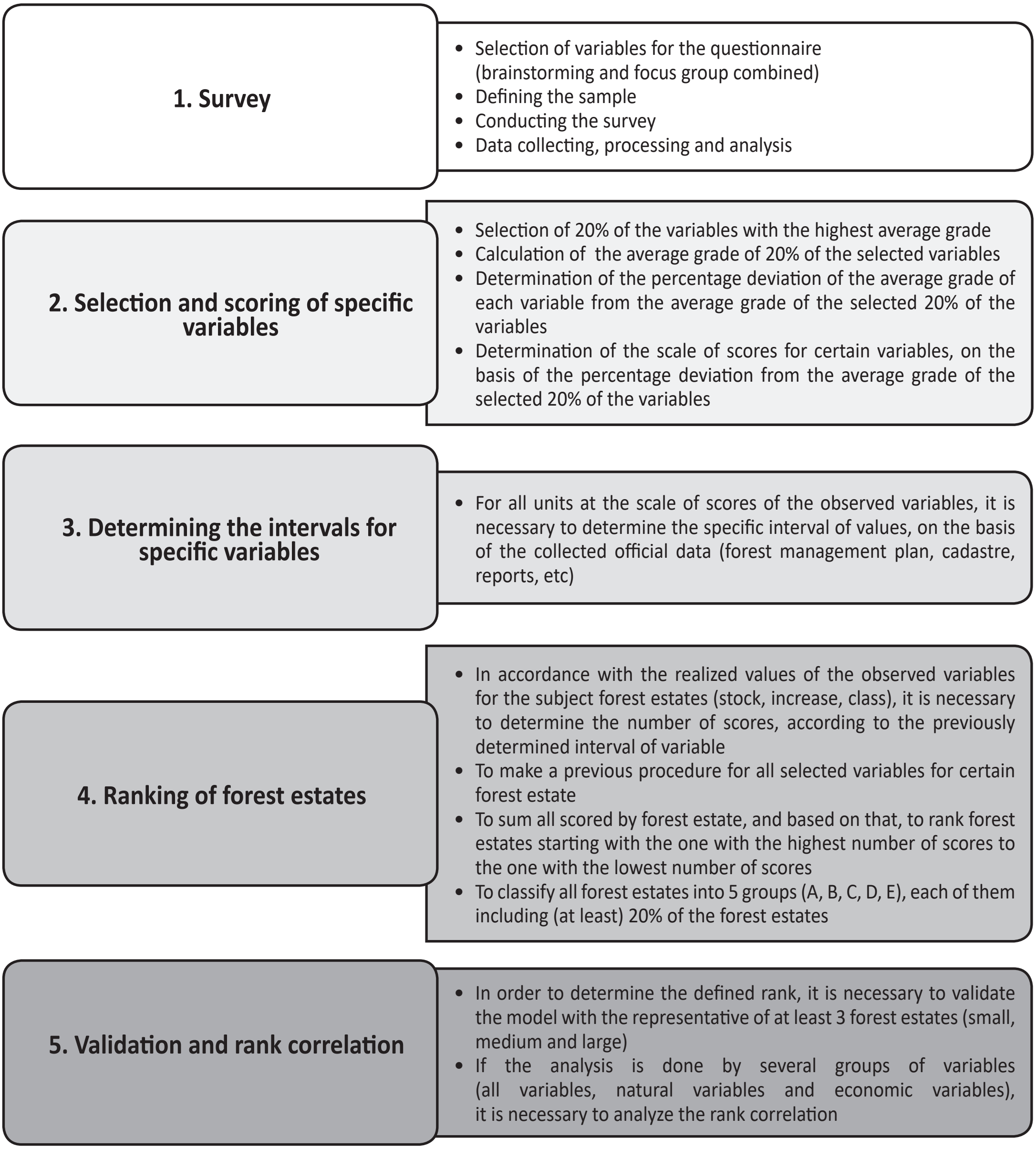

FIGURE 1. The algorithm for forest estates ranking – the MRG Model.

TABLE 5. Division of forest estates operating within PFE Forests of The Republic of Srpska into groups according to all the analyzed variables.

	Group A	Group B	Group C	Group D	Group E
1.	Visocnik	Borja	Vucevica	Banja Luka	Birac
2.	Romanija	Ribnik	Drina	Sjemec	Milici
3.	Gradiska	Gorica	Vrbanja	Cemernica	Doboj
4.	Prijedor	Klekovaca	Jahorina	Panos	Zelengora
5.	Maglic	Ostrelj	Lisina	Treskavica	Majevica
6.					Botin

TABLE 6. Division of forest estates operating within PFE Forests of The Republic of Srpska into groups according to the natural variables.

	Group A	Group B	Group C	Group D	Group E
1.	Romanija	Gorica	Vucevica	Drina	Majevica
2.	Visocnik	Prijedor	Klekovaca	Panos	Zelengora
3.	Gradiska	Borja	Banja Luka	Cemernica	Botin
4.	Ribnik	Jahorina	Vrbanja	Lisina	Treskavica
5.	Maglic	Ostrelj	Sjemec	Birac	Milici
6.					Doboj

TABLE 7. Division of forest estates operating within PFE Forests of The Republic of Srpska into groups according to the economic variables.

	Group A	Group B	Group C	Group D	Group E
1.	Klekovaca	Treskavica	Vucevica	Ribnik	Zelengora
2.	Drina	Prijedor	Doboj	Romanija	Botin
3.	Vrbanja	Gradiska	Maglic	Cemernica	Jahorina
4.	Visocnik	Milici	Ostrelj	Sjemec	Birac
5.	Lisina	Borja	Gorica	Banja Luka	Panos
6.					Majevica

DISCUSSION

Implementation of the MRG Model involves 5 basic steps with 7 phases to be performed in the order specified in this paper. Discussion on certain steps (phases) refers to the following:

- The selection of variables which will be part of the MRG Model is crucial. It is necessary to apply all the above scientific methodologies and techniques, as well as to conduct the survey on a representative sample, as large as possible. This will ensure the actuality of the selected variables, and give credibility to the defined ranks.
- It is best to classify variables into several groups (in this specific case, into economic, ecological and planning – forest management), without favouring any of the groups of variables. It is necessary to randomly classify the variables in the questionnaire, without grouping them into the defined groups. This will ensure impartiality during the survey, which is one of the basic conditions for defining a quality model.
- The survey sample has to be representative and include individuals who are directly or indirectly involved in the forestry sector. The MRG Model suggests that the questionnaires represent individuals' attitudes, and possible modification may imply that this represents the official attitude of institutions. However, this might lead to possible non-objectivity due to different interests of participants in the survey, and therefore a sample with as many experienced individuals as possible is recommended.
- Due to the convenience of the model, it is necessary to determine the realistic number of variables to be analyzed thoroughly. It is recommended always to use the Pareto principle (80/20), which would certainly involve a different number of variables in accordance with the subject area analyzed.
- Although it might seem that all selected variables are significant, and although in some cases average grades for certain variables do not differ much, it is always necessary to give each variable the importance in accordance with the survey results. This is possible by defining a custom scale for each variable, as explained in this paper. Within the MRG Model, the initial scale ranges from 0 to 5, and possible modification can be made in terms of creating the initial scale from 0 to 10. Although this would provide even more precise differentiation, there is a possibility of complicating the model which would lead to more difficult work during the data analysis.
- In accordance with the specifics of each research area, it is necessary to determine the interval of value for each variable, which would be evaluated by the defined number of points in the previous step. This operation will vary most in accordance with the area analyzed.
- It is always necessary to validate the defined model, i.e. the data and final ranks, through pilot samples. Within this survey, three pilot samples were used, although a larger number of forest estates could be used as well. This is very important since it contributes to the credibility of the defined model, which might further have a decisive importance in the differentiation of forest estates according to the rate of allocated funds.
- Certain forest estates are ranked in accordance with the total number of scores for all analyzed variables. It is always necessary to define three ranks, as follows: for all analyzed variables, as well as for economic and for natural variables. That procedure will enable additional analysis and identification of the causes of problems for

specific forest estates. It should be noted that in some cases, one group of variables (economic or natural) might not be selected by the participants in the survey. It is always recommended for both groups to be present in the model (they do not have to be in the same ratio), which is why the determining of the sample is crucial. In that sense, representatives of different stakeholders (including the owners and users of forests, forestry enterprises, higher education institutions, the Chamber of Commerce and non-governmental sector) must be included in the sample.

- The classification of forest estates divided into 5 groups (A, B, C, D and E), as well as the ranking within the groups (A-4, C-1, D-3 etc), is considered quite satisfactory. If necessary, in case of a large number of organization units within a business system (this research included 26 forest estates), the introduction of additional groups may be considered.
- Finally, since there are three ranks, it is necessary to always consider mutual correlation of these ranks, by performing a statistical analysis rank correlation. In this way, mutual correlation of specific ranks is determined, i.e. it is determined whether the ranking for all variables is more compatible with the rank for natural variables or the rank for the economic ones. This provides the possibility for additional business analysis and identification of the causes of problems for specific forest estates.

Application of the MRG Model requires a strict adherence to all parts of the methodology defined within this paper, which implies that all activities must be adapted to the conditions of the area subject to research. Similar methods might be created for future ranking, but all elements of the MRG Model must be implemented from the very beginning.

In this concrete research, a control method was also carried out (based on the Pareto principle), but it was not addressed in this paper. However, the application of a control method is recommended in order to compare the obtained results and to indicate possible deviation of the ranks defined according to different methods. The control method and its testing on pilot forest estates confirmed that the MRG Model is fully applicable and that it enables a realistic forest estates ranking .

CONCLUSIONS

Finally, here is a list of basic conclusions:

- The MRG Model can be used in all forest enterprises where it is necessary to rank certain organizational units/estates, regardless of the ownership structure;
- Due to the variability of the selected variables and the change of their values in certain time intervals (especially in the case of *economic* variables), it is recommended to rank forest estates periodically, every five years (or even more often);
- It is recommended to use the control method, since it can indicate certain deviations in forest estates ranking , but it is not mandatory;
- Primary purpose of the ranking using the MRG Model is to indicate the possibility or differentiation of specific forest estates for allocating funds for simple and expanded reproduction of forests. This would (approximately) enable equitable and continuous development of all areas managed by forestry enterprises (or those in their use);
- The allocation rates for forest estates should be a subject of another survey, and should be adapted to areas (states) in which the survey is conducted;
- In order to avoid discontent in forest estates that, due to their higher ranks, should allocate more funds, it is necessary to create special administrative or financial measures of stimulation.

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REVIEW PAPER

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A Review on Turkish Hazel (*Corylus colurna* L.): A Promising Tree Species for Future Assisted Migration Attempts

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ABSTRACT

Background and Purpose: Turkish hazel (*Corylus colurna* L.) has been overused because of its valuable wood. Recently, Turkish hazel has been found only in small isolated populations, and very small populations within its natural distribution area, so it has been protected under IUCN with the status "Least Concern (LC)". Therefore, the remaining Turkish hazel populations have a critical importance. Genetic conservation of this tree species plays a key role in sustainable forest development. There have been only a few studies of single populations, but an overview including all countries is still missing. The aim of this publication is to give an overview of ecological and economic importance of Turkish hazel, which is considered as a tolerant tree species to climate change, for dry and warm conditions in Central Europe.
Materials and Methods: This review paper has been prepared based on the existing literature such as reports, theses, project documents and publications related to Turkish hazel. This paper applies a literature review of the concepts of: i) Distribution and threats of Turkish hazel, ii) Ecological and economic importance, iii) Regeneration, soil demand and shading tolerance, iv) Seed, seedling, plant production and planting, v) Competitiveness in forest communities, vi) Invasiveness and hybridization, and vii) Future stand mixtures.
Results and Conclusions: This review paper should interest forest practitioners and scientists in all countries who work with this important and valuable tree species under climate change. At first, an inventory of all populations in each country is needed. For this purpose, research should focus on the cultivation of convenient provenances of Turkish hazel under climate change. Next, genetic differences should be determined in the laboratory using genetic markers. After the assessment of the phenotype and genotype of different provenances, it would be possible to recommend provenance for each ecological condition and assisted migration (AM). Main recommendations for each country are used for selecting and establishing gene conservation units (in-situ and ex-situ) and seed orchards that will ensure the survival of Turkish hazel, and for building the base for cultivation in the future. In addition, the results might be a basis for future provenance tests, plantations and possibilities of assisted migration attempts.

Keywords: next tree species, climate change, ecological importance, wood production, forest genetic resources.

INTRODUCTION

Climate change affects all forest ecosystems, as well as services and goods provided by forests. A possible and suitable adaptation strategy to stabilize forest stands is usually provided by establishing mixed forests. By improving the existing spectrum of tree species in Central Europe, the risk can be minimized. The origin of the reproductive material of a tree species plays a key role in its adaptation to environmental conditions, and possible cultivation. Turkish hazel (*Corylus colurna* L.) has been currently discussed as a valuable alternative in Europe [1].

Turkish hazel has been overused because of its valuable wood [2], which is why it is now found only in isolated and very small populations within its natural distribution area [3]. Turkish hazel is a protected species according to the IUCN list [4]. Therefore, the remaining Turkish hazel populations have a critical importance. These populations can be used as a natural reservoir for seed collection. These trees are already well-adapted to difficult environmental conditions [5]. In countries where this species occurs naturally, the required propagation material should not be imported, and plant materials should be grown in these areas.

Turkish hazel is a semi-shade tolerant tree species that can create mixed stands with other species, and has a low invasion potential. This tree species has many characteristics such as high resistance to abiotic and biotic damage, less expectation of soil fertility, drought tolerance, winter and late frost resistance, which can contribute to the stabilization of forest stands. In its natural distribution area (i.e. the Balkan Peninsula, northern Turkey, Caucasus and Afghanistan), Turkish hazel grows mainly on shallow, low-nutrient and dry lime soils, but it can also grow in locations which include lime and silicate rock. The average annual temperature in the area of origin varies between 5 and 13°C, while the annual participation ranges from 570 to 800 mm [2]. The natural spread extends northwards to Romania in Vâlcan Mountains (Tismana), and in north-west to Bosnia and Herzegovina (Konjic) [6, 7]. The import of Turkish hazel to Central Europe started in the 17th century. Since then, it has been cultivated to a very small extent in Italy, Austria, Germany, Poland, Ukraine, and Hungary. In many countries of Central Europe, Turkish hazel is only known as a garden and park tree. Even in the origin countries, the distribution of Turkish hazel is rather rare.

The aim of this review is to give an overview of the ecological and economic importance of Turkish hazel, which is considered as an important tree species in changing climate conditions. A basis for future provenance tests and assisted migration, plantation in Europe and genetic conservation of this valuable tree species in its natural distribution area are also aimed. Recently, there have been only studies of single populations, which means that a comprehensive overview is missing.

DISTRIBUTION AND THREATS OF TURKISH HAZEL

Turkish Hazel as a Tree Species

The Turkish hazel belongs to the birch family (*Betulaceae*), which has *Corylaceae* as the subfamily with four genera. The hazel (*Corylus*) genus contains at least 12 species classified in the temperate zones of Eurasia and North America [8-10]. The Turkish hazel is a member of the Europe-Siberia flora region [11], and it is a taxon gene-originated from Turkey [4]. It is known as "tree hazelnut", "rock hazelnut", "Balkan hazelnut", "bear hazelnut", "filbert" and "Turkish hazelnut" in literature [3, 12].

Within the species, four aspects including leaf shape, bark structure, hairiness of the petioles and fruit cups differentiate *Corylus colurna*. For example: f. *Rotundifolia* has rounded leaves with blunt tips, while f. *Cuspidata* has elongated leaves with pointed and slightly curved apex. Leaf handle and fruit bowl of f. *Colurna* are bald, and of f. *Glandulifera* are finely gorged hairy [5].

In contrast to the common hazelnut (*Corylus avellana* L.), Turkish hazel can reach heights of 25 to 30 m, and diameter at breast height (DBH) of 50 to 60 cm, while in exceptional cases it can reach a DBH up to 170 cm and an age of 400 years depending on the location [2, 5, 10, 13, 14]. The crown appears pyramidal in youth and usually assumes a dull-conical crown in older ages. The nuts ripen in 5 to 6 pods are surrounded by deeply divided lobes. The edible fruits are 17-20 mm in length and smaller than those of *C. avellana*. The leaves are slightly larger and darker green, and the bark is greyer than that of the hazelnut. Between Turkish hazel and common hazelnut, hybrids of species can be formed [5, 15, 16].

Distribution of Turkish Hazel

The natural distribution area of the Turkish hazel includes the regions of Asia Minor, the Caucasus, Afghanistan, and the Balkan Peninsula. Its occurrence on the Balkans covers Bosnia and Herzegovina, Romania, Bulgaria, Serbia, Macedonia, Kosovo, Montenegro, Albania, and Greece (Figure 1). In these regions, it can grow at altitudes between 100 and 1300 m, but it is mainly found between 300 and 800 m. Turkish hazel is mainly distributed in the southern Carpathians of Romania, in Bulgaria on the Balkan Range, Sredna Gora, Rhodope Mountains and in the western and north-eastern forest stands. In Greece, it grows in the Pindus Mountains and in Turkey, the populations, even if relatively marginal from the geographic point of view, find optimal ecological conditions (Table 1) also in the Northern Anatolian forests, where the local range is relatively extended in the North Anatolian Mountains [3, 5, 17-20]. Although the continental climate is ideal for its growth, there is also some occurrence in the Mediterranean climate. The species is resistant to drought, and it mostly occurs on sunny slopes.

In Caucasia, Turkish hazel can be founded mainly in oak and beech forests at altitudes of 600-1700 m above sea level (e.g. the Racha region), but its occurrence focuses in Georgia. In Armenia, its distribution is very rare. There is a 120-150 years old Turkish hazel reservation at 1400-1600 m above sea level (near Getahovit) with DBH over 1 m [5, 13]. In Bosnia and Herzegovina, Turkish hazel creates the north-west border of its natural distribution area. In Serbia, there are over 25 populations presented. In former Yugoslavia, this tree species had been protected for over 40 years [2]. Formerly, populations were found in the Hyrcan and Turan regions of northern Iran [5]; however, there are currently no Turkish hazel populations recorded in Iran. Because of its valuable wood, many tree populations in their natural distribution area have been exploited [13]. From the end of the 16th century through 1850, large quantities of Turkish hazel wood were transported to Austria for furniture manufacturing. After yew wood, Turkish hazel was the second most popular and precious timber in Vienna. Due to the exploitation of Turkish hazel, the original distribution area of the species considerably declined, and vast areas of the natural range are nowadays karst areas [10]. For this reason, Turkish hazel has been included in the IUCN Red List (entry 2014) with the status "least concern" [4].

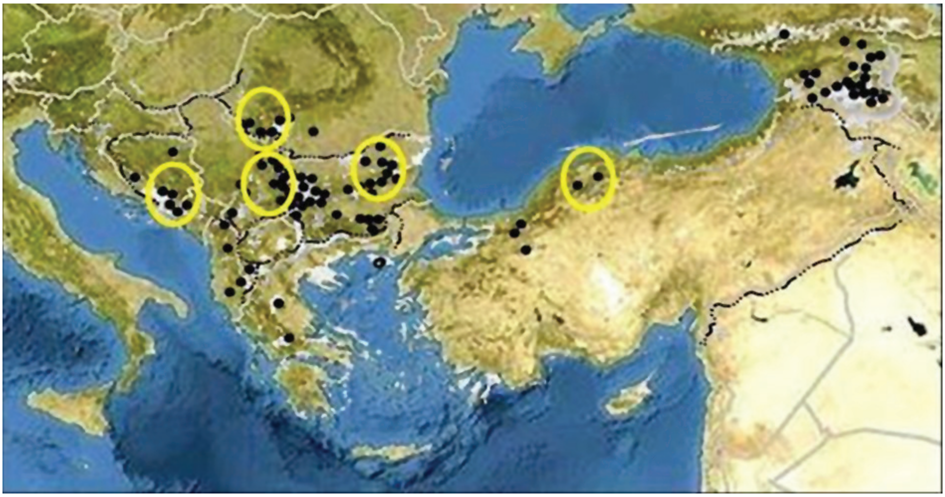

FIGURE 1. Natural distribution area of *Corylus* colurna from Alexandrov [5] and adapted by Šeho et al. [21]. Black dot: individual populations; yellow circle: sample area.

TABLE 1. Populations of Turkish hazel (*C. colurna* L.), which are investigated in the context of the CorCed (www.asp.bayern.de) research project.

Country	Origin	Altitude (m)	Annual temperature (°C)	Annual precipitation (mm)
Bulgaria	Klisura	950	10.3	603
	Bjala	250	10.2	623
	Elin Pelin	800	10.2	586
	Varbitsa	650	10.6	589
	Smjadovo	650	10.8	599
Bosnia and Herzegovina	Rogatica	950	10.2	1006
	Konjic	1300	12.7	1211
Romania	Oravita	620	10.5	699
	Tismana	578	10.5	625
Turkey	Tosya	960	10.7	490
	Arac	1020	10.5	537
	Tunuslar	1320	8.5	668
	Müsellimer	1150	8.5	668
	Afyon	1724	11.2	440
Serbia	Surdulica	1070	10.3	550
	Maljen	710	11.3	788
	Zlatibor	960	10.6	896
	Derdap	560	10.7	650
	Kozijak	995	11.3	550
	Ozren	830	10.3	653
	Kuršumlija	940	11.8	573
Georgia	Mazhieti	1620	5.5	1010
Armenia	Getahovit	1500	12.3	435

Ecological Importance

The climate of the main distribution area of Turkish hazel in Eastern Europe to Asia Minor (Ukraine to the Black Sea, the Caspian Sea to the Caucasus) is continental with high amount of precipitation at relatively higher altitudes [22]. In suitable conditions where Turkish hazel naturally grows, the species is described as a warm-embrace tree species that prefers warmer and sun-exposed slopes. For the maturation of nuts, it needs warmer sites with longer sunshine periods and a longer growing season [10, 23].

Turkish hazel generally has very high resistance to abiotic and biotic agents, and it can survive under short-term temperature extremes of -38.2°C to +40°C [5]. Palashevand Nikolov [24] state that Turkish hazel range is generally between the altitudes of 100 and 1400 m. However, because of frost hardiness, some populations of the species can grow in altitudes of up to 1700 m above sea level, but they cannot tolerate cold air accumulation [10]. According to the winter hardiness zone classified for Central Europe for trees, *C. colurna* belongs to winter hardiness zone "5b", being frost-hard and cultivable at -23.4°C to -26.0°C [25]. It is known to be a winter-hard tree species in Central Europe and Southern Scandinavia. According to results from the forestry research station Mariunolskaya (former USSR), winter hardiness and drought resistance are not valid for the first years [10]. The annual average temperatures range from +5°C to +10°C (on the Balkan Peninsula they fluctuate between 5-6°C and 12-13°C), while the annual precipitation ranges from 570 to 850 mm, which falls mostly in the summer [5].

The cover leaf can survive temperatures below -16°C to -18°C, but pollen inoculation is lost at and below -20°C. While mature pollutants can overcome -26°C without change, germinating pollen is damaged at -10°C to -14°C [10]. It is not endangered by late frosts in May and June, as it is usually expelled at the end of March. If frost occurs at this time (i.e. during March), Turkish hazel can be damaged. However, new shoots can overcome the damage. Turkish hazel also shows damage from early frost [5, 14, 26]. It has extreme frost hardiness, drought resistance, and resistance against early drought in August with leaf shedding, thick cork, and an insensitivity to solar radiation [10]. In addition, its very strong branching strength resists snow break hazards [10, 30]. Furthermore, it is able to endure floods of up to three months [10]. The species is also considered to be appropriate to plant in agricultural lands which are stable to drought [27, 28], abstemious according to ground claim [24, 29], and used specially to rehabilitate drought lands. It is tolerant to air pollution, and it can also be planted to protect and stabilize soils. It has been found that Turkish hazel can resist low temperatures such as -20°C, high temperatures and drought, as well as harmful gas emission [27]. Palashev and Nikolov [24] state that Turkish hazel needs a minimum of 500 mm annual precipitations, and an annual average temperatures ranging between 5°C and 13°C.

Turkish hazel can be attacked by all types of wild animals, with the exception of the wild boar, and is often sept by roebucks. In particular, young Turkish hazels are heavily consumed by rabbits [10, 30]. Harmful insects do not present a serious threat for Turkish hazel. However, it can be assumed that insects that occur in the common hazelnut can also attack *C. colurna* [10]. As a rule, Turkish hazel which grows in mixed stands can be classified as relatively insensitive to biotic and abiotic risks, and therefore it can contribute to the stabilization of forest stands.

Soil and Root Formation

Turkish hazel has low demands on soil fertility and wide regional amplitude. In better locations, its competitiveness is weak in comparison to other tree species (tolerant tree species) which have relatively higher growth rates. It grows on a wide range of sites: from flat to deep, dry to almost wet, nutrient-poor to nutrient-rich sites. Due to the formation of a strong, 3-4 m deep pile root, Turkish hazel is able to populate on *skeleton-rich soil,* poor, crooked and stony, and very shallow sites [5, 16]. According to Alexandrov [5], it has optimal growth conditions in shady, humid locations, within beech and hornbeam forests on nutrient-rich, fresh to semi-dry soils. It grows best on clay, loamy or humid sands soils with sufficient moisture [10, 16]. It prefers nitrogen-poor sites, and has a high demand on the base availability. The optimum pH range is between 5.5 and 8, which means that acidic soils are possible but not optimal [23, 31].

With increasing moisture and nutrient content, it loses its competitive ability to mesophilic tree species, but its competitive capacity increases again in dry and poor locations [5]. Turkish hazel is most common at warm and dry sites within its natural distribution areas. Dry sites dominated by Turkish hazel can consist of medium to coarse debris, gravel or gravel with grain size over 2 mm in the root area [10, 23].

Rather, wet sites throughout the year, as well as very dry sites are unsuitable [5, 23]. However, extremely dry sites are not excluded as locations. Thus, it grows on very dry karst locations with low usable field capacity and partly lacking summer precipitation in the Romanian Carpathians [14].

Turkish hazel is sensitive to soil compaction [16]. It is only conditionally resistant to salinized soil, and is rarely found on raw or peat soil [23, 25]. Mature trees can develop lateral roots. These lateral roots can reach a length of 15-18 m, and usually extend beyond the crown projection area [5]. The root system promotes high stability in stands so that it is particularly suitable for wind protection systems and forest edge design. Leaf litter is well decomposable and has a soil-improving effect, especially in mixtures with hornbeam. Because of its robust root system, Turkish hazel is suitable for erosion protection. Moreover, its roots symbiose with fungi and bacteria [10].

Competitiveness in Forest Communities

Turkish hazel is usually found in beech stands at higher altitudes, as well as in oak stands at lower altitudes. This tree species can often be found growing as individual trees, as well as in groups, or a cluster in association with beech (*Fagus sylvatica* L.), Oriental beech (*F. orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), Oriental hornbeam (*C. orientalis* Miller), sessile oak (*Quercus petraea* (Matt.) Liebl), Hungarian oak (*Q. frainetto* Ten.), common ash (*Fraxinus excelsior* L.), manna ash (*F. ornus* L.), mountain maple (*Acer pseudoplatanus* L.), Norway maple (*A. platanoides* L.) and silver linden (*Tilia tomentosa* Moench). Turkish hazel does not constitute pure stands [5].

In Bulgaria, almost 50% of Turkish hazel populations are found in stands dominated by *Fagus* and *Carpinus* species [5, 32]. Turkish hazel can also be found in beech and oak forests as a rare mixed tree species in the Caucasus area [13]. This tree species occurs in stands composed of, for example, *Quercus frainetto* Ten., *Fraxinus ornus* L., *Carpinus orientalis* Miller, and *Crataegus* L. in dry and poor locations [5]. On the south-western edge of the Carpathians, it exists in mixed lime-beech forests [16].

Regeneration and Shading Tolerance

The relatively heavy nuts fall very close to the parent tree, and are mainly spread by wildlife animals. Vegetative propagation is rather rare. Vegetation-free or raw floor sites offer favourable conditions for germination [5]. In the case of first reforestation, losses should be expected. Most of the fruits are consumed by wildlife animals. Turkish hazel is considered a semi-shade tolerant tree species and is, therefore, suitable for cultivation on open spaces and in semi-shade conditions. In critical locations, it reacts like a shade-intolerant tree species. Even in semi-shade conditions, it exhibits straight stem forms. Young growth especially tolerates dense canopy [2]. The tree species is robust against lateral pressure, and it does not behave phototropicly. Side branches are preserved for a long time and contribute to photosynthesis [5].

Invasiveness and Hybridization

Turkish hazel is considered as a non-invasive species, and is not listed among the invasive species in Germany [2]. Due to its low competitiveness, it is excluded mainly from European beech stands at better site conditions. Natural hybridizations with other *Corylus* species are possible, but not quite usual. Erdogan and Mehlenbacher [15] described clusters of 20% between *Corylus colurna* x *C. avellana* set when *C. avellana* was the pollen parent, but 92% of the nuts were empty. The reciprocal cross, *C. avellana* x *C. colurna*, set nuts in only one of three years during the studies. Turkish hazel can also provide different phenotypes such as different leaf shapes, hairs of leaf stalks and fruit pots, which complicate its identification. The first genetic differences should be determined in the laboratory using genetic markers [33].

Future Stand Mixtures

Turkish hazel can supplement an existing spectrum of tree species, and can be mixed in stands as a single tree or in groups. It is especially suitable when mixed with beech, grape oak, pointed acorn, mountain ash, hornbeam or linden, as well as chestnut and Hungarian oak. Experiments conducted in mixture with bird cherry in a 5x1.5 m band and winter line (5x2.5 m) showed that mixing accelerated natural branch pruning in spite of strong competition. The results of an experiment in southern Germany indicated that Turkish hazel can also be used for advance planting under spruce and pine [2]. Turkish hazel can, however, be planted in open spaces (2x2 m) or in wide areas (5x5 m, 7x7 m). It is recommended that seedlings be protected from wildlife and mice in the first years after planting [2, 14].

ECONOMIC IMPORTANCE

Turkish hazel can reach an age of 400 years, heights of more than 30 m and a DBH greater than 170 cm [2]. The growth performance on nutrient-rich, fresh soils is roughly comparable to the hornbeam, and almost reaches the growth capacity of mountain maple, common ash and sessile oak. On flat, nutrient-poor and dry lime soils, it shows even a double growth rate compared to other secondary tree species (e.g. *Carpinus orientalis*) [5]. Turkish hazel is clearly superior to beech in I. site quality class at age 65 in terms of growth performance. Annual ring studies of rootstocks of Turkish hazel and beech with a diameter of 60 cm have shown that, under the same condition, the radial growth of beech was achieved by Turkish hazel at the age of 100 years [10].

The previous experiences in Germany and Austria substantiate the good height-growth performance of Turkish hazel [14, 26]. The annual height growth during a southern German cultivation trial in a productive site (i.e. vineyard area on fine clay soil) was between 75 and 87 cm (max. 140 cm). The average height of the 6-year-old plants was 4.3 m. At the age of 16, heights of 14 m were reached (Figure 2), proving that Turkish hazel grows faster than the neighbouring wild cherry [2].

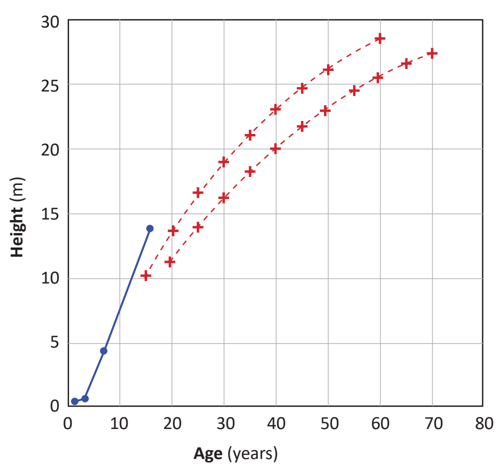

FIGURE 2. Height growth over age of Turkish hazel (blue) and *Prunus avium* L. Table class I and II [34] from Šeho *et al.* [2] (chart by M. Schölch).

Arslan [27] and Ghimeey [35] state that Turkish hazel is a valuable reserve tree species in Hungary, and it is considered as a fast growing species. For the reasons stated above, it is also selected as a valuable rootstock source [36].

Turkish hazel tree grows predominantly straight, and develops full-timbered stems. Its characteristic crown is especially prominent in the youth phase. Like many species of laurel trees, self-pruning of Turkish hazel easily occurs up to a height of 6–8 m [5, 37]. In stands with low density, Turkish hazel can produce high-quality wood. In the event of a strong breeding, individual secondary branches may occur. Logging is carried out according to objectives. Due to its dark colour, its wood is regarded as decorative, and is used for furniture and turnery. On submission, prices range from € 300 to € 650 per cubic meter [2, 37].

Turkish hazel was first cultivated as a mixed tree species for scientific purposes about 20 years ago in Central Europe. However, the results of observations on provenance and precise recommendations of origins have not been given. In general, less is known about the history of older cultivations. According to the results of first visited countries of origin, we observed that individual locations differ greatly in their growth and qualitative characteristics [2]. Therefore, it is essential that the establishment of provenance tests and the evaluation of the cultivation should be taken into consideration. A genetic characterization of the material should be carried out [32, 33].

According to a research conducted in Austria, the mean height during 10 years was 7.5 m, while the mean DBH was 6.8 cm [26]. The height growth of Turkish hazel in its natural area of distribution is decisively dependent on site conditions. In an open area, as well as in semi-shade and shadow stand conditions, Turkish hazel exhibit straight growth. Double-topped trees (Zwiesel) that may be caused genetically can be observed. The crown form can be optimised by different forest management treatments. Un-thinned stands show lower diameter growth. The thinning methods should be examined. Current experiences from the natural distribution area show that Turkish hazel should be maintained by positive selection. It can be treated as part of hardwood tree stands [2].

In soil and environmental conditions with lower growth capacity, Turkish hazel can easily cope with mixed tree species including sycamore maple and ash, which occur there and reach similar heights. Due to the low population size, investigations have not been carried out on the overall growth performance. However, Turkish hazel shows a long-lasting diameter growth. According to Ghimeey [35], Turkish hazel can be overgrown by beech in diameter growth at the same sites after reaching the age of 100 years.

Wood Use

The wood of Turkish hazel is characteristic and decorative; in each case, about 50% of the cross-section in yellowish-reddish sapwood and reddish-brown heartwood are monitored. The technological characteristics are characterized by an elastic, medium-hard, scattered pore-like wood, similar to the characteristics of sycamore maple. Its wood is easy to process, but it tends to shrink during rapid drying. Bulk density is about 0.61 $g \cdot cm^{-3}$ [5]. It was formerly known as "Turkish nut" or "rosewood", and was commonly used for producing excellent furniture manufacturing [2]. It can be used as construction timber (inside and outside), and for carving and turning as well.

The reddish colour of the wood is unique. The production of valuable wood of Turkish hazel in good growing conditions can be faster than that of oak [2]. The occurrence of ingrowing branches and callus form may be disadvantageous. According to Zeidler [38], the wood is mainly used in furniture industry and in production of decorative veneers and cabinetry.

Seed, Seedling and Plant Production

The trees fructify by the age of 10, and continue every 2 to 4 years. Nuts should be harvested before full maturity from August to October, and green fruit pods should be removed [10, 16, 25].

One hectolitre of nuts without fruit pellets weighs 43 to 50 kg [39]. One kilogram of seed contains about 600 nuts [10, 25]. The average germination percentage is 40 to 75% [5]. Germination capability can last up to 1 ½ years [39].

The current supply of seeds from Turkish hazel in Central Europe is mainly covered by the cultivation of park and street trees. The number of parent trees and their genetic status plays a crucial role for adaptability, growth, and quality. It is not advisable to use this seed for the cultivation of forestry plants. The risk of inbred effects and genetic narrowing is very high. Individual contacts with seed farmers in the countries of origin have already existed, and should be further developed for future seed supply. It is recommended to use only seeds from natural populations [2].

Nut characteristics of Turkish hazel which are beginning to gain commercial value have started to create additional income. Ayan *et al.* [20] carried out a research on Turkish hazel pomological features. Table 2 shows the descriptive statistics of 14 different nut characteristics of randomly selected cluster and nut samples from four different populations of this species. The nut per cluster ratio was between 1 and 10, the kernel ratio was between 18.1 and 57.9%, while nut weight was between 0.61 and 2.61 g. Erdoğan and Aygün [40] examined nut characteristics and fatty acids composition of *C. colurna,* and found that shell thickness was between 0.67 and 3.69 mm, nut weight varied between 1.33 and 2.91 g, while the kernel ratio was between 25 and 36%. In another study, Mitrovic *et al.* [41] monitored Turkish hazel in Serbia, and found that nut weight was between 1.20 and 2.59 g, kernel weight between 0.38 and 0.74 g, kernel ratio between 29 and 40.1%, and shell thickness between 1.0 and 1.3 mm. In addition, Srivastava *et al.* [42] found the following values for *C. colurna*: nut count was 2.83-3.53, nut weight 1.29-1.75 g, kernel weight 0.47-0.53 g, kernel ratio 28-41%, nut length 16.28-18.13 mm, nut width 16.36-17.88 mm, and nut thickness 11.67-12.54 mm. Moreover, Miletic *et al.* [43] found the following average values of *C. colurna*: nut coarseness was 16.3x14.0x11.0 mm, kernel coarseness was 13.9x9.7x6.5 mm, nut weight was 1.00-1.75 g, and kernel weight was 0.3-0.65 g.

According to Ayan *et al.* [19], significant differences were found among populations in terms of protein content, while there were no significant differences in terms of fat content. The fat content of the Turkish hazel populations ranged from 59.85% to 64.07%, while protein content varied from 14.80% to 18.34% at population-based scale (Table 3). Many studies have reported that the nut compositions of hazel are affected by variety, harvest year, soil, climate and method of cultivation [44-46].

The seedling development was monitored in the first and second year in the Rimski Sancevi fruit tree nursery, Novi

Sad, Serbia. In the agro-ecological conditions of the nursery, monitoring of the one- and two-year-old Turkish hazel seedling growth indicators demonstrated that one-year-old plants were not viable rootstocks. However, two-year-old seedlings, based on the development of the root neck and the achieved plant height, showed potential for grafting hazel on Turkish hazel rootstocks. Hazel cultivar grafting was performed on two-year-old Turkish hazel seedlings by tongue grafting method. The results indicated excellent compatibility and grafting success rate. Measurements of one and two years-old seedlings' height, as well as root length and other characteristics are shown in Table 4 [36].

Mill Strength and Stratification

There are significant differences in seed quality from seeds collected from different locations in Turkey (Table 4). The size and weight of Turkish hazel nuts depend on the respective harvest year [21]. The altitude is rather unlikely because all stands, where seeds were harvested in Turkey, were located at an altitude of approximately 1000 m above sea level. However, low temperatures at the beginning of the vegetation period had a considerable influence demonstrating a negative effect on the size and quality of the nuts [36]. The number of seeds per kilogram was 549 to 1049 pieces. Of these, 172 to 489 seeds were viable [21].

Various attempts of certification at the laboratory of Bavarian Office for Forest Seeding and Planting have shown that a stratification of at least 120 days is promising [21]. The best results have been obtained by previous research [36, 47] with autumn seeding (64%) and stratification of 120 days (14.2%). It is only by the treatment with gibberellic acid, which promotes germination, and an interruption of the germination, that the results are clearly better. Another method is to attack the pericarp prior to sowing. According to Jansky *et al.* [48], it

TABLE 2. The descriptive nut characteristics [20] (Std. Dev. – standard deviation, Min. – minimum, Max. – maximum).

Nut Characteristics	Mean	Std. Dev.	Min.	Max.
Nut Counts per cluster (number)	4.2	1.6	1	10
Nut Length (mm)	15.45	1.15	11.04	18.83
Nut Width (mm)	15.53	1.55	10.32	19.61
Nut Thickness (mm)	12.04	1.30	7.67	16.92
Nut Size (mm)	15.49	1.10	10.74	18.53
Nut Shape	1.00	0.11	0.71	1.49
Nut Weight (g)	1.48	0.33	0.61	2.61
Shell Thickness (mm)	2.28	0.68	0.92	11.88
Compression Index	1.30	0.10	0.86	1.73
Kernel Length (mm)	12.46	0.94	9.16	15.45
Kernel Width (mm)	11.37	1.05	8.05	16.64
Kernel Thickness (mm)	7.56	0.78	4.52	10.09
Kernel Weight (g)	0.50	0.09	0.25	0.83
Kernel Ratio (%)	34.8	6.1	18.1	57.9

TABLE 3. Basic statistics of fat and protein values [19] (Std. Dev. - standard deviation, Min. - minimum, Max. - maximum, C_v - coefficient of variation).

	Population	Mean	Std. Dev.	Min.	Max.	C_v (%)
Fat (%)	Araç-Güzlük	63.49	1.42	61.12	65.42	2.24
	Tosya-Küçüksekiler	63.72	4.09	57.32	69.62	6.42
	Ağlı-Müsellimler	64.07	3.22	59.34	68.84	5.03
	Ağlı-Tunuslar	59.85	2.85	56.60	63.32	4.76
	Total	62.78	3.22	56.60	69.62	5.09
Protein (%)	Araç-Güzlük	14.80	1.68	11.79	16.81	11.35
	Tosya-Küçüksekiler	15.40	1.47	13.41	17.94	9.55
	Ağlı-Müsellimler	16.73	1.41	14.22	18.43	8.43
	Ağlı-Tunuslar	18.34	0.60	17.62	18.91	3.27
	Total	16.32	1.82	11.79	18.91	11.40

TABLE 4. One and two-year-old Turkish hazel (*Corylus colurna* L.) seedlings' morphological characteristics (x̄ - mean, C_V - coefficient of variation) [36].

Genotype	Seedling height		Seedling root length		Root neck thickness		Number of first order roots		Seedling mass		Root mass	
	x̄ (cm)	C_V (%)	x̄ (cm)	C_V (%)	x̄ (mm)	C_V (%)	x̄	C_V (%)	x̄ (g)	C_V (%)	x̄ (g)	C_V (%)
1st aged seedling characteristics												
a_1	13.48a	11.56	34.23ab	16.87	5.89a	17.75	42.76ab	20.27	2.32b	45.17	3.72a	32.56
B_2	16.01b	13.63	35.13b	21.91	5.84a	19.44	49.36b	25.02	2.53b	47.65	4.18a	40.52
B_4	16.82ab	13.71	33.13ab	18.48	5.66a	20.04	40.28a	18.12	2.00a	48.21	3.75a	36.19
B_5	17.82a	14.39	32.18ab	18.83	5.67a	18.94	40.51a	18.31	2.81c	50.19	4.09a	37.65
B_9	16.84ab	16.31	30.81a	29.7	5.71a	20.43	32.30c	24.05	1.80a	56.43	2.93a	49.37
2nd aged seedling characteristics												
a_1	42.53a	31.04	46.83a	13.27	12.38a	34.98	19.56b	30.44	12.56a	48.05	11.00a	41.57
B_2	46.82c	26.75	48.13ab	23.8	9.74b	20.22	22.63e	30.79	9.16b	44.85	14.29b	36.97
B_4	47.63e	31.67	51.01b	18.56	11.11d	25.32	16.36a	23.88	10.66d	28.95	15.28c	43.57
B_5	47.34d	35.41	48.80ab	19.79	10.76c	21.03	19.70c	31.41	12.56a	33.48	17.50e	44.51
B_9	46.63b	24.68	49.66ab	17.15	9.36a	24.46	21.50d	26.92	9.36c	38.49	15.69d	31.75

TABLE 5. The number of seeds per kg and seed origin.

Origin	Crop year	1000 seed weight	Seed·kg^{-1} (piece)	Viable seeds·kg^{-1} (piece)
Turkey-Bolu	2013	953	1049	405
Turkey-Bolu	2014	1236	809	226
Turkey-Tosya	2015	1819	549	489
Germany-Gotha	2014	1269	788	404
France-Vilmorin	2013	1404	712	172

improves the germination rates to 30%. In contrast, 14% of the nuts germinated with intact pericarp. When the seed shell was removed, a complete laboratory germination was carried out [48]. At an early start of germination, the seed can be stored at least -3°C until sowing [21].

Planting

Turkish hazel has an early vegetation activity; thus it should be planted before the end of March. Shoot activity depends on the location and weather in spring. The dipping of seedlings in protectant against evaporation is recommended. On intensive grassy surfaces, stronger ranges should be selected with height from 50 to 80 cm or 80 to 120 cm, especially in spring plantings [16]. Because of intensive root formation, the seedlings should not be older than two years during planting [2]. Sufficient moisture for roots before and during the planting is necessary for the success of the application [16, 37]. If necessary, a proper root cut can be performed. Natural regeneration is also possible in older stands. Turkish hazel can also be introduced by autumn seeding [2, 36]. These protect the seeds against late frost as well as against high-growth and darkening weed growth in the growth cover [37].

DISCUSSION AND CONCLUSIONS

The selection of suitable stands, where the seeds can be collected, plays a crucial role for the main tree species (native tree species) of each country in Europe. Although most stands of the main tree species in Germany (e.g. beech, spruce, fir, oak) are naturally regenerated, the classification of the origin areas for the plant material is restricted, and subject to legal requirements (e.g. EG-Law:1999/105/EG, German-Law 2003. FoVG-Forstliches Vermehrungsgutgesetz). The individual areas of origin were selected in accordance with natural growth conditions. In order to take account of these growth conditions of stands and therewith associated phenotypic and genotypic properties, origin areas should be identified. The provenances should have the characteristic name and a description of the forest locations. The recommended origins may only be replaced by the compensation origin if the seed supply cannot be ensured.

In contrast, the non-native tree species, as alternative tree species, are not well known and examined, and the selection of the plant material is more or less random. In most cases, when plants were offered by forestry nurseries in Europe, the origin and quality of the seed, seedlings and saplings were undescribed and unknown.

To protect all forest ecosystems as well as the services and goods that forests provide from potential future climate change, mixed forests should be composed. All alternative tree species (e.g. Turkish hazel, cedar) which are discussed in some European countries such as France or Germany for mixing, should be examined. For future adaptation during climate change, the populations where seed will be collected should contain high genetic diversity, higher growth rates and better wood quality.

So far, there has been limited knowledge on the genetic diversity of *C. colurna* in the remaining populations of the natural distribution area. The initial studies were done by Šeho *et al.* [33] and showed clear differences between provenances from the Balkan Peninsula and Turkey. However, Ayan *et. al.* [20] state that due to relatively narrow genetic distances among populations and their scattered distribution in the natural distribution areas, conservation programmes should integrate improvement, on the one hand to preserve in-situ populations, while on the other hand selected materials can be preserved ex-situ as progeny or clonal archives and seed orchards [3, 20]. Genetic conservation of Turkish hazel should play a key role in future sustainable forest development in all countries where this species is distributed (e.g. Turkey, Bulgaria, Romania, Serbia, Bosnia, and Georgia). It can be used under changing climate conditions as a native tree species to stabilize labile forest stands [3, 20, 31-33, 49, 50].

The question of the origin was not further discussed, but it certainly plays a decisive role in silviculture and has a major economic impact. In the case of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), the most important non-native tree species in Central Europe, this sequence was observed in the form of contamination by fungi and significant differences in growth performance. As for black pine (*Pinus nigra* J.F. Arnold), there were clear differences in growth between the individual herds [51, 52]. These differences, which are seen in introduced tree species in Germany, can probably be seen in the imported Turkish hazel. Especially those tree species which have a very widespread area (east-west) and occur in the coastal area as well as inland, have adapted to the prevailing growth conditions. The phenotypic and genotypic properties that characterize these populations should therefore be examined in detail to identify the appropriate origins for Germany and Turkey. A systematic establishing of provenance tests can play a major role for the assessment of individual origins. At the same time, environmental conditions, as well as possible locations, should be covered. These trees are already well-adapted to difficult environmental conditions. In the countries where this species occurs naturally, the required propagation material should not be imported from other countries. The plant material should be grown in domestic nurseries of the related country. State forests organisation should be responsible for the production of plants. Seedlings should be planted in small populations (e.g. Konjic, Afyon, Tismana). Furthermore, these seed stands can be included and protected as an in-situ gene conservation unit. If it is not possible to protect these populations, the forest sector of each county should prepare a concept for ex-situ gene conservation.

From a scientific point of view, there should be at least 20 mother trees chosen for seed collection [53, 54]. For the wild cherry (*Prunus avium* L.) at least 25 mother trees are recommended [55].

Especially, for insect-pollinated tree species the pollen exchange is intensive between neighbour trees. This effect called “actual neighbourhood size” is for the service tree (*Sorbus torminalis* (L.) Crantz) counts six trees, but the distance among trees can be in some cases up to 2.5 km [56]. The distance between trees that can be used for seed collection should be at least 20 m [54, 57]. In this way, sufficient genetic variation of the seed and plant material will be ensured, and can be used to establish seed orchards.

The regular and straight stem forms of this tree seems to be interesting from the technological point of view. The detected variation in terms of nut quality could be an added value for the species, as well as for its use in plantations and the agroforestry system. No adequate information is available on *C. colurna,* thus the present paper has to be considered as a first step to widening the knowledge on the genetic, ecological, economic and cultural potential of the species as a multiservice supplier. In the view of that, the set of data produced gives useful information to start genetic improvement programmes aimed to extend the planted productive area and cultivation systems. The extension of the potential area where *C. colurna* can be planted should be preliminarily detected according the delimitation of the ecological niche where the species can find suitable conditions [20].

Future research should focus on two types of assisted migration. The first AM should focus within the current range of the species or within modest range extensions with the aim to sustain forest productivity and health under climate change and increase the genetic diversity [58-61]. This practice has already been implemented for other tree species in several regions, and can be adapted for Turkish hazel. The second type of AM is outside of the natural distribution range of species (e.g. Turkish hazel provenances transfer to Germany). This activity should supplement the spectrum of the existing tree species in Germany and at the same time conserve it from extinctions under climate change [33, 58].

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Site Index and Volume Growth Percentage Determination for Privately Owned Uneven-aged Stands of *Quercus pubescens* and *Quercus ilex* along the Croatian Adriatic Coast

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ABSTRACT

Background and purpose: Although organized forestry has existed in Croatia for more than 250 years, this mostly entailed state forests. During the last decade, Extension Services have started to support the development of forest management plans for privately owned forests. Lately, FMPs have been developed for nearly 3/4 of privately owned forests in Croatia. During the creation of those plans, yield tables and normal models for state-owned forests, primarily even-aged stands with long-time management, were used because similar data was not developed for uneven-aged and poorly managed forests. This research encompasses privately owned forests in the Croatian Mediterranean and sub-Mediterranean regions where holm oak (*Quercus ilex* L.) and downy oak (*Quercus pubescens* Willd.) are the prevailing species in forest stands. The main goal was to determine site indices revealed in the analysis of yearly radial increments and to create relevant yield tables.
Materials and Methods: In this study, 1286 oak trees were cored to the centre on 377 locations spread in privately owned forests in Croatian Mediterranean and sub-Mediterranean regions. The ratio of trees and locations was approximately 3:1 for *Q. pubescens*. Some cored trees were more than two centuries old. After the standard sample preparation for dendrochronological analysis, cores were scanned, and tree-ring widths were determined. In total, ring width for over 67,000 rings was determined and measured.
Results: Based on the data dispersion of cumulative tree increments at 40 years of age, 2 site index classes for *Q. ilex* and 3 for *Q. pubescens* were created based on *k*-means clustering. Prodan's growth function was fitted to the created clusters to determine the site's "model" tree. For the model trees, the percentage of volume growth was calculated. For easier field site index determination, height curves based on field data for each site index were calculated.
Conclusions: For the first time in Croatia, systematic and controlled data on the growth (and age) of uneven-aged privately owned forests in the Croatian Mediterranean and sub-Mediterranean area were collected. Based on the data collected in the field, three different site indices for downy oak and two site indices for holm oak were determined. These results could find their application during operational forest management and forest exploitation because they allow for more accurate determination of the site production strength in the explored stands.

Keywords: privately owned forests, dendrochronology, uneven-aged forests, site productivity, site index

INTRODUCTION

More than a half of the Croatian Mediterranean and sub-Mediterranean area - circa 800,000 ha - are covered with forest vegetation, and more than 95% of it consists of holm oak (*Quercus ilex* L.) or downy oak (*Quercus pubescens* Willd.) forests, mainly in degraded forms (coppice or shrubs/maquis).

In the study of Gea-Izquierdo *et al.* [1] it is stated that *Quercus* sp. is a widespread genus in the Northern Hemisphere, and that it is the most important broadleaf genus in the Mediterranean region. The most widespread evergreen oak species in the West Mediterranean region is holm oak. Its distribution ranges in latitude from Southern France to the Anti-Atlas in Morocco [2]. In Croatia, Mediterranean climate only affects islands and the narrow area on the coastline. Larger proportion of coastal area is influenced by sub-Mediterranean climate, where downy oak prevails. Downy oak has a wide areal distribution that extends from the north-east of the Iberian Peninsula to Asia Minor. Downy oak, together with pedunculate oak and sessile oak is the most common oak species in Central Europe [3].

Regarding ownership, half of those forests are private properties. Although organized forestry has existed in Croatia for more than 250 years, it mostly entailed state forests. Privately owned forests were not actively managed in the past although they had to adhere to certain laws and regulations throughout history, but forest owners had a possibility to decide what and when to do with their ownership. This led to uneven-aged forests with great diversity of stand structure in small areas. This is reflected in the small size of forest plots and the presence of multiple owners on one plot, making sustainable management impossible. The average private forest plot in these areas is 0.27-0.37 ha, with forest estates ranging from 1.73 to 2.43 ha, in many cases having several owners [4].

Čavlović [5] stated that there are multiple challenges for private forest owners: small area management, heterogeneity of stands, low quality of cadaster and land registry, unmarked cadastral plot borders and forest degradation.

After the WWII, some Forest Management Plans (FMP) for privately owned forests were created, but they encompassed only a few percentages of privately owned forests. For many of these areas, FMP were created up to the 1990s.

During the last decade, Extension Services have started to systematically support the development of forest management plans for privately owned forests. Currently, FMPs have been developed for nearly 3/4 of privately owned forests in Croatia. For the aforementioned plans, growth tables and normal models for state-owned forests, primarily even-aged stands with long-time management, were used because similar data has never been developed for uneven-aged and poorly managed forests.

Due to the presence of double ring or absent ring and its high wood density (compared to other European species), holm oak is not a widely researched species. Additionally, holm oak is an evergreen tree species, which means that it can potentially grow during the whole year, which could lead to problems related to tree-ring boundary recognition and calls to special attention when measuring tree-ring widths. Previously conducted research was oriented more towards dendrochronology and dendroecology and correlation between climate and tree-ring width than towards radial increment investigation [1, 2, 6-8]. The only research known to the authors and comparable to this one was study of Gea-Izquierdo *et al.* [9].

Gea-Izquierdo *et al.* [1] also stated that holm oak, due to its wide distribution, confers great potential for dendroecology upon the species if tree rings can be correctly dated despite the presence of double and absent rings (e.g. [6, 10, 11]) or unclear tree-ring boundaries.

Downy oak has been more studied than holm oak, but not in a comparable manner. Previous papers focused on the influence of climate or environment on the growth in specific years [12, 13] or on 10-year average increment [14].

With this research, for the first time, privately owned forests have been encompassed in the Croatian Mediterranean and sub-Mediterranean region where holm oak (*Quercus ilex* L.) and downy oak (*Quercus pubescens* Wild.) forests are the most common forest species by coverage. The main goal was to determine site indices revealed in the analysis of yearly radial increments and to model volume percentage increment of the mean basal area of trees for those site indices.

MATERIALS AND METHODS

General Description of the Locations

The object of this research were privately owned forests in Croatian Mediterranean and sub-Mediterranean regions. These forest areas are covered mainly by holm oak (*Quercus ilex* L.) or downy oak (*Quercus pubescens* Willd.) forests, respectively (Figure 1).

By comparing these areas with CORINE land cover database for Croatia (CAEN) for reference year 2012 (categories encompassing forests and forest succession - codes 311, 312, 313, 323 and 324) and the coverage of the state-owned forests (Croatian Forests Ltd.), it was assumed that there are approximately 400,000 privately owned forests in Croatian Mediterranean and sub-Mediterranean regions (Figure 2).

In 2007, Extension Services started to systematically create forest management plans (FMPs) for privately owned forests, many of which were created for the first time. By the time of this project's establishment, FMPs have been created for almost half of the research area (Figure 3).

Data from FPMs are the only valid reference data for privately owned forest areas and management classes; therefore, only forest compartments in these management units where management classes consisted of holm oak or downy oak (coppice or high forests) were selected. In each compartment, 2-4 locations were selected, covering as many diverse forest stand characteristics as possible from FMPs (DBH, stand volume, elevation, slope, etc.), while

FIGURE 1. Ecological areas of holm oak (dark green) and downy oak (light green) phytocenosis.

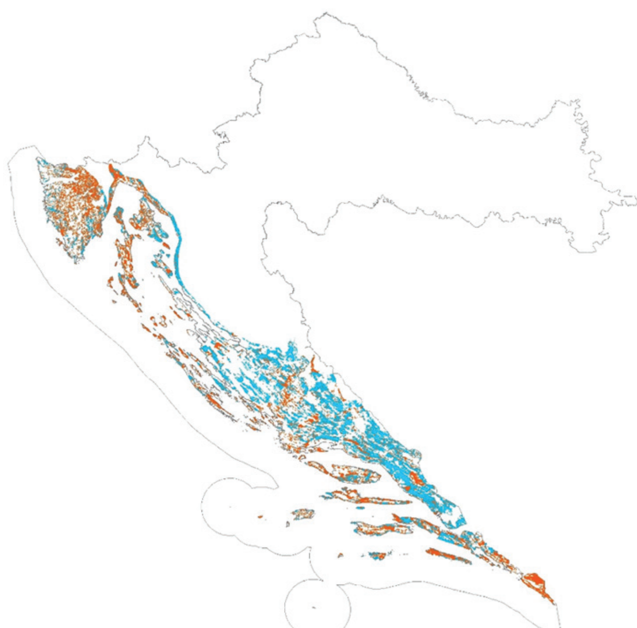

FIGURE 2. Areas of forests and forest succession by CLC 2012 and their ownership (blue – state-owned forests, red – privately owned forests).

FIGURE 3. Created FMPs in the researched area.

also trying to cover most of the research area. In total, 377 locations along the Croatian coast were selected (Table 1, Figure 4).

Sampling Strategy

On each plot 2-3 trees whose diameter corresponds to the mean basal area at the plot were sampled. Additionally, samples were taken from one dominant tree at the plot. From each sampled tree 2 cores per tree or one core through the tree were taken, or in some cases, stem disks were acquired as well. During a field campaign 994 *Quercus pubescens* (QUPU) and 308 *Quercus ilex* (QUIL) trees were sampled.

Sample Processing and Measurement

The samples were prepared in the laboratory according to the standard dendrochronological procedure [15]. The samples were dried and dry cores were then fixed into wooden holders (which was not the case with the stem discs). Finally, they were sanded on an industrial belt sander with sanding paper of progressively higher grade – 120, 240 and 360 and, if necessary, with 400 or 600 grade to achieve good visibility of tree-rings.

All samples were scanned using a high-resolution flatbed scanner and tree-rings were measured with CDendro and CooRecorder software. Measured tree-ring width sequences were converted to TUCSON decadal format and imported into COFECHA [16] program for quality control. COFECHA programme checked for measuring errors and cross-dating mistakes. If errors in the tree-ring width sequences were detected, it was checked (1) if all tree-ring boundaries were correctly detected, and (2) if tree-rings in question were correctly measured. A small number of measurements needed to be corrected because of wrongly dated year beneath the bark or wrong calibration in the CDendro software. Corrected measurements were then re-imported into the main database.

For further processing tree-ring width sequences were exported to R programming environment [17] and processed to get a file which could be used for the calculation of site productivity.

TABLE 1. Share of plots by region and tree species.

Region	Number of plots		Total
	Quercus pubescens	*Quercus ilex*	
Istria and Kvarner	210	75	285
Northern and Central Dalmatia	53	4	57
Southern Dalmatia	22	13	35
Total	285	92	377

FIGURE 4. Location of sample plots.

Calculation of Site Productivity, Volume Growth Percentage and Height of Mean Basal Area Tree

Site productivity of the forest stand is by definition the production of the forest stand in a certain period of time (e.g. 50 or 100 years) [9], which includes information on the achieved tree height, development of tree height over time, as well as diameter growth and radial increment. Given that the only available information was the age of trees and radial increments for each year, the definition had to be slightly modified and it was decided that the development of cumulative increment at average tree age of 40 years will be studied. The decision to calculate site productivity at the average tree age of 40 years is based on preliminary analysis of the age of cored trees. By setting age higher than 40 years, too many plots would be lost. In case of 40 year-old trees only 9% (8 out of 92 plots) of plots were lost for QUIL and 6% (18 out of 285 plots) for QUPU. Plots with trees younger than 40 years were simply not suitable for the calculation of the site productivity.

After that, cumulative value of the radial increment at 40 years was taken and this data was entered into *k*-means clustering in R [17] with request to form 3 groups for QUPU and 2 groups for QUIL. The number of groups per species was based on the range of cumulative radial increment in a given year. For QUPU this range was very wide, while for QUIL it was modestly narrow. A larger number of groups were tested, but due to smaller number of samples overlapping of site indices was bigger. This amount of selected sites showed the best discrimination with minor overlapping of data between sites.

To establish site index classes 1-3 for QUPU and 1-2 for QUIL we (1) allocated the cluster number to each location separately for two analysed tree species, and (2) calculated Prodan's growth function for each productivity group and tree species. For the latter, the NLS function in the R statistical environment was used [17].

By doing this normal (average) tree could be recreated, which was then used for the calculation of the transition time from one DBH class to another, which is the main input in volume growth percentage by [18].

Also, for easier determination of site indices in the field, relevant height curves were calculated (Mihajlov exponential equation [5]) with measured height and assigned site indices.

RESULTS

Age Structure on Studied Plots

Age structure of investigated trees is shown in Table 2 and Figure 5.

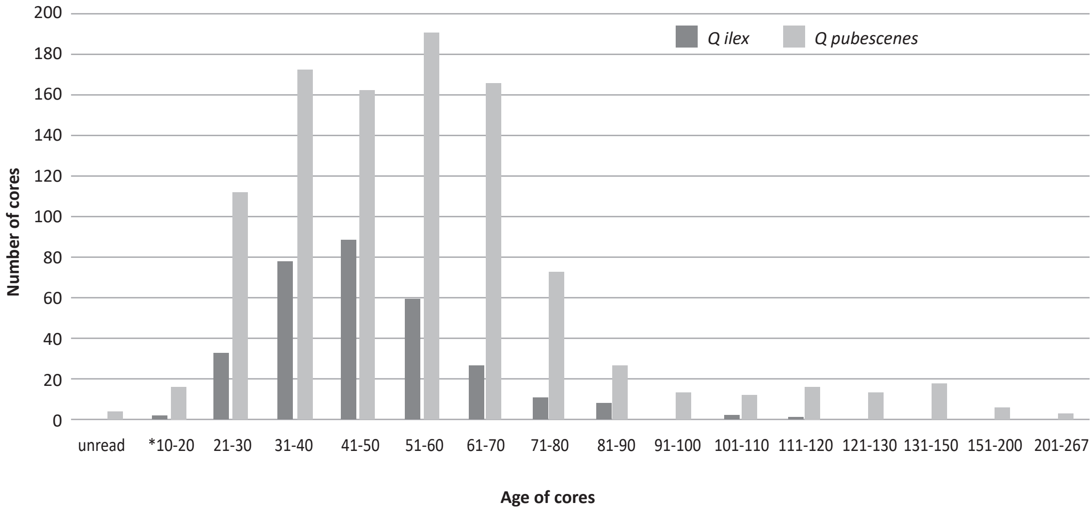

FIGURE 5. Cores grouped by age classes.

TABLE 2. Trees grouped in age classes.

Species	Unread	**Age classes** (years)															Total
		10-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-150	151-200	201-267	
Q. pubescens (QUPU)		2	32	77	88	59	26	10	8		1	1					304
Q. ilex (QUIL)	3	16	112	173	162	190	165	73	26	12	12	16	13	17	5	3	998
Total	3	18	144	250	250	249	191	83	34	12	13	17	13	17	5	3	1302

Since some cores (61) are not cored to the centre due to expressed peculiarity of investigated trees, those cores are not taken into account in further analysis.

Site Index for Quercus pubescens and Quercus ilex

To establish the site index, it was initially necessary to find differences between the studied plots. The most appropriate method for this was the clustering method by using annual increments on each plot. Therefore, *k*-means clustering was used with request to form 3 groups for QUPU and 2 groups for QUIL.

In the QUPU group 3 classes were identified – mean basal trees on the sites with the highest site index for QUPU achieved diameter of approx. 184 mm, while trees on the sites with the lowest site index for QUPU achieved diameter of only 87 mm at the age of 40. The diameters with the highest site index in QUPU group are more than 2 times bigger than the diameters in LOW QUPU group (Table 3).

Sites with predominantly QUIL trees showed smaller growth as compared to sites with predominantly QUPU trees. Therefore, sites with QUIL were split into two groups – those with high and those with low site index. In the HIGH group QUIL trees achieved diameter of about 120 mm at the age of 40, while in the LOW group they achieved only 88 mm at the age of 40.

Based on the cluster analysis and defined groups, growth curve for each of the site index classes was calculated. Prodan's function was used to express the relationship between age and growth (Equation 1). Prodan's function belongs to a group of so-called s-functions and it describes the relationship between growth and tree age particularly well.

$$y = \frac{t^2}{a + bt + c^2} \quad (1)$$

In Table 6 field data are grouped by investigated site index.

TABLE 3. Site productivity classes at the age of 40 for both tree species as calculated with the k-means clustering method

Species	Site productivity class	Average value of the cumulative 2-sided radial growth (mm)	Site productivity description
Quercus pubescens	1	184.92	High
	2	129.06	Medium
	3	87.58	Low
Quercus ilex	1	119.12	High
	2	88.32	Low

TABLE 4. Coefficients of Prodan's growth function for *Quercus pubescens.*

Site index	a	b	c
High	0.27505442	0.24795814	0.00461414
Medium	-0.300015346	0.465903921	0.003865383
Low	-0.559702284	0.735878702	0.004597677

TABLE 5. Coefficients of Prodan's growth function for *Quercus ilex.*

Site index	a	b	c
High	0.605188232	0.427293554	0.005386264
Low	0.559884275	0.517723183	0.007820995

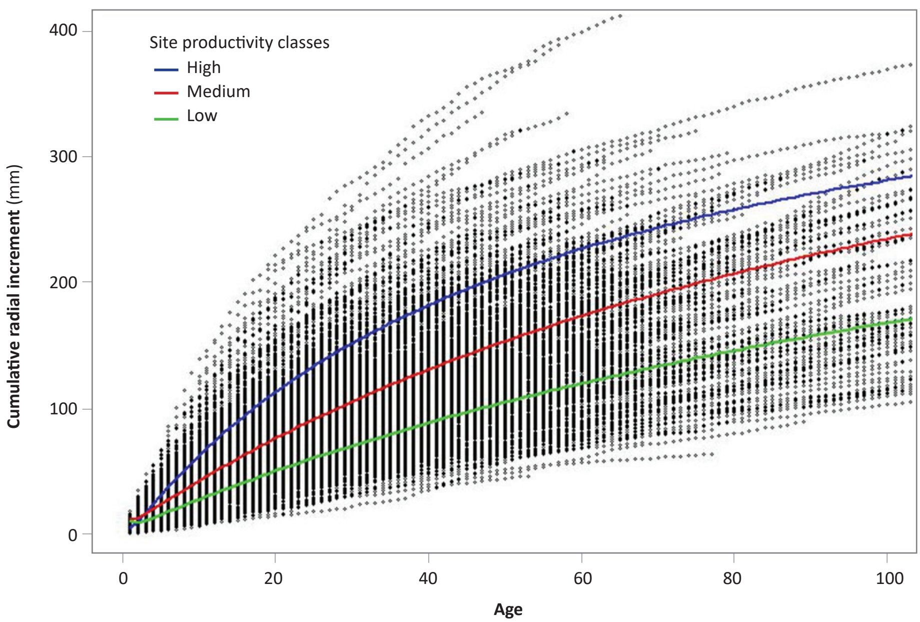

FIGURE 6. Site productivity classes with Prodan's curves embedded for *Quercus pubescens*. Differences in site indices are visible. Dots represent each analyzed tree-ring in data pool.

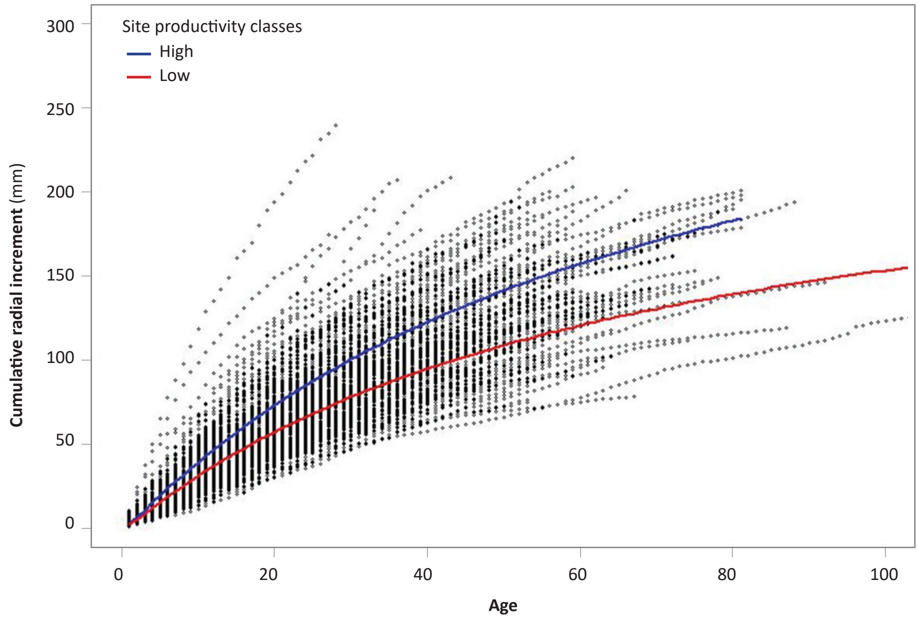

FIGURE 7. Site index classes with Prodan's curves embedded for *Quercus ilex*. Dots represent each analyzed tree-ring in data pool.

TABLE 6. Field data grouped by assigned site index.

Species	Site index	No. of data	Average age (years)	Average DBH (cm)	Average tree height (m)	Max age (years)	Max DBH (cm)	Max tree height (m)
Q. ilex	High	136	43.89	15.55	9.87	81	27.90	14.30
	Low	157	48.08	13.71	9.25	105	25.85	17.10
	Total	**293**	**46.14**	**14.56**	**9.54**	**105**	**27.90**	**17.10**
Q. pubescens	High	174	50.73	23.31	13.29	134	44.35	22.30
	Medium	411	53.14	18.86	11.75	149	42.85	24.40
	Low	363	62.72	15.63	9.22	267	42.25	16.70
	Total	**948**	**56.37**	**18.43**	**11.06**	**267**	**44.35**	**24.40**
Total		**1241**	**53.95**	**17.51**	**10.70**	**267**	**44.35**	**24.40**

Volume Growth Percentage

Based on the previous results, transition time from one DBH to another for average basal area tree by site index was calculated. This transition time was then used to calculate volume growth percentage by Klepac (Equation 2).

$$p = \frac{1000}{DBH - 5} * \frac{1}{Td} \qquad (2)$$

where p is volume growth percentage, DBH is diameter at breast height, and Td is transition time.

For easier field site index determination, height curves based on field data for each site index were also calculated using the Mihajlov's height equation (Equation 3).

$$h = 1.3 + b_0 * (e^{b_1/DBH}) \qquad (3)$$

where h is tree height, b_0 and b_1 are parameters and DBH is diameter at breast height.

Volume growth percentages and heights from height curves for each tree species and site index are shown in Table 7.

TABLE 7. Volume growth percentages and height by tree species and site index.

Species	Site index	Parameter	DBH of mean basal area tree (cm)						
			12.5	17.5	22.5	27.5	32.5	37.5	42.5
Q. pubescens	High	Height (m)	7.4	10.0	11.9	13.3	14.4	15.2	15.9
		Growth (%)	9.20	3.70	1.62	0.66	0.20	0.01	
	Medium	Height (m)	8.1	10.2	11.6	12.7	13.4	14.0	14.5
		Growth (%)	5.72	2.57	1.30	0.67	0.32	0.13	0.03
	Low	Height (m)	6.7	8.8	10.3	11.4	12.2	12.8	13.3
		Growth (%)	3.09	1.26	0.55	0.22	0.07		
Q. ilex	High	Height (m)	7.7	9.2	10.2	10.8	11.4	11.7	12.0
		Growth (%)	4.37	1.56	0.55	0.13	0.01		
	Low	Height (m)	7.6	9.1	10.1	10.8	11.3	11.6	12.0
		Growth (%)	1.66	0.23	0.01				

DISCUSSION

For the first time in Croatia, systematic and controlled data on the growth (and age) of uneven-aged privately owned forests in the Croatian Mediterranean and sub-Mediterranean area have been collected. Accordingly, the objects of the study were forests of holm oak or downy oak, which cover almost half of the forested area, in various forms, along the Croatian coastline (i.e. approximately 400,000 ha).

Based on the data collected in the field, three different site indices for downy oak and two site indices for holm oak were determined. Also, the volume growth percentage for each site index and species were determined. In addition, height curves were created for easier field site index determination.

From the measured data (Table 6) and equalized heights (Table 7), it can be noticed that the difference between the first and the second site index for holm oak is almost non-existing, while the difference in the mean diameters and volume growth percentages is significant. This confirms the justification for using the diameter growth and radial increment as a distinctive feature when determining site index in this type of forests.

As mentioned, studies on holm oak are sparse and not comparable to this one. The only comparable results [7] are shown in Table 8. It can be concluded that trees at the sites from this study are more than a half of size of the holm oaks from the previous study. This can be expected, since in the previous study the growth of holm oaks in agroforestry system with low tree density was studied, while in the present study only mean basal area trees in unmanaged, high tree density stands were encompassed.

Other comparable data are mean ring widths obtained from chronologies. In the study of Gea-Izquierdo *et al.* [8] it is reported that mean ring width on different sites amounts to 1.437 mm and 2.347 mm (respectively), while in this case mean ring width is 1.4257 mm on lower productivity sites and 1.7771 mm on higher productivity site. This clearly shows that sites for holm oak in Croatia are of lesser quality than in the Iberian Peninsula.

Downy oak has been studied more than holm oak, but not in comparable manner to this research. Rohner *et al.* [17] investigated growth dependence on environmental variables (slope, elevation, etc.), for *Q. petrea*, *Q. robur* and *Q. pubescens* together without any differentiation on the species level.

Pranjić and Lukić showed [14] showed the average radial growth rate of approximately 2 mm and 1.1 mm for two sites in Istria for 40 years long period. This is completely in accordance with our investigation and the determined average ring width on the lowest (0.125 mm) and the highest quality sites (0.230 mm) throughout Croatia.

Comparing the mean ring width reported by Kunstler *et al.* [11] (0.228 mm), the highest productivity site in this research has similar ring width, but on the lowest productivity site average ring widths of trees were almost half of that size (0.125 mm).

Regarding the reported average ring width in southern France [18] (1.0 mm for wet sites and 0.71 mm for dry sites), in this study all trees on the determined sites have wider average tree ring width.

Low measured tree heights as well as low modeled height with low percentage of volume increment in higher DBH classes clearly show the effect of harsh conditions on the life and development of these stands. These results are

TABLE 8. Comparison of holm oak (*Q. ilex*) results.

Age	DBH (cm)		
	Low density	High density	Gea-Izquierdo *et al.* [7]
30	7.8	9.9	15
60	12.0	15.8	27
90	14.7	19.6	34

evidence that biological and genetic potential had an impact when these trees were young and that they were supported by a certain amount of nutrients from these shallow soils. Furthermore, it can be concluded that external factors quickly affected the growth and development of these trees (and stands) negatively, as well as that these soils cannot support the needs of older and/or bigger trees.

These results could find their application during operational forest management and forest exploitation by enabling more accurate determination of the production strength of the explored stands. They can also help during the development of the NIR (National Inventory of Greenhouse Gases), since these results could be applied throughout the length of the Croatian coast.

CONCLUSIONS

For the first time in Croatia, systematic and controlled data on the growth (and age) of uneven-aged privately owned forests in the Croatian Mediterranean and sub-Mediterranean area were collected. Based on the data collected in the field, three different site indices for downy oak and two for holm oak were determined. These results could find their application during operational forest management and forest exploitation by enabling more accurate determination of the production strength of the explored stands.

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Windthrow Resistance of Norway Spruce (*Picea abies* /L./ Karst.) Forest Cultures - Preliminary Results

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ABSTRACT

Background and Purpose: Forest damage by wind is an important cause of economic loss in commercial forestry in the Republic of Croatia, as well as in many other European countries. Thus, windthrow resistance of trees represents a significant issue. Spruce forest cultures have shown the lowest resistance to windthrow so far. Nevertheless, there is not much insight into the relationship between trees and stand resistance to wind in the region. The objectives of this paper are to: (i) provide first evidence of the relation between tree characteristics prior to storm event in completely destroyed stands in comparison to slightly damaged stands, (ii) to evaluate the need to consider tree resistance to winds during thinnings, (iii) to evaluate if there is a need for windthrow stability assessment prior to replacement interventions.

Materials and Methods: The paper investigates three individual cases of spruce forest cultures on three localities in the hilly part of Central Croatia in the fifth decade of age. Two of three stands were completely destroyed by the storm event during the year 2013. The experiment was established in the spring of 2010 using randomised block design with three replications. Based on total tree height (H) and diameter at breast height (DBH) the following parameters were calculated: wood volume (V), basal area (B) and slenderness coefficient. Descriptive statistics and correlation analyses were made in STATISTICA 8.2.

Results: The results show overstocking, unfavourable structure and unfavourable slenderness coefficients (>80:1) in both cultures which were completely destroyed by wind. The correlation among variables revealed a significant relationship for all localities ($p<0.05$) when slenderness coefficient was compared with B and V (negative), but there was no correlation with H.

Conclusions: Research supported the claim that slenderness coefficient and stand structural analysis can be good predictors of damages caused by wind. With respect to the forthcoming increase of frequency and severity of storm events we propose to take evaluation of tree resistance into consideration prior to all silvicultural activities (especially high intensity interventions such as replacement/regeneration). Improved stability of trees against wind should be a silvicultural goal already from the first thinning (higher intensity thinings from below). In the case of unstable stands canopy cover should be opened cautiously to provide the remaining trees an opportunity to slowly respond to space increase. It should be noted that these initial findings should be supported by a more extensive research in the future.

Keywords: general stability, replacement, silvicultural guidance, thinning, afforestation

INTRODUCTION

Planted forests gain on their significance with the growing needs for timber, carbon sequestration and other non-wood products [1]. This is due to their high wood production and their role in loosening the production pressure from natural forests, acting as an important complementary, not their alternative [2]. In this respect Norway spruce (*Picea abies* /L./ Karst.) (further on - spruce) has a prominent role both in Europe [3] and in Croatia [4]. In addition, high occurrence of natural disturbances in natural forests adds to the importance of spruce monocultures through reforestation efforts. Moreover, due to their ameliorative role in preparing the site for stands with natural species composition [5], they have been highly important in afforestation and reforestation interventions for decades in Croatia.

Management driven exclusively by financial gain resulted with less input into silvicultural interventions in early stages of stand development. Because of this fact, growing stock was accumulated in many spruce cultures in Croatia [6]. In turn, this often left trees in a state of more competition and increased stress factors compared to trees in forest stands managed by "close to nature" principles. Problems related to low general stability of spruce cultures arose with the increase of storm events and bark beetle attacks. The avoidance of early thinning resulted in a stand structure, characterised by low tree vitality and unfavourable shape of trees, which showed higher susceptibility to the influence of windstorms. Forest damage by wind is an important cause of economic loss in commercial forestry for the Republic of Croatia as well as for many European countries [7-9], which is why windthrow resistance of trees represents a significant issue for all Croatian forests. Specifically, most of the annual cut in coniferous forest cultures is accomplished through sanitary and savage cuttings with lowered financial gains and lower value of wood assortments. In this respect, spruce cultures have had the highest share in salvage cut in recent years [6]. Reforestation is more expensive and includes more biological risks (in terms of soil loss, extreme influences on young plants etc.) in relation to timely replacement interventions. In turn, it has strong influence on stand properties and possibilities to regain natural composition of forests.

Research of windthrow stability of spruce stands is justified for several reasons. Firstly, the basic prerequisite for accomplishing productive and ameliorative functions of any forest culture is to maintain good vitality and achieve good production and general stability up to the end of stand rotation [6]. In addition, in the anthropogenic forest cultures characterized by decreased stability there is a good chance that at the end, or even well before the end of the rotation period, shelter of mature trees could be lost due to stem breakage or uprooting. At the time of conversion canopy cover should be opened significantly (by regeneration cut) in order to provide optimal light and temperature conditions for seedlings and saplings. This silvicultural activity further increases negative forcing on the remaining trees, increasing the risk of total canopy loss. Gaining insight into stability indices of present forest cultures enables us to prescribe silvicultural guidelines and to modify them according to predicted climate changes. These are the basic principles of contemporary silvicultural efforts, which are part of adaptive forest management (AFM) [10-12]. Secondly, in spite of numerous benefits, spruce is sensitive to different aspects of the changing climate [4, 5], especially abiotic influences such as wind, snow and ice loads mainly due to its shallow root system [3]. In this respect, the shape of trees can be crucial for the severity of disturbances [13]. Furthermore, negative climate influences are predicted to become more frequent and severe in the future, further adding the pressure to planted forests. Storm occurrences already increased in the last decade [14]. Climate change is not only likely to affect the growth of trees and stands but every aspect of forestry, including some of the fundamental methods employed in silviculture, such as thinning [15, 16].

Besides basic structural parameters such as the basal area, tree slenderness is also a measure recognised as a good indicator of the windthrow stability of trees [17]. The shape of trees can be influenced by silvicultural interventions, if applied early in the stand development. It indicates the "shape" of trees and together with tree vitality provides insight into general stability of planted forests. Spruce cultures are, because of their high productivity and easy establishment, well investigated in Croatia [4]. Nevertheless, there is no research connecting structural parameters, especially tree slenderness in stands devastated heavily by windstorms with stand structure and slenderness prior to devastation. Tree slenderness is used to predict sensibility to wind and storm events for conifer species for a number of years [17]. Despite significant damages caused by the windstorms in the last couple of decades, there has been little insight into the relationship between trees and stand resistance to winds in Croatia. Only Oršanić [5] investigated the structure of planted spruce forests in 1995, which are especially prone to this kind of damages. At very high speeds, wind can devastate forest stands independent of stand structure attributes such as density, species or tree dimensions [18]. Nevertheless, at lower wind speed stand structure is crucial [19]. Spruce cultures were selected because of: (i) their high importance for the country due to their high wood production [4-6], (ii) high sensitivity of spruce to climate changes, especially storm and drought events [20], (iii) higher management pressure in relation to natural stands, (iv) their high importance in preparation of the site for the retrieval of autochthonous tree species or reforestation after disturbances.

All of these facts raised the question in which cases spruce cultures should be immediately replaced [6], and which could be thinned to the end of rotation period to provide for the set managed goals and justifies the initial invested financial efforts. Thus, the paper investigates three individual cases of anthropogenic spruce stands in the hilly part of Central Croatia, two of which were completely destroyed by the storm event during the year 2013. The third withstanded the wind more successfully. The specific objectives of the paper are to: (i) provide first evidence of the relation between tree characteristics and the stability of spruce trees against winds prior to the storm event in completely destroyed spruce cultures, in comparison to slightly damaged stands, (ii) to evaluate the need of appropriate silvicultural interventions (especially early thinnings) in spruce cultures and to evaluate the need to consider resistance of trees to winds, (iii) to evaluate if there is a need for windthrow stability assessment prior to replacement interventions to prevent further financial and biological losses. The presentation of these first results aims at unravelling the way by which risks during the replacement of susceptible spruce cultures can be determined. Furthermore, it aims at assessing actual needs for the exclusion of such cultures from further management through immediate replacement with more resistant and resilient mixed species forest stands.

MATERIALS AND METHODS

Research Area

Research was conducted on three localities in central part of Croatia. The source of information on climate, relief, and past management were forest management plans [21, 22]. Specific trial plot data (e.g. inclination, altitude, exposition and soil characteristics) were gathered in the field (Table 1). Experimental plots on localities A and B are situated in the hilly area, on mild slopes, in the vicinity of Jastrebarsko (170–184 m a. s. l.). These trial plots have mild inclination (0–10˚) and south-west exposition. Climate of the area is warm to moderately humid (Cfwbx'' according to Köpen). Winters are cold, summers are fresh, while the climate is altogether humid. Mean temperature of the coldest month ranges between 18°C and -2°C. Winter is the driest part of the year, while the rain period is divided into spring (April to June) and autumn maximum (October). Mean annual air temperature is 9.8°C, 19.8°C in the warmest month (July) and -1.1 in the coldest month (January). Precipitation is evenly distributed during the year, with an exception of the maximum in June (96 mm) and autumn (94 mm). Mean annual precipitation in vegetation period is 87 mm (monthly values). The bedrock on the area consists of quartz sands, gravel and clay, while the predominant soil types are pseudogley, illimerized soil on loess and dystric cambisol (with inclusions of eugley and colluvium). From the aspect of potential vegetation this is the area naturally dominated by mixed European hornbeam – sessile oak forests (*Carpino betuli-Quercetum roboris typicum* Rauš 71).

Experimental plots on locality C are located on the north-west slopes of Medvednica Mountain in the vicinity of Zagreb. Climate of the area is the same as on the localities A and B (Cfwbx'' according to Köpen). Mean annual air temperature is 6.2°C. The lowest temperatures of the area (below 0°C) appear in the months from September to December and from January to May. Mean temperature of the coldest month ranges between 18°C and -2°C. Winter is the driest part of the year, while the rain period is divided into spring (April to June) and autumn maximum (October). The temperature of the warmest month (July) is 19.8°C, and of the coldest month (January) it is -1.1. The duration of the vegetation period is limited by the temperature threshold with the average daily temperature of 10°C (from 192 up to 200 days). On this area the mean annual air humidity ranges from 77 up to 83%. Annual rainfall amounts to 1 249 mm (700 mm or 56% in the vegetation period). Predominant pedosystematic unit is formed by dystric cambisol on methamorphic and clastic rocks. From the aspect of potential vegetation area the surrounding of the spruce monoculture is naturally dominated by mixed silver fir – European beech forests (*Festuco drymeiae–Abietetum* Vukelić et Baričević 2007). The main wind directions are SE (5%) and NW - N with 22.4% of occurrence. This area has double average value of wind intensity (according to Beaufort) than the rest of the surrounding lowland area.

The Experimental Design

The experiment on spruce cultures was established in the spring of 2010 using a randomised block design with three replications. In these field tests, three trial plots (10×10 m) were set in spruce monocultures on localities A and B, while on the locality C 16 plots were set (10×10 m). More detailed description of the experimental plots and site conditions are provided by Tijardović [6]. Despite the fact that trial plots were relatively small (three repetitions 10×10 evenly distributed on the area of studied spruce culture) we would like to emphasize that the structure of cultures is one-layered and very homogenous both in vertical and horizontal sense. The high homogeneity throughout whole spruce cultures is so high that there was no real need to include large trial plots (e.g. 0.25 ha) as it is usually used for determining the structure of heterogeneous forests. All investigated spruce monocultures were in the fifth decade of age based on the age of individual spruce trees determined through the analysis of tree rings (on felled trees during thinning and sanitary cuts). Prior to the establishment of spruce monocultures on localities A and B the area was used for forestry purposes, while the area of locality A was affected by forest fire and reforested (mixed silver fir-European beech forest). Spruce cultures on localities A and B were thinned only by sanitary cuts, while spruce culture on locality C was regularly thinned (selection thinning).

Field Measurements and Statistical Analysis

For this research total tree height (H) and diameter at breast height (DBH) were measured manually in the year 2010 (fifth decade after the establishment of cultures). Based on DBH and H, wood volume (V), basal area (B) and slenderness coefficient wood volume were calculated. Wood volume was calculated using local tariffs. Descriptive statistics for all parameters and the tested correlation were calculated (type I error (α) of 5% was considered statistically significant). H/DBH ratio (slenderness index) is as an indicator of the stem form [23] and is calculated rather easily, but both values have to be in the same unit (e.g. m). Regarding the fact that immense spruce decline appeared near trial plots, the vitality of trees was also determined and analysed (in two degrees: 1 – healthy trees, slight or moderate crown defoliation, <60% of needle loss; 2 – severe defoliation or dead trees, >60-100% of needle loss including needle yellowing). All analyses and graphs were made by using STATISTICA 8.2 statistical programme [24].

TABLE 1. Basic information on anthropogenic Norway spruce forest cultures included in the research.

Locality	Study plot code	Coordinates	Altitude (m)	Inclination (°)	Exposition
Dornja Kupčina	A	N 45°38'33.3"; E 15°33'41.9"	182-184	0-10	SW
Izimje	B	N 45°38'12.1"; E 15°34'16.6"	170-177	0-10	SW
Bistranska gora	C	N 45°53'33.5"; E 15°55'13.2"	729-740	10-30	N/NW

RESULTS

General Description of Studied Spruce Cultures and Tree Slenderness

The results showed that, on average, trees were more slender on localities A and B in comparison to locality C (Figure 1). On trial plots on locality A Norway spruce is also the sole tree species (100%), but this forest culture is denser than the aforementioned culture. From DBH, H and their ratio, it was determined that not one tree has favourable slenderness coefficient (ratio<80:1). Trees with slenderness in border classes summed up to 5.5% (80:1 to 90:1). Even trees with values higher than 200:1 were found. Consequently, almost all trees in this subdepartment have been uprooted due to the storm event in 2013, which was the year when measurements were completed. Out of 181 trees 143 trees were healthy (79.01%), while the remaining 38 trees were dead (21%). Mean tree volume on the trial plots amounted to 0.14, with minimum value of 0.01 m^3 and maximum of 1.73 m^3 (Figure 2). Descriptive statistics for all parameters and localities is given in Table 2.

In all three repetitions on locality B the only tree species in the stand was spruce (154 trees on 3×100 m^2), which makes this forest culture a monoculture. Total tree height (H) and DBH ratio is unfavourable for 98% of trees (>80:1), while 11.9% of trees are in border slenderness classes (80:1 to 90:1). The vitality of trees shows that 74% or 114 trees are healthy, while 26% or 40 trees are in the highest degree of decline (totally dead). Mean tree volume on trial plots has the lowest value out of all localities and amounts to 0.04 m^3, but with the smallest standard deviation (0.05 m^3). On trial plots as many as 47 trees are thinner than 7 cm, which makes 30.5% of total tree number.

According to species mixture, forest culture on locality C is mixed Norway spruce–silver fir forest culture. Out of 144 trees on trial plots (1600 m^2) 108 or 75% are spruce trees, 19.4% or 28 silver fir trees and the remaining 5.6% includes European beech, European hornbeam and maple. Forest culture on this locality is characterised by higher dimensions and better slenderness coefficient of spruce trees. Favourable slenderness coefficient possesses 51.4% of trees, while 21.49% are in border values (80:1 to 90:1). No trees were registered in slenderness class above 150:1. Tree volume on this locality has the highest value and amounts to 0.42 m^3, with the maximum value of 1.62 m^3. Basal area is also the highest with 0.051 m^2, showing the highest standard deviation (0.04 m^2), as well as the highest standard deviation of volumes (0.38 m^3). Registered trees lower than 7 cm were mainly silver fir trees, which spontaneously appeared in the forest culture. Even though all trees were healthy at the beginning of the research (in 2010), around 25% of trees died out in the next three years due to bark beetle outbreak.

TABLE 2. Descriptive statistics for all analysed parameters and localities.

Locality	N (number of trees on sample plots)	Variable	Mean	Minimum	Maximum	Standard deviation
A	181	DBH (cm)	9.8	1	22	4.56
		Tree height (m)	11.56	1.7	18.8	4.51
		Basal area (m^2)	0.019	0.00008	0.038	0.008
		Tree volume (m^3)	0.05	0.001	0.26	0.06
		Slenderness coefficient	123.1	62.5	325	26.8
B	154	DBH (cm)	9	2	20	4.48
		Tree height (m)	9.47	1.9	16.9	4.14
		Basal area (m^2)	0.008	0.0003	0.031	0.007
		Tree volume (m^3)	0.04	0.001	0.25	0.05
		Slenderness coefficient	109.6	30.8	162.7	18.5
C	108	DBH (cm)	23.3	7	46	10.45
		Tree height (m)	18.02	4.9	25.9	6.63
		Basal area (m^2)	0.051	0.004	0.166	0. 04
		Tree volume (m^3)	0.42	0.01	1.62	0.38
		Slenderness coefficient	80.9	52.2	135	15.1

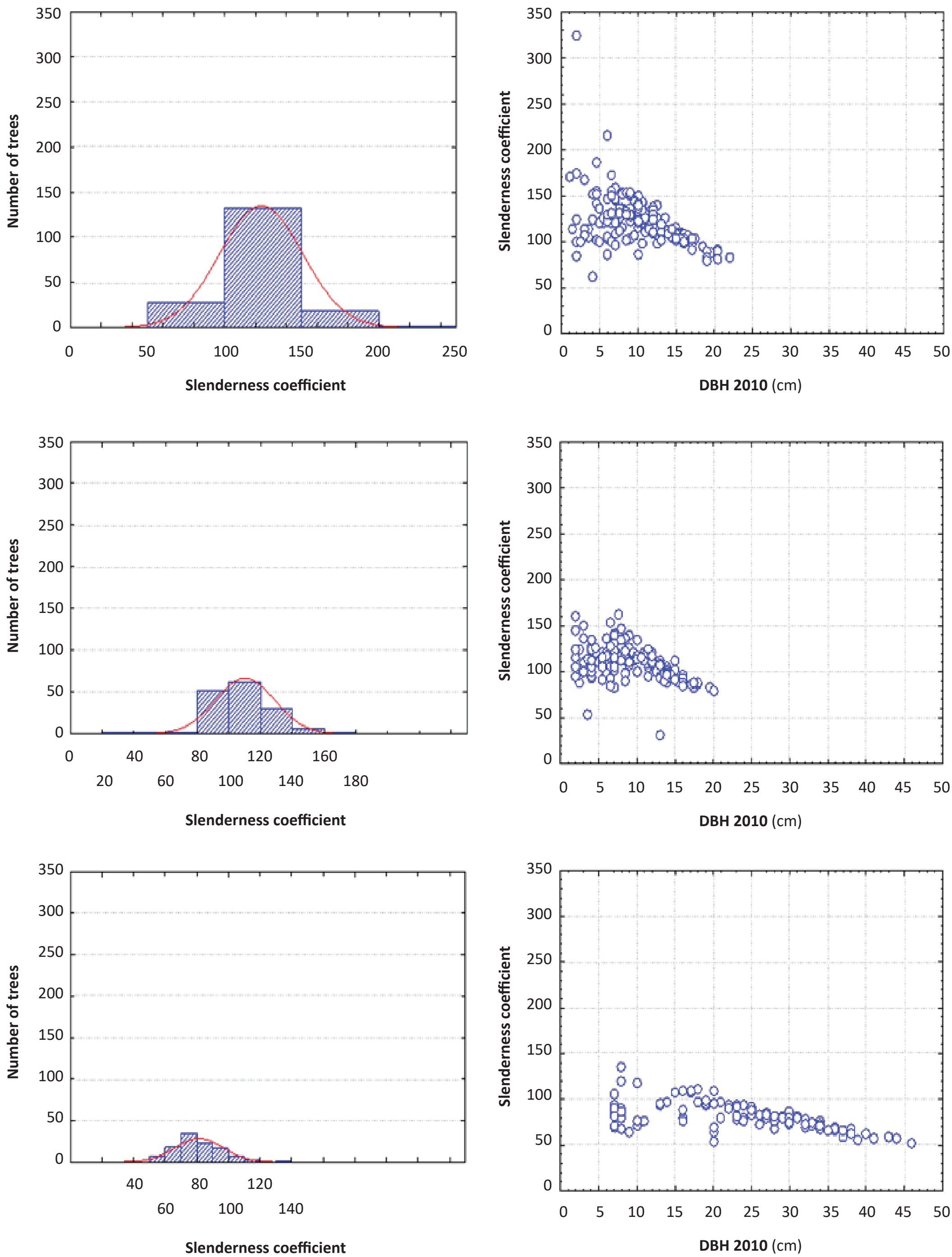

FIGURE 1. Distribution of trees according to tree slenderness for the three spruce cultures included in the study (location A – upper, location B – middle, location C – bottom).

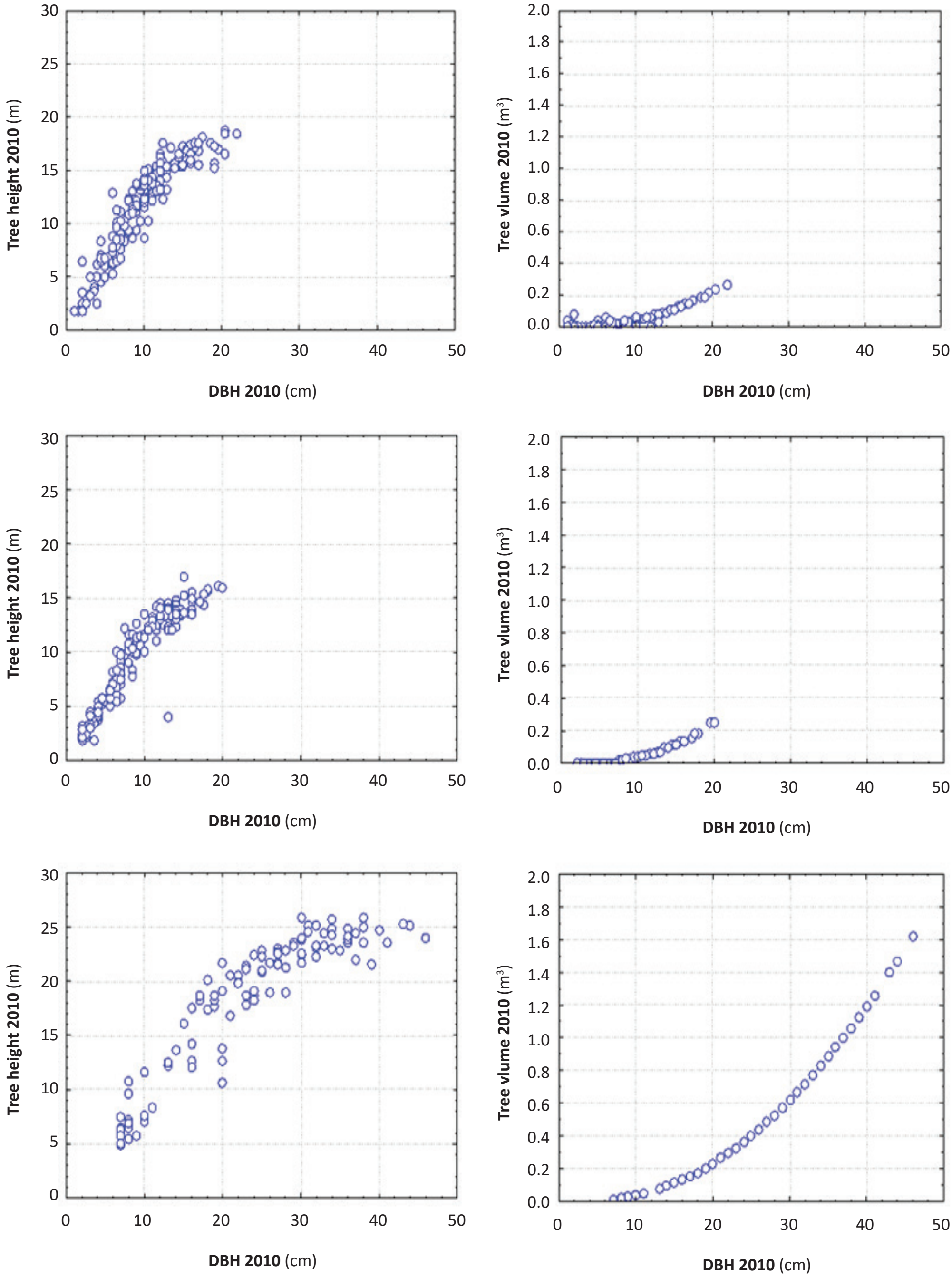

FIGURE 2. Distribution of trees according to diameter at breast height and tree volume (location A – first row, location B – in the middle, location C – bottom row).

Correlation of Tree Slenderness and Structural Parameters

The correlation among variables revealed the significant relationship for all localities (p<0.05) when slenderness coefficient was compared to basal area and tree volume. There is no significance in correlation with tree height (*r* ranged from –0.10 to –0.35). The correlation between slenderness coefficient and tree volume is negative for all tree localities.

DISCUSSION

The Need to Address Windthrow Resistance of Trees

Besides productivity and financial gain, one of the most important roles of spruce cultures is their ameliorative role of preparing the soil for autochthonous late successional tree species, as well as protecting them from adverse climatic influences [4, 5]. The need for planted forests (forest cultures) will increase in the future [25]. Thus, importance of forest culture stability is especially relevant at the end of the rotation period. Nevertheless, significant intrusion into the structure of forest cultures caused by seeding cut, which could not be avoided because optimal conditions for seedlings and saplings have to be provided, additionally exposes trees to wind [13]. Therefore, for Norway spruce, as a tree species with shallow, plate-like root system, which is especially prone to uprooting and stem breakage, determination of stability against wind is a basic prerequisite of meeting the set production goals. It is crucial for successful replacement of spruce cultures as well. Mast years additionally influence crown instability [5], while other possible negative influences are former management, bark beetle and fungi presence, damages which emerged during cutting and wood exploitation, site pollution and global climate changes [26].

There is a need to investigate and to create a method of assessing the risk of wind damage since it could have an important influence on silvicultural decision making, especially in terms of climate change adaptation strategies. Dobbertin [27] finds that the probability of damage increased with stand height, development stage, percentage of conifers, soil-water logging and soil depth in the areas affected by Vivian (in the year 1990) and Lothar (in the year 1999) storms. Some authors propose the replacement of pure stands (especially in the case of spruce) into mixed stands to enhance stand stability [5, 7]. Comparative research of mixed forest cultures comprised of spruce and broadleaved tree species (minimal share of broadleaves 20-40%) and spruce monocultures, showing that mixed cultures can support ecological, economic, social and cultural benefits and functions in the same or even better way than monocultures (30-40%). In addition, mixed forest cultures possess better chemical conditions and better organic matter decomposition on forest floor. Since this is generally highlighted as a prominent disadvantage of spruce cultures, admixing tree species could have a positive effect on general stability as well. Even though admixing beech into spruce monocultures resulted in growth stimulation, this depends strongly on site conditions [28-32]. Therefore,

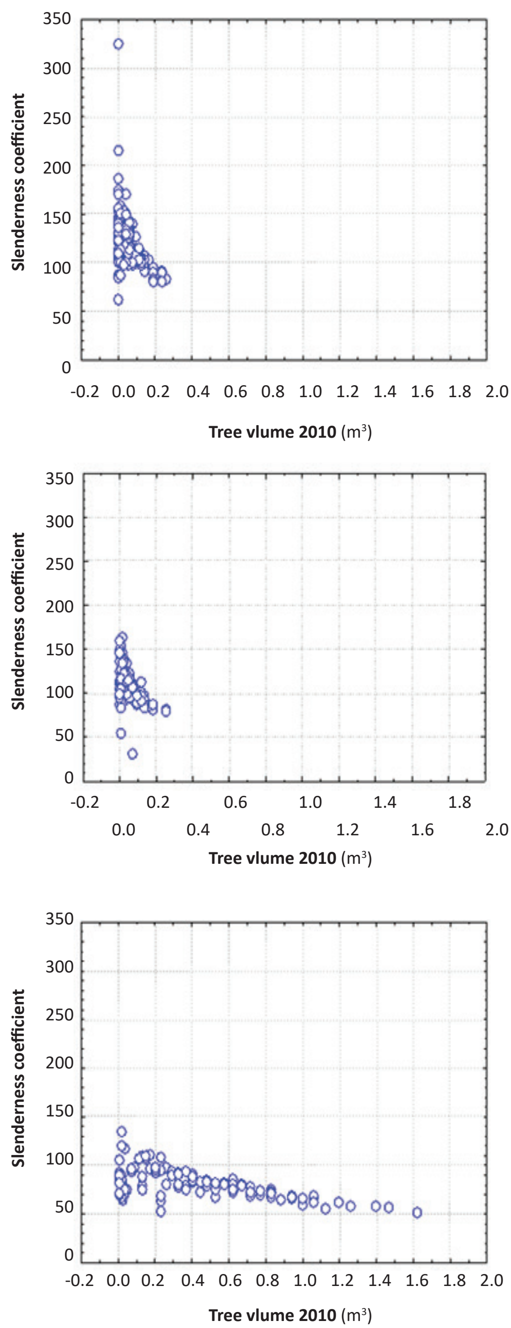

FIGURE 3. Dependence of slenderness coefficient and volume for studied spruce cultures on all localities (location A – top, location B – middle, location C – bottom).

this should be further investigated especially in the Republic of Croatia where these kinds of research are scarce. The combination of broadleaved tree species admixed into a spruce monoculture can be diverse and they depend on elevation. For example, spruce can be mixed with silver birch, *Acer pseudoplatanus* (L.), and small-leaved lime [5, 33-38]. In addition, conifers are more sensible and possess lower stability threshold in comparison to broadleaves. They retain needles during the winter, which has significant effect on static stability (the so-called "wet snow"), but also on the collection and retainment of pollutants which can be even three times greater than in stands consisting of broadleaves [39-43]. Species mixtures could present better solution for the production, amelioration and enhancement of stability. Related studies are scarce even at the European level.

Projected changes in precipitation and air temperatures from Meteorological and Hydrological Service of the Republic of Croatia point to the unfavourable trend for the areas of mountain and central part of the country, enhancing negative effects on forest ecosystems [44, 45]. In addition, in the last few years an increase of storm events occurrence was recorded on the whole continent, while the predictions point to even quicker rise in the future [14]. Lower frequency of soil freezing from late autumn to early spring, which is the period with highest wind occurrences, will increase wind damages in the future [46]. Other influences of global warming on forest cultures are yet to be further investigated [47, 48]. In the Republic of Croatia, there is a lack of scientific research which aims at developing instruments for estimation of storm occurrences, sensibility of forests to climate changes, as well as instruments for management adapted to such changes. In some European countries such instruments have already been developed and first successful application has been recorded [13, 49-53]. Significant loses in natural forest stands proved that damages caused by wind, snow and ice are a major disturbance interacting with forest development processes, which is why there is a strong need for this kind of research and its predictions.

Regarding the age of studied stands it can be pointed out that the avoidance or too low thinning intensities have irreversible influence on the spruce culture in the fifth decade (probably even earlier, but this has not been proven by the study). Thus, we stress the importance of appropriate species composition and the importance of early thinnings for the achievement of optimal tree characteristics, vitality, and for accomplishing the expected biological and financial gains altogether. The collected data are applicable to the hilly part of Central Croatia, for which the need of addressing stability issues is emphasized.

Indicators for the Evaluation of Stability of Spruce Trees against Winds

Basal area and tree slenderness have been used for the prediction of sensibility to wind and storm events for coniferous species for a number of years [17, 54-56]. However, this statement is true for the countries dealing with damages from strong winds for decades, while in Croatia there is a weak insight into indicators of tree resistance to winds. Tree slenderness, together with stand density data, are also needed for predictions of critical wind speeds needed for the uprooting of trees, which can be an important predictor for risk from wind damages and related management decisions. Even though stability can be predicted on the basis of crown dimension parameters (crown length and tree height ratio, crow diameter and DBH ratio, etc.), in regions with frequent snow occurrences such as the investigated areas this indicator is not accurate enough [14]. Thus, the parameters based on other tree dimensions such as basal area or tree slenderness are proved to be better predictors. Studies of tree slenderness are limited for Croatia [5] and tree resistance to winds or tree slenderness is not taken into account in regular thinning interventions. This study provided first results on the appropriateness of tree slenderness as a predictor of wind damages. The destruction of spruce cultures with the highest values of slenderness in the study was total, while spruce cultures with more favourable tree slenderness that withstanded the same storm were more successful. Regarding tree characteristics, the highest and the slenderest subjects were the most sensitive, both in terms of stem breakage and overturning. This is also proved in the studies by Peltola *et al.* [46] and Talkkari *et al.* [57]. These preliminary data should be further supported by more extensive research (e.g. including more localities, wind characteristics, etc.), especially since the importance of wind damages and the role of thinning intensities will grow in the future, and since the current insight into these issues on the national scale is weak. Interesting cases are pure forest stands in sinkholes, where spruce presents the best silvicultural option for the frost-prone areas. Here, special consideration should be given to the further studies on wind susceptibility and the related silvicultural interventions needed to enhance the stability of spruce cultures.

Regular thinning in cultures in completely destroyed trial plots on localities A and B was not conducted, while sanitary and salvage cuttings were. Research of structure on localities A and B pointed to high instability as a result of unconducted or inappropriate thinnings pointing to overstocking. Ratio 80:1 presents stability threshold for conifer species [46, 55]. On locality A, data analysis showed the most unsatisfactory structure. There was not one tree on the trial plots which had favourable slenderness coefficient (<80:1), while trees with ratio >200:1 were also recorded. On the selected trial plots, it is not justifiable to do conversion into climax tree species, so it can be concluded that basic goals set at the time of culture establishment were not met (the sites' ameliorative function was not met). That is also true if relatively low productivity or the value of the assortments are taken into account (average DBH in 45 years of age was 9 cm on locality A and 13 cm on locality B). High interspecific competition in soil up to 80 cm in depth and increased retention of precipitation on the canopy (lower amount of water that reaches soil [58]) are a direct result of a too high number of trees per hectare (ha^{-1}) caused by improper management. Lack of tending measures resulted with additional negative forcing and, consequently, increased the sensibility of trees to bark beetle attack, which was also evidenced on trial plots. High correlation of damages caused by wind and tree slenderness is also confirmed by Peltola [59]. The structure on locality C is more favourable in relation to the aforementioned localities. This culture was regularly thinned, which points to the conclusion that there is an influence of thinning on the formation of better tree characteristics. A slightly higher slenderness coefficient in another culture on Medvednica was found by Oršanić [5].

Thinning throughout the whole rotation period is a prerequisite for successful replacement as well. Good windthrow stability is needed for conversion under shelterwood when autochthonous late successional tree species composition is set as a silvicultural goal. Nevertheless, this is often neglected in management of forest cultures in the Republic of Croatia, and the resistance of trees to strong winds is not acknowledged as it should be. In addition, a better understanding of the reaction to thinning is important in order to design new thinning regimes in a changing environment [60]. Also, in some studies, the resistance of trees described by their slenderness is not only higher for suppressed than dominant trees of a particular stand, but the data indicate that slenderness is also notably smaller for trees grown under wider spacing [7]. This statement can have implications for future establishment and tending of forest cultures in terms of spacing and horizontal spatial pattern (for example, in mixed forest cultures) and it is proven with this study as well. Dominant trees possess higher stiffness in lower stem parts than supressed trees [7], so it is evident that in overstocked forest cultures without optimal vertical structure the risks of windthrow will be higher.

The Role of Silvicultural Interventions in Increasing Stand Resistance to Wind and the Need for Further Research

Basic structural characteristics (height, stem taper) are quite variable and change considerably for spruce under different silvicultural treatments [7], which implies great significance of proper and timely thinnings. This study adds tree slenderness as an important and additional characteristic, which can be influenced by proper silvicultural interventions.

Statistical analysis of the simulation results showed that wind speed is the most significant variable in explaining wind damage [8], thus pointing to the conclusion that the resistance of trees to wind can be influenced only upon certain "wind speed threshold". Up to the critical "wind speed threshold" we can and should influence positively the forming of more resistant trees. If the critical wind speed is set, that gives us the possibility to intensify the thinnings and management activities in the area with bigger risks. This, besides thinning, also incorporates better selection of tree species or species mixtures. Spatz and Bruechert [18] provide mechanistic explanation why structure is crucial. Both gravitational forces and wind loads induce bending moments, which the structure has to be able to withstand. The limit of the structure is reached if at any point the bending moment induced is larger than the critical bending moment. This in turn depends on structural parameters (the geometry of the cross-section) and properties of the material (the modulus of elasticity and the critical stresses at which failure occurs). In many cases, depending on the root-soil interaction, the bending moment on the trunk may lead to root lodging. In addition, bending under wind loads will lead to additional bending moments under gravitational loads. Whereas the young generation depends on the vitality as a prerequisite for snow and ice load resistance and flexibility, the manuscript does not tackle the youth because of the age of the stands included in the study. The expansion of research to the young generation is important to be tackled in future, especially the vitality of youth determined in the light of the growth and development of forms depending on light revealing the Honowsky index. The development of tree shape in relation to light is more complex in irregular forests as shown by Szymura [61], but the stability of irregular forest stands in relation to negative wind forcing is the highest among all silvicultural systems. Furthermore, despite the fact that these initial results reveal the relationship between tree shape and susceptibility of stands to the influence of wind, the relationship between stability and vitality should be included in further research efforts. Available studies mostly tackle tree vitality. For example, defoliation [62] and influence of drought [63] can improve prediction accuracy of models that predict tree mortality based on competition indicators and tree size alone, not taking wind damages into account. While it is known that negative influence of wind is affecting both healthy trees and trees with low vitality, and that crown recovery can be an important feature of tree recovery [64], research that would explain in detail the connection between tree vitality and susceptibility to wind would be very complex. Thus, there is a lack of scientific research which would shed more light on the connection of tree vitality and windthrow stability.

Talkkari *et al.* [57], for example, estimate the risk of wind damage by employing complex mechanistic models for predicting the critical wind speed needed to cause damage, a regional air flow model simulating relative wind climates for sites, a geographical database on forest stands in the area concerned and the probability distribution of long-term extremes in wind speed at the sites. This approach is well adapted to regular stands, but if one wants to adapt silvicultural measures in heterogeneous stands, not all trees are necessarily damaged at the same time and this kind of predictions are less accurate [8]. In Croatia there are no similar findings emphasizing the need to further proceed with research on these issues. From the aspect of stability, mixed stands also present a more or less heterogeneous forest structure, and have yet to be more investigated in the future. This kind of research is needed in the Republic of Croatia if the increase of storm occurrence is to be taken into account. Further investigations on the influence of soil type on forest damage are, however, generally required [27], and not only in the Republic of Croatia.

The existing knowledge emphasizes that the greatest risks are found in forest stands immediately after thinning or after regeneration cuts, and that risk is present in those stands which have not been thinned properly or are suddenly drastically thinned [65, 66]. This is why we advise that spruce stands in the same age as investigated, with similar structure, should not be further maintained, but should be immediately replaced, in order to lower biological and financial losses. In turn, we strongly advise that all newly established as well as young spruce cultures should be thinned regularly with respect to tree and stand resistance to wind.

Finally, it can be concluded that the monitored forest cultures possess high risks regarding replacement since their low resistance against wind prevents them to protect young and sensitive late successional tree species. Similar risks during conversion have been found by Lüpke *et al.* [3] in other parts of Europe. These findings evidently point to the fact that by influencing the forest structure we can enhance not only mechanical stability, but tree vitality and general stability as well. This can be accomplished through correct site selection and adequate afforestation practices, as well as appropriate tending throughout the whole rotation period. All these measures are crucial for the fulfilment of basic functions and goals, which are set at the time of the establishment of a forest culture. We also advise the evaluation of culture resistance to winds prior to the replacement, so that the aimed tree species composition could be selected accordingly (e.g. if the resistance is low the need to provide protection for late successional tree species against sunburn, frosts, wind and drought should be respected). In the conditions of unfavourable structure, it is strongly recommended to open canopy cover cautiously. For example, canopy cover can be opened only above regeneration areas (400 to 2000 m^2), only on 60% of the area of the forest culture, with belts of untouched canopy cover being 20 to 40 m in width [67]. Nevertheless, a better solution is to improve structure and stability with silvicultural measures already from first thinnings. Higher intensity thinings from below enhance stability indices [55, 68-70]. In mature forest cultures, which are comprised of trees with border stability indices (slenderness), a series of low intensity thinings are needed so the rest of trees would not be endangered, and also in order to leave the possibility for trees to positively react on space increase.

CONCLUSIONS

The presented preliminary results reveal the fact that avoidance or too low thinning intensities of anthropogenic spruce cultures in the first and second age class (until 40 years of age) permanently results with unfavourable shape and vitality of trees. It can be concluded that spruce cultures consisting of too slender trees should not be further maintained, but that they should be immediately replaced by more wind resistant stands (e.g. mixed species cultures). The reason for this is that they are simply cannot withstand at the present, and will not be able to withstand in the future, the influence of strong winds, especially if we consider the predicted increase of storm intensities and occurrences in the studied area and further stand destabilisation by silvicultural interventions in later development stages. If the complete destruction of studied spruce cultures, which happened recently, is taken into account, such cultures will not be able to produce expected financial or biological gains at all. We propose to get better insight into spruce tree characteristics and to evaluate their ability to withstand strong winds during the selection of trees for thinning, especially the horizontal spatial patter of such trees. The analyses of tree slenderness can also provide a good tool for predicting the critical wind speeds and the point of breakage of the managed spruce culture. In addition, tree slenderness proved to be a good predictor in this study, similar to other European studies from areas of frequent snow occurrences. Nevertheless, these are only preliminary results, which should be confirmed by further studies. In addition, proper silvicultural interventions early in the culture development are advised for achieving and maintaining optimal tree characteristics and vitality, providing favourable site conditions for subsequent replacement interventions and preventing early canopy losses.

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The Effect of Polypropylene Tree Shelters on Growth and Survival of Pedunculate Oak Seedlings (*Quercus robur* L.)

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ABSTRACT

Background and Purpose: The declining and dieback of lowland oak forests as the result of global climate change, as well as the attack of various pathogenic organisms, industrial pollution, and other negative effects reduce acorn yield and will continue to do so in the future. As a result of this fact, the areas on which artificial regeneration will be applied by planting seedlings will have to be increased. The artificial regeneration process is more expensive than the natural one, so protection measures need to be applied to minimize the loss of young seedlings.
Materials and Methods: Experimental plots were set up in the forest area of Spačva Basin. A completely randomized block design experiment in four repetitions was used, in which four variants of planting and protection of oak seedlings were examined. We tested polypropylene tree shelters and hydrophilic superabsorbent based on maize starch. Heights of the plants were measured by measuring tape, and survival was registered by numbering of dead and living plants. For statistical purposes, we have used analysis of variance (repeated measure ANOVA), which allows us to prove statistically significant difference between morphological traits of studied variants.
Results: Two years after planting, the lowest level of survival was found in unprotected seedlings (79.5%), while tree shelters provided the best conditions for seedlings survival (88.75%). In the case with the hydrophilic granules Zeba the result is slightly worse. When analyzing average height in a particular case, significantly higher plants are recorded in cases where the polypropylene tree shelters are used. The average height, with tree shelters (128.27 cm), is more than three times higher than the unprotected seedlings (37.97 cm). The addition of hydrophilic granules did not show a statistically significant difference. In cases where the seedlings were not under the tree shelter protection, the effect of hydrophilic granules was also not statistically significant.
Conclusions: Sheltering accelerated the height growth of the planted oaks substantially and also provided best conditions for seedlings survival. During the research period the usage of Zeba did not justify the purpose for which it was applied. Although the first results are promising in order to gain a complete insight into the potential of tree shelters it is necessary to record the changes and maintain the experiment for a further 2-3 years with quantification of other harmful factors that may appear (drought, game etc.) after which a more reliable judgment regarding their usefulness could be provided.

Keywords: Spačva Basin, artificial regeneration, Zeba granules, polypropylene tree shelters, *Corythucha arcuata*, *Microsphaera alphitoides,* pedunculate oak

INTRODUCTION

The decline of pedunculate oak (*Quercus robur* L.) in the last few decades has been intense in the whole territory of its areal [1-3], and Croatia is no exception [4, 5]. From the total felled tree volume of pedunculate oak trees from forests of Spačva in the period from 1996 to 2006 almost 58% referred to dead and damaged trees [6]. Changes in the water regime (decrease in groundwater level or increase in humidity, or the so-called "swamping"), along with the influence of droughts [6], water and air pollution, and tree defoliation due to insects or fungi, are the most important factors that cause dying of oak trees in Croatia [7, 8]. Most recently, new invasive species the oak lace bug (*Corythucha arcuata*), which has potential negative impact, has been spotted in pedunculate oak stands in Croatia [9], but changes in the vegetation cover have been recorded as well, in the form of movement to drier plant communities [10, 11]. Along with all the above mentioned facts, as well as the trend of average, maximum and minimum air temperature rise throughout Croatia [12] and models predicting decrease in quantities of rainfall in the wettest but also in the driest months [13], management of oak stands will require adaptation to the actual occurrence of climate change, both in Croatia and south Europe [14]. Reconstruction of these stands in the future will be a real challenge and an increase in the intensity of the forest works can be expected, as well as changes in the ways of management so far, in terms of adaptive forest management. The main characteristic of adaptive forest management is the flexibility and adaptation of all activities to the specific biological, ecological and structural features of forest ecosystems and the changes that occur in [15].

Global climate change and the attack of various pathogenic organisms lead to the decline of forests or dieback of trees in forest. Lowland forests of pedunculate oak and other lowland tree species are most intensively affected by these occurrences [16, 17]. This process manifests itself as the defoliation of tree crowns [18, 19]. With increased intensity of crown defoliation, the yield of acorn decreases as well [20]. Forest areas with increased intensity of defoliation or the share of areas with significantly defoliated crowns of oak trees are growing [18], and it is expected that the area on which artificial regeneration with seedlings will have to be applied will increase as well. The artificial regeneration process is more expensive than the natural one, so the loss of seedlings is not economically acceptable, because in that case the whole work would have to be repeated several times.

Competitiveness of weeds and game is the most harmful factor that reduces plant growth and survival. Dense weeds quickly overgrow seedlings, overshadow them, and reduce the intensity of photosynthesis, which affects plant vitality and height gain [21]. In addition, weeds are very competitive for water and nutrition to planted young seedlings. In winter, the overhanging parts of weeds mechanically press and bend the seedlings. The game cut off the tops of seedlings and thus reduce their competitiveness compared to the weeds surrounding them [22].

Polypropylene tree shelters, which in 1979 were introduced by the English forester Graham Tuley, can significantly reduce the negative impact of weeds and game. As reported by Jeffrey and Stephens [23] due to wild game browsing the leaves of unprotected black walnut, seedlings were higher at the start of the experiment than three years later, while the protected seedlings grew from 36.1 cm to 89.0 cm. Liović [24] states that 20% of unprotected plants had a cut-off top of the seedlings.

The use of the polypropylene tree shelters does not exclude the use of herbicides (used during preparation site for stand regeneration and for several sprayings after planting), but fewer quantities are spent because the whole surface for regeneration is not needed to be sprayed. After the planting, once a year herbicide spray needs to be applied to the 1 m diameter around each tree shelter, which is economically and ecologically more favorable [25].

The use of the polypropylene tree shelters also reduces to some extent the onset of plant disease (powdery mildew) due to the specific climate within it [26]. Similarly, Liović [24] in his research states that 15% of unprotected control plants were browsed by oak defoliators while seedlings within the shelters were not damaged. The basic advantage of polypropylene tree shelters is the accelerated height increase of seedlings and their survival, as reported by many authors [24, 27-29]. The rapid height increase shortens the time of the plant growing in the shadow of weeds and has a significantly higher probability of survival.

Pedunculate oak seedlings and offspring were particularly sensitive to the conditions of weed competition because of their great demands for light. Therefore, in the first few years after planting, it is necessary to tend young oak plants, i.e. to release them from weeds. The procedure is not easy because of the fact that on eutrophic and wet soils the weeds grow rapidly and turn into lush (Figure 1). Therefore, during the year it is needed to tend them at least twice. Mechanical treatment with a large number of people is expensive and, because of young people leaving to work abroad, there is a problem of the lack of workers today. The use of herbicides on large surfaces is neither ecologically nor economically justified. Due to the problems mentioned above, the aim of this study is the implementation of forest regeneration methods into forestry practice which are not labor intensive and which include less use of pesticides.

MATERIALS AND METHODS

Experimental plots were set up (November 2014) in the area of Forest Administration (FA) Vinkovci, Forest Office (FO) Županja, Management Unit (MU) Kragujna, Rašćica, Compartment (Comp.) 35a. This area belongs to the forest

FIGURE 1. Eutrophic and humid soil supports the rich growth of weeds.

area of Spačva Basin, one of the largest complexes of lowland pedunculate oak forests in Europe, where the management class of oak forests occupy 96% of them and spread over 40.000 ha (1/5 of all pedunculate oak forest stands in Croatia). Because of its specific hydrological characteristics, almost the whole area is situated on alluvial flat terrain with moderate micro-elevations. The main types of soil are accompanied by a topological gradient: pseudogley and pseudogley-gley dominate on river terraces, while different types of gley soil are found on micro-elevations and micro-depressions [30].

Research plots have been placed in relative forest soil area that had been for a long time overgrowing with scarce bushy vegetation, sometimes used as wild game feeding grounds. The scope of the experimental field encompasses the area of light-strips along the forest road that has been used for a long time for this purpose (Figure 2). There is also a trench along the forest road for the purpose of drainage (as the element of the road) with additional enlargement for its maintenance. Nearby old oak stands on micro-elevation belong to the forest community of common hornbeam and pedunculate oak forests (*Carpino betuli - Quercetum roboris*, Rauš 1969) located on the edge of the micro-depression area where the experimental plots are situated.

FIGURE 2. Trial location (FA Vinkovci, FO Županja, MU Kragujna, Rašćica, Comp. 35a).

The climate in this part of Croatia is continental. The average annual temperature is 11.4ºC, the hottest month is August, with a moderate temperature of 21.8ºC, while the coldest month is January, with an average temperature of -0.5ºC. The average rainfall is 686 mm, with a maximum in June [31].

The object of the study are pedunculate oak seedlings used for the regeneration of oak forests in this area through various methods. In the study a completely randomized block design experiment in four repetitions was used, in which four variants of planting and protection of oak seedlings were examined (Figure 3).

Each repetition consisted of four variants: seedlings protected with polypropylene shelters with addition of hydrophilic granules Zeba (SŠHG), seedlings protected with polypropylene shelter (SŠ), seedlings without protection and Zeba (S), and unprotected seedlings with addition of Zeba (SHG).

Zeba (United Phosphorus, Inc.) is a superabsorbent based on maize starch whose high water absorption capacity (500 times their own weight) is used to improve the supply of water to seedlings during the dry season [32, 33]. Additionally, it is completely biodegradable. Numbers of seedlings are shown in Table 1.

Polypropylene shelters are cream-colored, green or brown, made of double layer polypropylene, resistant to UV rays. The upper edge of the tree shelter was bent outwards to avoid damage to the plants after it had overgrown. Due to the more economical and easier transport and storage, the shelters selected for this experiment are packed in 4 pieces, one in the other, so their diameters are between 8.3 and 10.8 cm. They are manufactured to be from 0.2 m high for

TABLE 1. Different cases and the number of seedlings of pedunculate oak.

Case	Number of seedlings (pieces)
SŠHG	280
SŠ	280
S	800
SHG	800
Total	2160

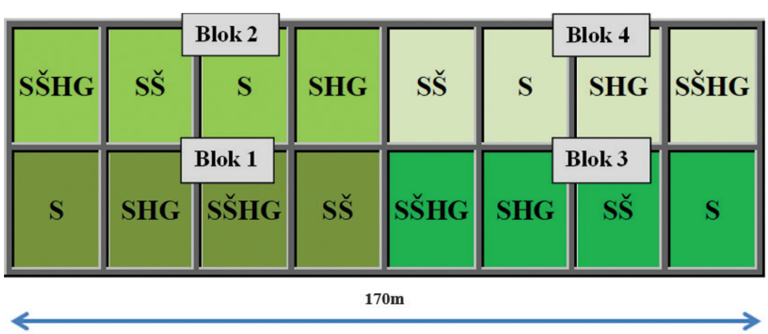


FIGURE 3. Completely randomized block design experiment in four repetitions.

the protection from voles and up to 1.8 m for the protection from wild game (common and roe deer). We used 1.2 m height shelters. The shelter is secured using a stake and is fastened with two plastic straps.

In order to reduce the negative impact of weeds, during the month of May around every shelter in the circle of 1 meter diameter all vegetation was sprayed with herbicide based on the glyphosate active substance (Figure 4). However, the weeds continued to grow lushly, so in 2016 herbicide was applied in diameter of 1 meter around each shelter again.

At the end of the vegetation period, for each seedling the total height were measured by measuring tape and the survival were established by numbering of dead/living plants.

FIGURE 4. Herbicide treatment around tree shelters.

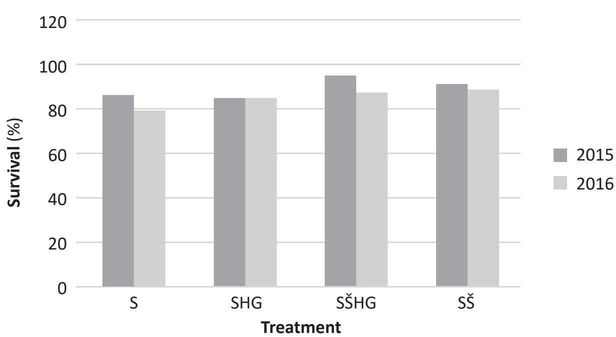
Any biotic factors that occurred during the study period and that could negatively affect the growth and development of seedlings were just visually recorded without analyzing the impact on the growth and development.

With the aim of answering set research question, we have used analysis of variance (repeated measure ANOVA), which allows us to prove statistically significant difference between morphological traits of studied variants. In cases when statistically significant difference between variants was confirmed, it was necessary to determine which variants differed. Thus, differences gathered by repeated measures ANOVA were tested with „post hoc" LSD test. Type I error (5%) was regarded as statistically significant. Furthermore, descriptive statistics was compiled for acquired data. Data analysis was conducted using Statistica software (StatSoft Inc. 2007) [34]. The condition of variance homogeneity is satisfied.

RESULTS AND DISCUSSION

Survival

The results are shown in tabular form (Table 2) and graphically (Figure 5). Planting which includes the protection and support by polypropylene tree shelters provided the best conditions for seedlings survival, so in that case 88.75% seedlings survived. In the case where Zeba were used the results are slightly inferior (87%) and it can be said that they do not justify its application. The lowest survival rate was in the case of unprotected seedlings (79.5%). Seedlings without protective shelters, but with the addition



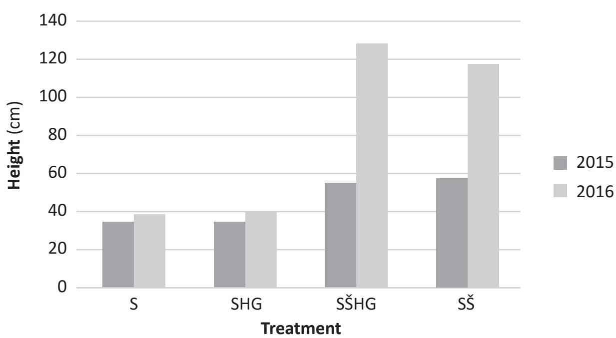


FIGURE 5. Survival and height of seedlings during research period.

of hydrophilic granules have about 5% better chances of survival. These results are in agreement with the results of Liović [35], in which the mortality rate of oak seedlings protected by shelters was 6% and unprotected seedlings 24%, but we must emphasize that Liović [35] did not study effects of Zeba. In Valkonen [36] sheltering improved the survival of planted seedlings of pedunculate oak a little, but the difference was not significant.

TABLE 2. Survival and height of seedlings at the end of 2015 and 2016 vegetation.

Case	Survival (%)	Height (ME ± SD) (cm)
	2015	
SŠHG	95.57	54.94 ± 17.26
SŠ	91.97	56.64 ± 17.37
S	86.46	34.36 ± 9.70
SHG	85.54	34.71 ± 9.41
	2016	
SŠHG	87.00	128.72 ± 33.42
SŠ	88.75	117.27 ± 41.27
S	79.50	39.04 ± 12.62
SHG	84.75	37.97 ± 12.01

ME - mean; SD - standard deviation

Height

ANOVA showed statistically significant difference between variants height during research period (ANOVA: F=18.156, p<0.001). These points to the fact that variants do not act in a similar way during the investigated years. When analyzing the mean height in a particular case (Figure 5, Table 2), it was found that the results were higher in cases where polypropylene tree shelters are used. The average height with tree shelter protection is more than three times bigger than of the unprotected seedlings. The results are comparable to the measured plant heights after 2 years of research in the Lantagne [29]. In this experiment, control seedlings were three times lower than those protected by the shelters since the weed competition was significantly stronger. Namely the weeds around the shield were treated with a systemic herbicide that destroys overground parts of the weed but also the root of the weeds. On the other hand weeds on control unprotected seedlings were mechanically removed and shortly thereafter re-growth and compete for nutrition, water and light. Liović [35] presents similar results: 6 vegetation periods after planting, the average height of oak planters protected by shelters was over 200 cm and the height of unprotected seedlings 50 cm, while some seedlings reached a height of up to 4 m. In Valkonen [36] sheltering had accelerated the height growth of the planted oaks substantially. Other studies under different conditions had similar results regarding height growth and survival [29, 37, 38]. Such increase in height allowed a rapid outgrow of the weed competition zone (Figure 6) and brought all the benefits that have resulted in such heights. We believe that such a large difference in height between unprotected and sheltered seedlings was due to the effective application of systemic herbicides that reduced the competition of weeds in protected plants for a long time.

The tendency of trees to grow taller with increasing water availability is common knowledge. There are also numerous studies about tree height and water availability [39-41]. Based on that studies and high water absorption capacity of Zeba we hypothesized that variants with added Zeba would be taller than variants without it. But our results showed that addition of hydrophilic granules affected the average height increase only by about 10 cm. In cases where the seedlings are not sheltered, the effect of hydrophilic granules is very small, around 2 cm.

FIGURE 6. Faster growth makes it possible to quickly leave the competition zone of weeds.

SŠHG significantly differs from SŠ (p<0.001), S (p<0.001) and SHG (p<0.001). SŠ significantly differs from S (p<0.001) and SHG (p<0.001). There is no significant difference between S and SHG (p=0.315).

Biotic Factors

During the year 2015, attack of the oak lace bug (*Corythucha arcuata* Say) and the oak slug sawfly (*Caliroa annulipes* Klug.) have been recorded during the trial (Figure 7). Pesticides were not used.

FIGURE 7. Attack of the oak lace bug (green leafs of field maple for comparison).

During the year 2016, an attack of powdery oak mildew – (*Microsphaeraa alphitoides* Griff. et Maubl) that covered almost all plants that overgrow the height of the shelter was recorded (Figure 8). Fungicide protection measures were not implemented.

FIGURE 8. Attack of powdery oak mildew.

Inside the shelter powdery oak mildew is visually weaker or is not present (Figure 9). Stakes (with a bigger white mass on outer wood) decayed in two years, broke and the shelters fell, so the plants bent down as well (Figure 10). Fortunately, the plants did not break, so it was enough to replace the stake and reset the shelter.

FIGURE 9. Inside the shelter powdery oak mildew did not generally developed.

FIGURE 10. Prostrated plan.

CONCLUSIONS

During the two-year period of research, in case where the polypropylene shelters were used, seedlings are found to be significantly higher than in non-sheltered cases. The average height of the shelter-protected seedlings (128.27 cm) is more than three times taller than of the unprotected seedlings (37.97 cm). Likewise, survival of unprotected seedlings that were most exposed to harmful factors was 79.5%, while planting within the shelter provided the best conditions for seedlings survival (88.75%). We believe that such a large difference in height between unprotected and sheltered seedlings was due to the effective application of systemic herbicides that reduced the competition of weeds in protected plants for a long time. During the observed study period, the use of the Zeba superabsorbent which is well-known for its water absorption capacities, did not significantly affect the growth and development of seedlings. In order to gain a complete insight into the potential of protection in terms of protecting planters from unfavorable factors, it is necessary to record the changes and maintain the experiment for a further 2-3 years with quantification other harmful factors that may appear (drought, game etc.) after which a more accurate judgment on their usable value could be given. Also, one must be aware that using pedunculate oak for artificial regeneration without shelters requires repeated weed control measures for a longer time period– a costly burden that forest owners may tend to underestimate at the planning stage.

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