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Height to Crown Base Modelling for the Main Tree Species in an Even-Aged Pedunculate Oak Forest: A Case Study from Central Croatia

Saray Martín-García[1,2,*], Ivan Balenović[3], Luka Jurjević[3], Iñigo Lizarralde[1,4], Krunoslav Indir[3,5], Rafael Alonso Ponce[1,4]

(1) föra forest technologies SLL, Campus Duques de Soria s/n, ES-42004 Soria, Spain; **(2)** Universidade de Santiago de Compostela, Departamento de Enxeñaría Agroforestal, Biodiversity-LaboraTe-IBADER, ES-27001 Lugo, Spain; **(3)** Croatian Forest Research Institute, Division for Forest Management and Forestry Economics, Trnjanska cesta 35, HR-10000 Zagreb, Croatia; **(4)** Sustainable Forest Management Research Institute, University of Valladolid-INIA, Campus Duques de Soria s/n, ES-42004 Soria, Spain; **(5)** Croatian Forest Research Institute, Research Centre for Urban and Private Forests, Vilka Novaka 50c, HR-42000 Varaždin, Croatia

*** Correspondence:** e-mail: saray.martin@fora.es

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ABSTRACT

The height to crown base (hcb) is a critical measure used in many investigations as an input variable to investigate the vigour of the stands, the social position of the trees, and to evaluate the behaviour of forest fires, among other uses. Though measuring height-related variables in the field is always time-consuming, the foremost benefits offered by modelling hcb are that it permits to generalize and average a very uneven attribute and, furthermore, provides insights about which tree and stand variables have a significant impact on hcb. However, there are many species in which models of the crown base height have not been developed in Croatia. The objective of this research was to develop a height to base crown model for each of the main species present in the two-layered mixed stands of this study. According to previous investigations, logistic models provide the highest precision and require the lowest inventory cost owing to less frequent measurements. Tree- and plot-level variables with distance-independent competition indexes were studied in the fitting model. In this research, we obtained models for the main stand species: *Acer campestre* (root mean squared error (RMSE) = 2.28 m, R^2 = 82.80%); *Alnus glutinosa* (RMSE = 1.78 m, R^2 = 85.36%); *Carpinus betulus* (RMSE = 2.47 m, R^2 = 67.55%); *Fraxinus angustifolia* (RMSE = 2.46 m, R^2 = 82.45%); *Quercus robur* (RMSE = 2.60 m, R^2 = 80.57%); *Tilia* sp. (RMSE = 2.01 m, R^2 = 89.07%); and *Ulmus laevis* (RMSE = 1.71 m, R^2 = 92.42%). The combination of the total height, tree, and plot-level variables with distance-independent competition indexes contributed to the prediction accuracy of proposed model significantly.

Keywords: two-layered mixed stands; distance-independent competition indexes; logistic models; leave-one-out cross-validation.

INTRODUCTION

Tree crowns are involved in many key physiological processes, such as photosynthesis (Ma et al. 2017, Liu et al. 2019), respiration (Plain et al. 2009, Drake et al. 2016), and transpiration (Köstner et al. 1992, Gupta et al. 2018), and they also influence soil water storage (Meinzer et al. 1999, Zhang et al. 2007) and the interception of radiation (Stenberg et al. 1994, Chen et al. 2017), being the most important part of the tree.

The crown structure also affects the biomass productivity (Valentine et al. 1994, Russell and Weiskittel 2011), stem form, and wood quality (Maguire et al. 1991, Hein et al. 2008) and individual tree competition status (Kershaw et al. 1990, Cameron et al. 2020). The crown structure includes decisive parameters to assess the crown fuel characteristics that influence potential crown fire behaviour (Cruz et al. 2003, Ruiz-González and Álvarez-González 2011, Jiménez et al. 2013).

Therefore, these metrics are critically important for informing forest management (Li et al. 2020). However, crown measurements require an appropriate abstraction of crown size and shape; however, direct measurement of the crown shape or profile is difficult (Cameron et al.

2020). In addition, the labour-intensive and time- and money-consuming endeavour of measuring descriptive crown parameters hinders the wide application to forest management (Hasenauer and Monserud 1996, Fu et al. 2017, Luo et al. 2018) particularly in mixed stands.

This has motivated many studies to focus their efforts on modelling crown parameters, such as tree height to crown base (hcb). hcb is an important variable often included as a predictor in various forest models that serve as the fundamental tools for decision-making in forestry (Sharma et al. 2017). hcb reports important information to assess the social position of the trees and the competition they suffer, closely related to the crown size and may affect the tree vigour (Hasenauer and Monserud 1996, Fu et al. 2013). Although traditional field-based methods can obtain reliable and accurate hcb measurements (Dean et al. 2009, S. Luo et al. 2016), it is rarely measured in the field and it is often predicted using static models (Rijal et al. 2012).

hcb models for many tree species have been developed from data at the tree and plot level using: (1) basic models methods (Rijal et al. 2012, Fu et al. 2017, Sharma et al. 2017, Jia and Chen 2019, Pan et al. 2020) to obtain high precision models with low field inventory cost, and (2) mixed-effects models (Fu et al. 2017, Jia and Chen 2019, Pan et al. 2020), which have been widely used in recent years as they show an increase prediction accuracy to an extent (Jia and Chen 2019, Pan et al. 2020).

The variability of hcb has been evaluated through three groups of variables: (1) tree size metrics referred to as tree-level variables, (2) variables of the size and vigour of the plot or stand denominated as plot-level variables, and (3) variables of the site quality and distance-independent competition indexes. For instance, the dominant height is usually used to describe the site quality and the stand development age, since it is strongly correlated with the growth condition of the dominant trees (Fu et al. 2017, Sharma et al. 2017, Li et al. 2020, Pan et al. 2020), and the total basal area of all trees with a diameter larger than the target tree is usually used to assess competition effects (Fu et al. 2017). These variables have been used combined or separately in many studies (Rijal et al. 2012, Fu et al. 2017, Pan et al. 2020).

In this work, hcb is defined as the height from the ground to the base of the first living branch that is a part of the crown, ranging from 0 to the height of the tree (Rijal et al. 2012, Fu et al. 2017). This must be differentiated from the concept of the Canopy Base Height, a parameter used in the study of forest fires, which represents the mean vertical distance, in meters, between the ground and the beginning of the living canopy at which there is enough fuel to spread the fire vertically through the canopy (Scott and Reinhardt 2001).

Although hcb is often assessed in research or monitoring (e.g., International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)) projects, in general, hcb modelling was not a research focus in Croatia. Such models were often not validated. The objectives of this study were (i) to develop species-specific hcb logistic models for the main tree species in the mixed, lowland pedunculate oak (*Quercus robur* L.) forests in Central Croatia; and (ii) to study which variables best explain the variability of hcb for each species and how each group of variables (tree-, plot-, and competition-distance index variables) affects the accuracy of the models. Mixed pedunculate oak forests are among the most important forest ecosystems in Croatia with exceptional ecological, economical, and sociological significance (Novotny et al. 2013). Pedunculate oak is also a key tree species of European forests (Čater 2015). Despite these facts and to the best of authors knowledge, there were no previous studies dealing with hcb modelling in pedunculate oak forest ecosystems.

MATERIALS AND METHODS

Study Area

The study area is located in the continental part of Croatia, near Jastrebarsko and 35 km southwest of Zagreb, within the Pokupsko Basin lowland forest complex (≈12,000 ha, Figure 1). The forests of the study area consist of even-aged pedunculate oak stands mixed with other tree species: common hornbeam (*Carpinus betulus* L.), black alder (*Alnus glutinosa* (L.) Gaertn.), and narrow-leaved ash (*Fraxinus angustifolia* Vahl.). Other tree species that sporadically occur are *Ulmus laevis* Pall., *Tilia* sp., *Populus* sp., *Acer campestre* L., *Betula pendula* Roth., *Pyrus pyraster* (L.) Burgsd., etc. These stands commonly have a two-layered structure (a dominant and suppressed tree layer) with pedunculate oak in the dominant crown class layer and other tree species in the suppressed crown class layer. The understorey is dominated by two shrub species: hazel (*Corylus avellana* L.) and common hawthorn (*Crataegus monogyna* Jacq.), while alder buckthorn (*Frangula alnus* Mill.) occurs sporadically. The terrain of the study area is mostly flat (105–118 m a.s.l.). Soils are hydromorphic (hypogley, eugley, and pseudogley) on a clay parent material. The climate is warm temperate with the mean annual temperature of 10.6 °C and precipitation of 962 mm·y^{-1} (Ostrogović Sever et al. 2019).

The pedunculate oak forests of the study area are state-owned, and they are actively managed for sustained timber in 140 year-long rotations, ending with two or three regeneration fellings during the last 10 years of the rotation. This management approach provides sustainability in terms of the yield, biodiversity, and ecosystem stability (Klepac and Fabijanić 1996). It has been applied for all even-aged pedunculate oak forests in Croatia where they cover an area of 225.000 ha or 9% of the total forest area (Croatian Forests Ltd. 2016). Further detailed information on sustainable management of pedunculate oak forests in Croatia can be found in Ostrogović Sever et al. (2019).

Field Measurements

Field data were collected from a total of 164 circular sample plots during 2017. The plots were systematically distributed throughout the study area, i.e., within the 30 stands of different age classes and with a total area of 576.32 ha. The radius of plots (8, 12, and 15 m) and systematic distance between the plots (100 × 100, 100 × 200, and 200 × 200 m) were defined in respect to the stand age and size. The positions of the plot centres were recorded during the leaf-off conditions (beginning of March 2017) using a Global Navigation Satellite Systems (GNSS) receiver (Stonex S9IIIN) connected to a network of GNSS reference stations

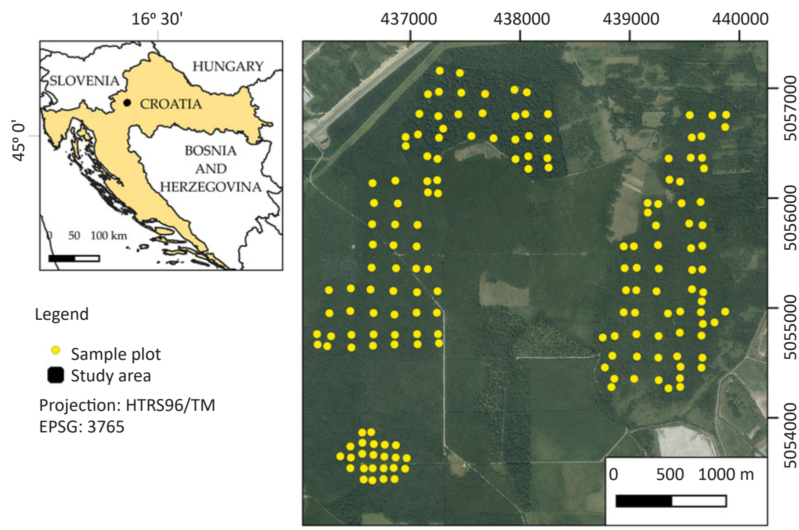

Figure 1. The location of the study area in Croatia (left) and spatial distribution of sample plots (yellow circles) within the study area (right).

(the Croatian Positioning System (CROPOS)) to achieve high positional accuracy. The average receiver reported precision of the plots positioning was 0.13 m (Balenović et al. 2019).

At each plot, the tree species and its location were recorded, and the diameters at breast height (dbh) were measured for all trees with dbh ≥ 10 cm. The position of each tree in the plot was recorded by measuring the distance and azimuth from the plot centre to each tree using a Vertex III hypsometer and Haglöf compass, respectively. Out of 4953 trees sampled within the 164 plots, the tree height was measured for 3247 trees using a Vertex III hypsometer, while the heights of the rest of the trees were estimated using the species-specific dbh-height models fitted with Michailloff's function (Michailoff 1943). In addition to the total tree height, the height from the bottom of the tree to the first live branch, i.e., the hcb, was measured for 3163 trees that were subsampled from trees with height measurements. A summary of the main forest attributes for the entire sample of 164 plots used for developing hcb models at tree-level is presented in Table 1. The plot-level volume values in Table 1 refers to the merchantable tree volume comprising of stemwood and branchwood up to a diameter of 7 cm overbark. It was calculated for each sampled tree using the Schumacher-Hall equation (Schumacher and Hall 1933) and parameters from Croatian two-entry (dbh and height) volume tables (Špiranec 1975, Cestar and Kovačić 1981, 1982, 1984), and summarized at plot-level.

Development and Validation of Tree Height to Crown Base (hcb) Models

Species-specific hcb models were developed for all species present in the dataset consisting of 164 sample plots. A model was adjusted for all species that had at least 20 trees measured in the field. The models were fitted with the outliers removed (Montgomery 2009).

For model development, the logistic equation of Walters and Hann (1986) (Equation 1) was used:

$$hcb = \frac{ht}{1+\exp(\sum_{i=1}^{k} a_i * x_i)}$$

where ht is the total height of the tree, a_i are model parameters to be estimated, and x_i are plot-, tree-level, or competition explanatory variables (Table 2). The hcb values in this equation are constrained to be less than the total height and greater or equal to zero (Ritchie and

Table 1. Summary of the main plot-level forest attributes for the 164 measured sample plots (DBH—diameter at beast height, H_L—Lorey's mean height, N—stem density, G—basal area, and V—volume).

Forest attribute	Mean	Minimum	Maximum	Standard deviation
Age (years)	88	33	163	39
Mean DBH (cm)	31.7	17.0	69.4	11.3
H_L (m)	26.5	17.4	37.9	4.5
N (trees·ha^{-1})	526	56	1840	303
G (m^2·ha^{-1})	31.9	13.7	67.0	8.3
V* (m^3·ha^{-1})	427.1	158.0	1020.1	153.2

Hann 1987). This equation presents several advantages over other crown base height equations. First, it is well constrained and should, thus, be a more reliable expression of the true relationships between crown length and the predictor variables; second, this equation provides slightly better fits than similar equations; and third, it is more easily interpreted than other crown base height equations (Ritchie and Hann 1987).

In addition to field-measured tree-level variables (e.g., the dbh and total tree height), various plot-level metrics and distance-independent competition indexes (Table 2) were calculated from field data and considered in hcb modelling. A total of 17 potential explanatory variables were included in the statistical modelling.

Variable selection was performed in R 3.6.2 (R Core Team 2019) through a stepwise procedure with the linearized form of Equation 1 using the *step* function from the stats package (R Core Team 2019). This function eliminates predictors one at a time, until it finds the optimum Akaike Information Criterion (AIC) value. Next, the selected independent variables were included in the original form of the equation, and the model was fitted by nonlinear least squares with the 'nls' function from the stats package (R Core Team 2019).

The models were selected and inspected graphically and evaluated numerically through the root mean squared error (RMSE), both absolute and relative; mean error (BIAS) in percentage and its p-value to assess whether it is significantly different from 0; EF: the model efficiency in percentage; and coefficient of correlation (R^2) of the observed versus predicted results in percentage. Finally, to avoid overfitting, the 'vif' function of the package *car* (Fox and Weisberg 2019) was applied to select the most parsimonious model.

Leave-one-out cross-validation (LOOCV) was used to assess the predictive value of each regression model (Picard and Cook 1984, Varma and Simon 2006). The LOOCV was chosen because certain tree species had a smaller number of field measurements, which disabled dividing them into modelling and validation subsets. For this purpose, the root mean squared error for cross-validation ($RMSE_{CV}$): absolute (m), and relative (%); mean error ($BIAS_{CV}$); and its p-value were used to assess whether it the LOOCV significantly different from 0.

Table 2. Field derived variables used for the development of the tree-level height to crown base (hcb) models. Plot-level variable acronyms are upper-case, while tree-level variables use lower-case acronyms.

Variable acronym	Variable description
DM	Mean diameter at breast height (cm)
DG	Quadratic mean diameter at breast height (cm)
HM	Mean height (m)
HL	Lorey's mean height (m)
HO	Dominant height (m)
G	Total basal area with slope correction ($m^2 \cdot ha^{-1}$)
N	Stem density ($trees \cdot ha^{-1}$)
IH	Hart–Becking Index (%)
AGE	Stand age (years)
ht	Total tree height (m)
dbh	Diameter at breast height (cm)
bal	Basal area of trees thicker than target tree ($m^2 \cdot ha^{-1}$)
balmod_g	bal/(G·IH) (-)
bar	Normal tree section ratio (m^2) and G (%)
rddg	dbh/DG (-)
rbad	bar^{rddg} (-)
dhratio	dbh/ht (-)

RESULTS AND DISCUSSION

The species-specific hcb models (Table 3) were developed for seven tree species (*A. campestre*, *A. glutinosa*, *C. betulus*, *F. angustifolia*, *Q. robur*, *Tilia* sp., and *U. laevis*) that had at least 20 trees measured in the field. Other species (*Populus* sp., *B. pendula*, and *P. pyraster*), that had fewer measurements, were not included in any model.

Table 3 displays a statistical summary of all the predictor variables per model. The crown base heights to be predicted varied remarkably among species, motivated by their different morphologies and bioecologies, with the minimum inventoried being 0.30 m for *A. glutinosa* and the maximum of 32.10 m for *Q. robur*. The independent parameters that are repeated in different models varied considerably among species, which gives an idea of the great variability present in the study area. N is the variable with the highest dispersion for the two models in which it has been used as a predictor, followed by AGE and bal in the third place. The maximum ht values show how *Q. robur*, *F. angustifolia,* and *C. betulus* are the species that reached the highest heights and, therefore, the dominant species in the study area.

ht and dbh predictors have been used as the main predictor in many hcb modelling studies (Fu et al. 2017, Sharma et al. 2017, Pan et al. 2020). Instead, we only used ht as the main predictor in the base model (see Equation 1), and dbh did not enter any of the evaluated models. The hcb models used ht plot-level variables with tree-level variables and distance-independent competition indexes.

Table 4 incorporates the hcb model performances. The results showed accuracies between 67.55% (*C. betulus*) and 92.42% (*U. laevis*) of R^2 and p.BIAS between 0.7115 (*U. laevis*) and 0.9488 (*F. angustifolia*). The RMSE ranged from 12.02% for *A. glutinosa* to 34.05% for *C. betulus.* One of the reasons for the greater variation among the models' performances may be the intraspecific morphology diversity since some species present higher heterogeneity among their crowns than others. Namely, the number of sampled trees differ from species to species; they were collected from forest stands of different ages where certain species may have different status (e.g., dominant, co-dominant, intermediate, suppressed layers) and consequently form different crown shapes and dimensions. Thus, the *C.*

Table 3. Statistical summary of the dependent and predictor variables (parameters) of the hcb models. See acronyms in Table 2.

hcb model	Parameter	Mean	Minimum	Maximum	Standard deviation
Acer campestre	hcb	8.79	1.80	15.20	4.01
	ht	16.39	10.80	23.30	3.54
	IH	17.13	13.10	25.20	4.05
Alnus glutinosa	hcb	14.79	0.30	21.70	3.39
	ht	20.92	8.60	28.40	3.21
	bar	0.16	0.03	0.59	0.11
	dhratio	1.12	0.63	1.87	0.27
	rbad	0.19	0.05	0.61	0.11
	bal	21.34	0.00	50.05	8.66
Carpinus betulus	hcb	7.24	0.50	17.80	3.33
	ht	18.84	5.20	31.50	4.22
	dhratio	1.09	0.54	3.18	0.28
	balmod_g	0.82	0.00	1.00	0.19
	bal	28.05	0.00	66.85	11.07
	DG	29.31	17.00	58.20	6.95
	AGE	88.85	33.00	163.00	38.66
	bar	0.12	0.01	0.58	0.10
Fraxinus angustifolia	hcb	14.69	3.40	25.80	4.34
	ht	24.71	7.80	38.60	6.44
	AGE	79.91	43.00	163.00	39.85
	dhratio	1.24	0.57	3.26	0.37
Quercus robur	hcb	15.34	2.00	32.10	4.39
	ht	27.19	9.4	43.50	5.52
	N	548.04	55.70	1691.00	279.56
	AGE	76.76	33.00	163.00	33.73
	dhratio	1.38	0.63	3.49	0.42
	IH	18.71	10.90	50.40	6.09
Tilia sp.	hcb	8.73	1.50	19.90	4.37
	ht	17.99	3.90	28.40	5.83
	DM	26.31	20.80	31.70	3.10
	HL	25.80	23.10	32.80	1.79
	AGE	85.59	63.00	163.00	17.69
	dhratio	1.17	0.59	3.27	0.31
Ulmus laevis	hcb	7.30	1.80	12.69	4.02
	ht	14.43	7.60	23.20	4.55
	G	31.07	21.10	51.10	7.73
	HO	25.43	22.40	35.40	3.27
	AGE	89.43	43.00	163.00	49.93
	N	739.60	367.80	1392.60	363.69

betulus hcb model clearly performed worse than the rest of the species and had the highest relative RMSE associated.

In view of these results, the models developed were unbiased, and they adequately explained the variations in the height to crown base. While it is true that the models offer good results, some models have been built with small samples and should be applied carefully, particularly *A. campestre* (27 trees), which shows a narrow interval of stand density (IH 13.1-25.2). Nevertheless, in the case of *U. laevis* (21 trees), the range of variation of both the predicted and explanatory variables is quite wide, which makes the fitted equation suitable for a broad spectrum of stands.

In this study, a high correlation was found among plot variables, the distance-independent competition index, and the hcb for each species. The plot variables gave rise to the most accurate models, since hcb is a dimensional measurement of a tree and since it is more strongly correlated with other dimensional measures (Rijal et al. 2012), whereas competition measures better describe competitive interactions among species (Petritan et al. 2007, Thorpe et al. 2010, Sharma et al. 2017).

Distance-independent competition indexes originate models whose accuracies are conditioned by intra- and inter-species competition and stages of development, originating more variable precisions that depend on the intimate mixture of trees present in each plot. Several studies have shown that competition variables and stand density have a remarkable influence on hcb values (Garber et al. 2008, Russell et al. 2014). Therefore, it is not surprising that the most repeated parameters in the models were dhratio and AGE.

Table 4. Regression coefficients and goodness of fit parameters for predicting the crown base height by species. Trees with measured hcb in field (M) and used in the models (U); root mean squared error (RMSE): absolute (m) and relative (%); BIAS: in percentage; p.BIAS: BIAS p-value; R2: coefficient of correlation of observed versus predicted (%), EF: Model Efficiency (%); Parameter: independent variable; Est: parameter estimates; VIF: Variance Inflation Factor of parameter estimates; p-value: significant codes: ***: 0, **: 0.001, and *: 0.01.

hcb model	Trees	RMSE	BIAS	p.BIAS	R^2	EF	Parameter	Est.	VIF	p-value
Acer campestre	27 M 27 U	2.28 m 25.95%	-0.1074	0.8084	82.80	67.63	Int	-1.957	-	**
							IH	0.107	0.00	**
Alnus glutinosa	283 M 281 U	1.78 m 12.02%	-0.0078	0.9413	85.36	72.56	Int	-1.909	-	***
							bar	-3.506	4.50	***
							dhratio	1.210	4.44	***
							rbad	3.251	2.31	***
							bal	-0.019	2.46	***
Carpinus betulus	875 M 871 U	2.47 m 34.05%	0.0142	0.8647	67.55	45.31	Int	-1.467	-	***
							dhratio	1.241	2.13	***
							balmod_g	0.531	3.36	**
							bal	-0.013	2.88	***
							DG	0.031	2.59	***
							AGE	-0.002	1.86	*
							bar	-1.670	4.81	***
Fraxinus angustifolia	237 M 235 U	2.46 m 16.74%	0.0103	0.9488	82.45	67.84	Int	-0.896	-	***
							AGE	-0.002	1.64	*
							dhratio	0.537	1.64	***
Quercus robur	1549M 1538 U	2.60 m 16.99%	-0.0126	0.8491	80.57	64.85	Int	-0.175	-	*
							N	-0.0005	2.39	***
							AGE	-0.008	2.69	***
							dhratio	0.795	1.88	***
							IH	-0.016	1.95	***
Tilia sp.	140 M 139 U	2.01 m 23.09%	-0.0529	0.7545	89.07	78.76	Int	-2.955	-	***
							DM	-0.101	1.76	***
							HL	0.230	1.73	***
							AGE	-0.009	1.06	***
							dhratio	0.488	1.02	**
Ulmus laevis	21 M 21 U	1.71 m 23.39%	-0.1285	0.7115	92.42	81.95	Int	5.639	-	**
							G	0.080	3.45	*
							HO	-0.222	2.86	**
							AGE	-0.011	1.53	**
							N	-0.002	3.33	*

Pan et al. (2020) observed that additional explanatory variables can significantly improve the prediction accuracy of an hcb model; however, introducing too many variables into a model can lead to overparameterization, which can produce a biased prediction (Fu et al. 2017) and increased forest inventory costs by requiring more measurements in the field (Pan et al. 2020). There are models with a high number of variables, e.g., six for *C. betulus*, but the Variance Inflation Factor (VIF) remains low.

Logistic models are considered by some authors to be those that provide the most accurate predictions for many tree species (Fu et al. 2017, Sharma et al. 2017). Rijal et al. (2012) observed that they significantly reduced bias and eliminated convergence problems.

In this study, the best accuracies were obtained for the *U. laevis* (21 used trees and R^2=92.42%) and *Tilia* sp (139 used trees and R^2=89.07%) models. On the other hand, the main species *C. betulus* (871 used trees and R^2=67.55%) and *Q. robur* (1538 used trees and R^2=80.57%) models had the lowest accuracies. These two species appeared in both the main and secondary vegetation layers, increasing the variability of hcb, which explains the low precision of their models. An alternative to reduce the variability of the hcb models would be to create models by species for each layer considered.

As expected, the correspondence between the field hcb and estimated hcb increased with outlier removal in all models in which outliers were detected. No outliers were found in *A. campestre* and *U. laevis*models. In *Tilia* sp. models, only one outlier was found; two in *A. glutinosa* and *F. angustifolia* models; four for *C. betulus;* and 11 for *Quercus robur*. The larger the database, the larger the outliers found.

Our accuracies are moderately higher than those found in similar investigations. Rijal et al. (2012) evaluated the hcb in thirty species of the North American Acadian Region using a logistic equation with plot-level variables and competition variables, obtaining performances ranging from 47% to 79% of R^2. Fu et al. (2017) studied the hcb of Mongolian oak natural forest located in the Northeast China. They obtained accuracies of 49.72% of R^2 with logistic models using ht and dbh as the only independent variables. Sharma et al. (2017) applied logistic models to estimate the hcb for *Picea abies* and *Fagus sylvatica* in the Czech Republic, with 68% and 67% explained variances, respectively. They employed tree-level (ht), plot-level (Ho), and competition variables (the bal and basal area proportion of a species of interest) in their models.

Jia and Chen (2019) applied different methods to *Larix olensis* hcb modelling in Northeast China. Among them, the logistic model offered an accuracy of 73.04% R^2 using plot-level variables. Pan et al. (2020) studied the hcb of *L. olensis* in Northeast China, and they obtained 70.63% of R^2_{adj} applying logistic models. As final variables, tree size measures and the spacing index were selected. Li et al. (2020) worked with *Pinus massoniana* in Southern China, obtaining an 88.03% R^2_{adj} by applying logistic equations in hcb modelling with ht and dbh as predictive variables.

Figure 2 represents the hcb residual distribution of fit plots against the predictions obtained. The distribution of the errors is homogeneous throughout all the predictions, thus, ruling out the presence of heteroscedasticity in the models.

Validation results of the eight hcb models are shown in Table 5. After LOOCV, it can be seen how the values of the validation statistics increased slightly compared to those obtained in the fitting procedure, as in Fu et al. (2017), demonstrating the robustness of the models. None of them presented significant bias, and the RMSE ranged from 12.27% for *A. glutinosa* to 34.24% for *C. betulus*. The most abundant species (*Q. robur*) showed an error of 17.04%.ercentage; and p.BIAS$_{CV}$: BIAS p-value.

CONCLUSIONS

In this work, seven main species without previous hcb models were fitted. These proposed hcb models have high importance in their novelty, but foremost by their management implications. hcb is a tree structural measure and is, therefore, related to other structural variables. However, it is a characteristic strongly conditioned by the competence and social position of each tree. This makes it essential to consider the factors that describe the competition to which each tree is subjected. Therefore, the combination of tree and plot-level variables with the site

Table 5. The leave-one-out cross-validation (LOOCV) parameters: RMSE$_{CV}$: absolute (m) and relative (%); BIAS$_{CV}$: in percentage; and p.BIAS$_{CV}$: BIAS p-value.

hcb model	RMSE$_{cv}$ (m)	RMSE$_{cv}$ (%)	BIAS$_{cv}$	p.BIAS$_{cv}$
Acer campestre	2.53	28.77	-0.0770	0.8755
Alnus glutinosa	1.81	12.27	-0.0105	0.9226
Carpinus betulus	2.48	34.24	0.0140	0.8677
Fraxinus angustifolia	2.49	16.98	0.0119	0.9417
Quercus robur	2.61	17.04	-0.0126	0.8502
Tilia sp.	2.09	23.95	-0.0510	0.7740
Ulmus laevis	2.10	28.80	0.0181	0.9690

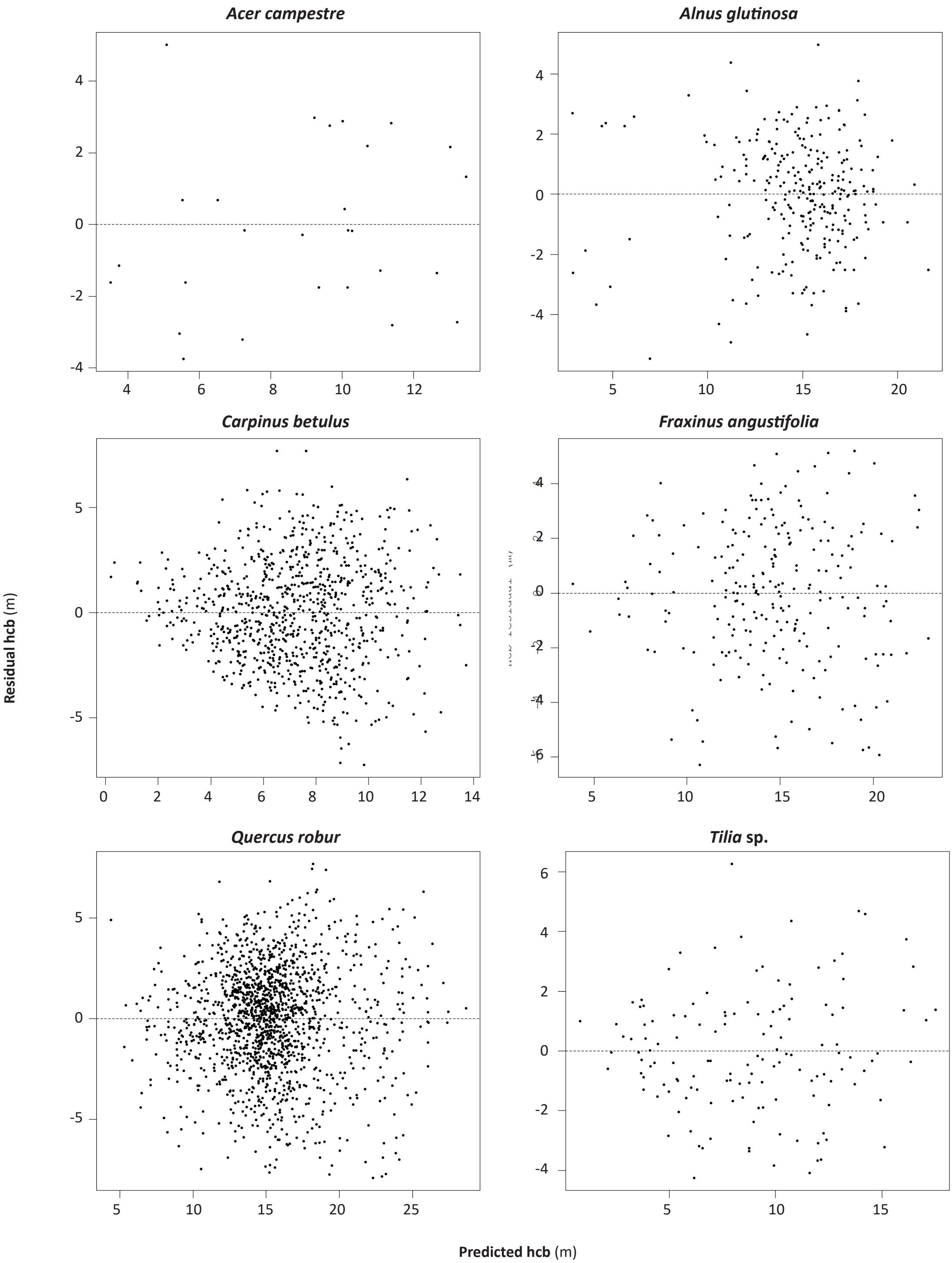

Figure 2. Residual vs. predicted hcb values for eight selected models.

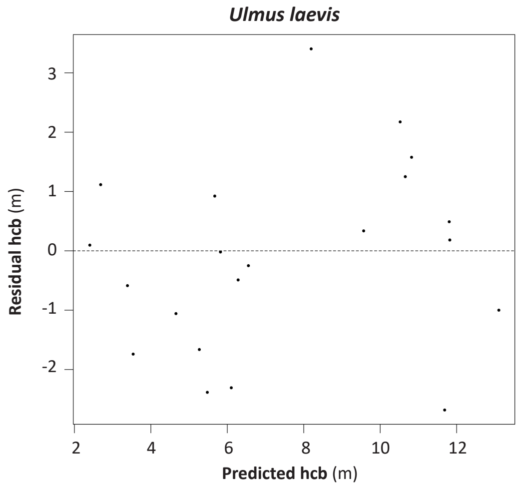

Figure 2. continuation Residual vs. predicted hcb values for eight selected models.

index significantly contributed to the prediction accuracy of the proposed models. The distance-independent competition indexes explained the inter- and intraspecific critical relationships among trees to predict the hcb. These logistic models demonstrated their great versatility as they showed good precision in a wide range of species. The leave-one-out cross-validation further confirmed the high robustness of our logistic models.

Author Contributions

Conceptualization: RAP; methodology: RAP, SMG; processing: SMG; validation: SMG, RAP, IB; formal analysis: RAP, IB; investigation: SMG; resources and data curation: IB, LJ, IL; writing the original draft: SMG, IB, KI; review and editing the manuscript: RAP, IB; supervision: RAP; research funding: IB, IL. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Materials

Suplementary File 1. Observed vs. predicted hcb values for 8 selected models. The diagonal line shows a 1:1 relationship.

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Interactions of the Effects of Provenances and Habitats on the Growth of Scots Pine in Two Provenance Tests in Bosnia and Herzegovina

Mirzeta Memišević Hodžić[1,*], Dalibor Ballian[1,2]

(1) University of Sarajevo, Faculty of Forestry, Department of Silviculture and Urban Greenery, Zagrebačka 20, BA-71000 Sarajevo, Bosnia and Herzegovina; **(2)** Slovenian Forestry Institute, Večna pot 2, SI-1000 Ljubljana, Slovenia

*** Correspondence:** e-mail: m.memisevic-hodzic@sfsa.unsa.ba

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ABSTRACT
This research aims to determine the interaction of the effects of provenance and habitat conditions on provenance tests on the growth of Scots pine on two experimental plots in Bosnia and Herzegovina. Provenance tests are located on plots with different ecological conditions and altitudes: Romanija Glasinac, 1000 m, and Gostović Zavidovići, 480 m. Both tests include 11 provenances and two clonal seed plantations with 10 families in each, and five repetitions. Tree heights and diameters at breast height were measured at the age of 21 years. Interactions were determined using multivariate analysis for measured traits. The highest average heights on the provenance test Glasinac had provenances Bugojno, Romanija Glasinac, and Šipovo (8.8 m), and on the Gostović provenance Rogatica (11.0 m). The highest average diameter at breast height on the Glasinac test had Šipovo provenance (13.9 cm) and on the Gostović test Bosanski Petrovac provenance (12.3 cm). Variance analysis showed statistically significant differences among provenances in terms of diameter at breast height and height values. Multivariate analysis showed the presence of interactions of effects of provenances and habitat conditions on provenance tests. For provenances that did not show interaction, it is recommended to use provenances that performed better in the given ecological conditions, and for those that showed interaction, it is necessary to choose those provenances which are expected to show better results in given conditions later in life. The obtained results are very important for the conservation activities of this species.

Keywords: *Pinus sylvestris*; morphological traits; genetic structure; environmental conditions

INTRODUCTION

Scots pine (*Pinus sylvestris* L.) is one of the most important tree species in European forests. It is characterized by high genetic variability and complex population structure (Stefanović et al. 1980, Omanović 2008). In Bosnia and Herzegovina, differences within Scots pine populations can be expected at the morphological level (Stefanović 1980). Differences can be expected in the production potential of provenances as well (Mikić 1991). Due to the importance of this species for the forestry of Bosnia and Herzegovina, clonal seed plantations were established (Ballian and Božić 2004, Ballian et al. 2005), two of which were used in this research.

Knowing whether a species has resilience and adaptability to changing environmental conditions, as well as stress conditions, is important for the functioning of modern forestry and conservation of forest ecosystems. Higher genetic variability makes the species more resilient and better adapted for survival in changing environmental conditions and in stress conditions (Villani and Eriksson 2006).

There have not been many studies on the interactions between the effects of provenance genetic structure and habitat conditions on Scots pine. Some authors studied morphological traits of Scots pine in international provenance tests in Poland (Barzdajn et al. 2016), Spain (Alía et al. 2001), Turkey (Gülcü and Bilir 2017), and in

Bosnia and Herzegovina (Ballian et al. 2009, Cvjetković et al. 2014, Ballian and Šito 2017, Ballian et al. 2019). Taeger et al. (2013) studied the impact of climate and drought events on the growth of Scots pine provenances in an international provenance test which also contained a provenance from Bosnia and Herzegovina, and the results indicate a better adaptation to drought of the provenance from Bosnia Herzegovina and of local German provenances compared to other provenances.

Unfortunately, so far there has been little research dealing with provenance interactions. So far, interactions among provenances originating from different countries, from a greater geographical distance (Memišević Hodžić et al. 2020), but not provenances from a narrower geographical area such as Bosnia and Herzegovina, have been analyzed. Thus, Memišević Hodžić et al. (2020) studied the interaction between the effects of provenance genetic structure and habitat conditions on international provenance tests of Scots pine in two locations in Bosnia and Herzegovina. Obtained results indicated interactions on some provenances.

For studying the variability and adaptability of Scots pine in Bosnia and Herzegovina, provenance tests were established in 1988 on two locations, Romanija Glasinac and Zavidovići Gostović. The study aims to determine whether there is an interaction between the effects of provenance genetic structure and habitat conditions on the growth of Scots pine in both test plots, for selection and breeding of provenances adapted to habitat conditions.

MATERIALS AND METHODS

In this paper, the material from two provenance tests of Scots pine in Bosnia and Herzegovina was investigated. Information about the locations of test plots are shown in Table 1.

Provenance tests were established from seed material from 11 seed stands of Scots pine and two clonal seed plantations (Sarajevo-Rakovica and Doboj-Stanovi). A random block system was applied, and the distribution of provenances was the same at both provenance tests. The seeds were sown in 1986 in the nursery "Slatina" of the Faculty of Forestry in Sarajevo. At the age of two years (1 + 1), seedlings were planted in two experimental plots, with planting spacing of 2x2m. Each provenance within the plot was composed of ten families with four plants, and each provenance was planted in five replications. The list of provenances and information about their locations is shown in table 2 and their geographical distribution in figure 1.

In the spring of 2007, plant heights and diameters at breast height were measured. Data were processed using the statistical program SPSS 26.0. Descriptive and multivariate analyses (Two-way ANOVA) were performed. Two-way ANOVA shows whether there is an interaction of two independent factors (provenance and habitat) on the dependent variable (height and diameter). In other words, it shows whether the influence of one of the independent variables on the dependent variable is the same for all values of the second independent variable (and vice versa).

RESULTS

Average values of height per provenances and provenance tests are shown in Figure 2. All provenances had higher values of average heights on the Gostović than on the Glasinac plot. The highest average heights on the Glasinac plot had provenances Bugojno, Romanija Glasinac, and Šipovo (8.8 m), and on the Gostović plot provenance Rogatica (11.0 m). The lowest average height on the Glasinac plot had Olovo and Zavidovići provenances (7.3 m), and on the Zavidovići plot seed plantation Doboj had the lowest average height (9.0 m).

Table 1. Information about Scots pine provenance tests' locations.

Information / Provenance test	Romanija Glasinac	Zavidovići Gostović
North Latitude	43°52'43.10''	44°20'55.27''
East Longitude	18°50'31.34''	18°08'04.03''
Forest Management Area	„Sokolačko“	„Krivajsko“
Management Unit	„Romanija Glasinac“	„Gostović“
Department	15	42
Altitude	1000 m	480 m
Exposition	E	SW
Inclination	5°	20°
Geological substrate	Limestone	Serpentine-peridotite
Soil type	Calcomelanosol	Ranker, eutric cambisol
Vegetation	*Piceo Pinetum illyricum pyroletosum*	*Pinetum silvestris nigrea serpentinicum*
Average annual temperature	7.08°C	9.35°C
Vegetation period duration	157 days	184 days

Table 2. List and location information of provenances in the provenance test.

Provenance	North Latitude	East Longitude	Altitude (m)	Soil type	Geological substrate
Bosanski Petrovac	44°29'28"	16°29'21"	920	rendzina	dolomite, limestone
Bugojno	44°03'10"	17°19'55"	1230	dolomite rendzina	dolomite
Foča	43°20'51"	18°56'25"	1370	distric cambisol	quartzporphyrite
Han Kram	44°01'53"	18°56'32"	1100	swampy, charred, brown podzolic	tuff sandstones
Kladanj	44°16'46"	18°37'47"	900	district cambisol and brown podzolic soil	sandstones, clay minerals, cherts
Olovo	44°14'50"	18°20'54"	850	eutric cambisol	peridotite
Rogatica	43°48'06"	19°08'32"	1100	distric cambisol, luvisol	cherts
Romanija – Glasinac	43°54'20"	18°42'50"	1235	calcocambisol	limestone
Romanija – Palež	44°02'14"	18°45'50"	780	pseudogley	diabase gabbro
Seed plantation Doboj	44°45'11"	17°59'50"	180	fluvisol	sandstone
Seed plantation Sarajevo	43°52'14"	18°12'52"	570	clay, ortstein	marl
Šipovo	44°14'31"	17°13'26"	1200	dolomite rendzina, calcocambisol	dolomite, limestone
Zavidovići	44°19'56"	18°12'44"	480	ranker, eutric cambisol	serpentine peridotite

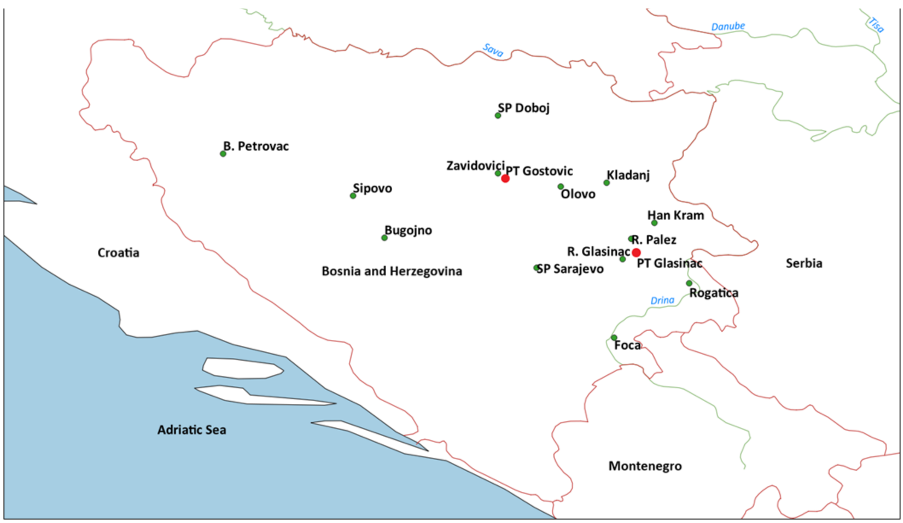

Figure 1. Provenances included in provenance tests Glasinac and Gostović (SP – seed plantation; PT – provenance test).

Average values of breast height diameter per provenances are shown in Figure 3. Unlike for the trait of height, all provenances had higher average values of diameter at breast height on the Glasinac than on the Gostović plot. The highest average breast diameter on the Glasinac plot had Šipovo provenance (13.9 cm) and on the Gostović plot Bosanski Petrovac provenance (12.3 cm). The lowest average values of breast height diameter on the Glasinac plot had provenance Olovo (11.9 cm) and on the Gostović plot seed plantation Doboj (9.8 cm).

In the multivariate tests table for height and diameter at breast height together (Table 3) it is visible that Wilks' Lambda showed Sig. value of 0.000, which indicates $p < 0.0005$ for both factors and interaction between factors. It means that values of heights and diameters at breast height are significantly dependent on provenances, habitat conditions on provenance tests, and interaction of provenances and habitat conditions on provenance tests.

Considering that an interaction effect can usually be seen as a set of non-parallel lines, it is visible in Figure 4 that there is a statistically significant interaction of effects of provenance and environmental conditions on experimental plots for the trait of height for some of the researched provenances. The provenance of seed plantation Doboj was most clearly distinguished by the interaction of provenance x habitat, with estimated marginal mean of height among

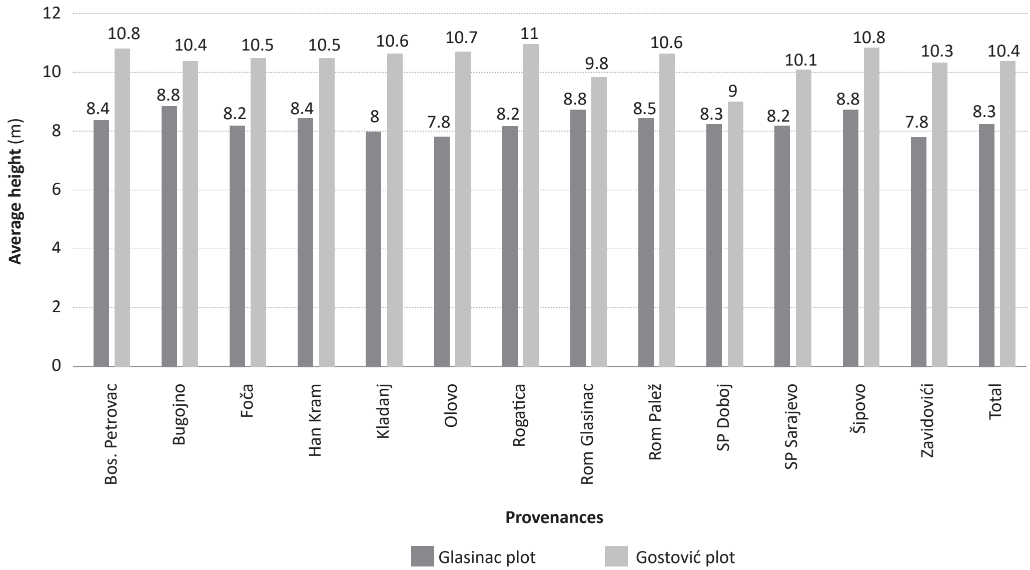

Figure 2. Average values of height of plants per provenances and experimental plots.

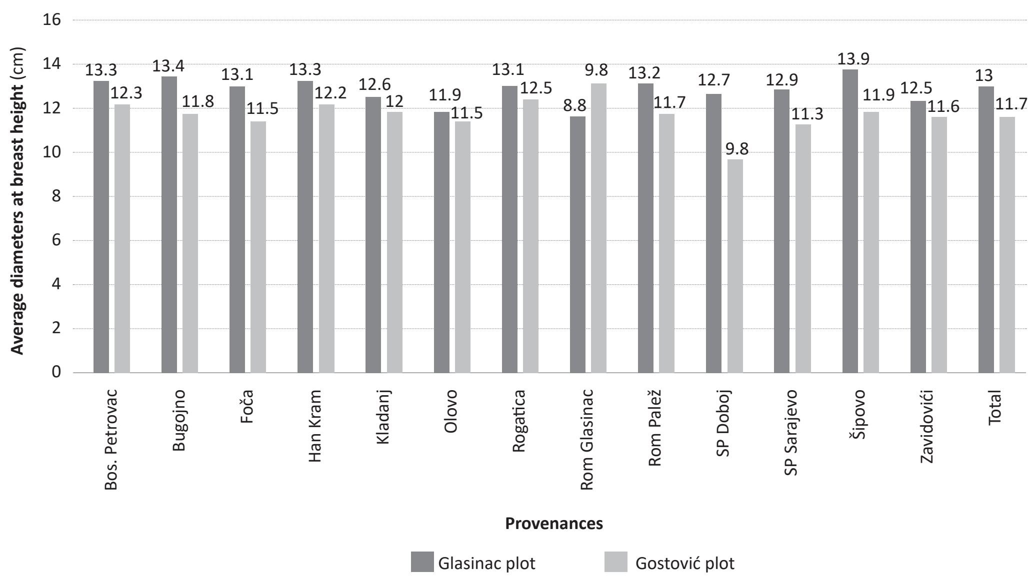

Figure 3. Average values of breast height diameter of plants per provenances and tests.

other provenances on Glasinac, but lower than other provenances on the Gostović plot. Provenance Romanija Glasinac had one of the highest estimated marginal means on the Glasinac plot, but one of the lowest marginal means on the Gostović plot. Provenance Rogatica had estimated marginal mean of height about average for all provenances on the Glasinac plot, but the highest estimated marginal mean on the Gostović plot. Provenance Šipovo had the highest estimated marginal mean for height on the Glasinac plot, and one of the highest marginal means on the Gostović plot. Provenances Zavidovići and Olovo had the lowest estimated marginal means for height on the Glasinac plot, but on the Gostović plot, their values were among the values of other provenances.

Tests of between-subjects effects table (Table 4) for the trait of height showed the presence of statistically significant interaction between provenances and habitat conditions (Fizr.>Ftab., Sig.<0.005).

In the graphical representation of estimated marginal means for the trait of diameter at breast height (Figure 5),

Table 3. Results of multivariate testsa for the height and diameter at breast height.

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	0.961	45238.595[b]	2.000	3651.000	0.000
	Wilks' Lambda	0.039	45238.595[b]	2.000	3651.000	0.000
	Hotelling's Trace	24.781	45238.595[b]	2.000	3651.000	0.000
	Roy's Largest Root	24.781	45238.595[b]	2.000	3651.000	0.000
Provenance test	Pillai's Trace	0.541	2150.029[b]	2.000	3651.000	0.000
	Wilks' Lambda	0.459	2150.029[b]	2.000	3651.000	0.000
	Hotelling's Trace	1.178	2150.029[b]	2.000	3651.000	0.000
	Roy's Largest Root	1.178	2150.029[b]	2.000	3651.000	0.000
Provenance	Pillai's Trace	0.030	4.656	24.000	7304.000	0.000
	Wilks' Lambda	0.970	4.669[b]	24.000	7302.000	0.000
	Hotelling's Trace	0.031	4.682	24.000	7300.000	0.000
	Roy's Largest Root	0.025	7.655[c]	12.000	3652.000	0.000
P. test * Provenance	Pillai's Trace	0.030	4.690	24.000	7304.000	0.000
	Wilks' Lambda	0.970	4.713[b]	24.000	7302.000	0.000
	Hotelling's Trace	0.031	4.736	24.000	7300.000	0.000
	Roy's Largest Root	0.028	8.602[c]	12.000	3652.000	0.000

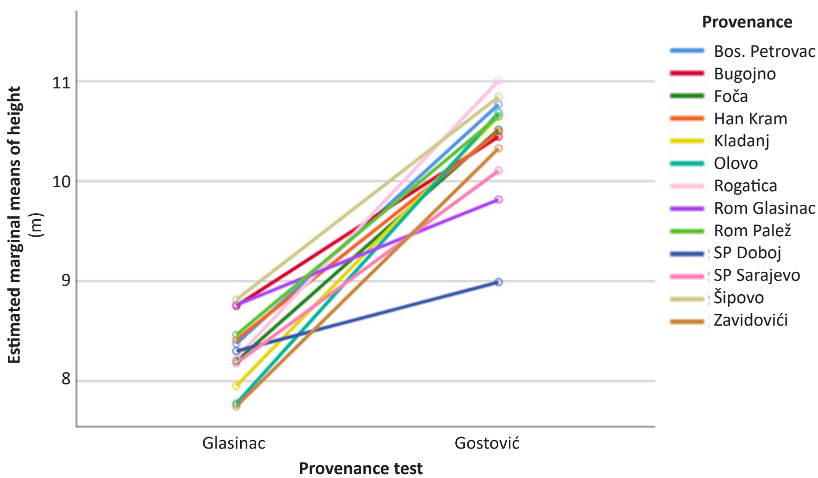

Figure 4. Graph of the interaction of effects of provenance and habitat conditions for height

it is visible that there is a statistically significant interaction between provenance and environmental conditions of experimental plots for some of the researched provenances. Similar to the trait of height, the provenance of seed plantation Doboj was most clearly distinguished by the interaction of provenance x habitat for the breast height diameter, with estimated marginal mean among other provenances on Glasinac, but lower than other provenances on the Gostović plot. Provenance Romanija Glasinac had one of the highest estimated marginal means on the Glasinac plot, but one of the lowest marginal means on the Gostović plot. Provenance Rogatica had estimated marginal mean of diameter at breast height about average for all provenances on the Glasinac plot, but the highest estimated marginal mean on the Gostović plot. Provenance Šipovo had the highest estimated marginal mean for diameter at breast height on the Glasinac plot, and one of the highest marginal means on the Gostović plot. Provenance Olovo had the lowest estimated marginal mean for diameter at breast height on the Glasinac plot, but on the Gostović plot, its value was among the values of other provenances.

Tests of between-subjects effects table (Table 5) for the trait of breast height diameter showed that there is a statistically significant interaction of effects of provenances and habitat conditions on provenance tests conditions (Fizr.>Ftab., Sig.<0.005).

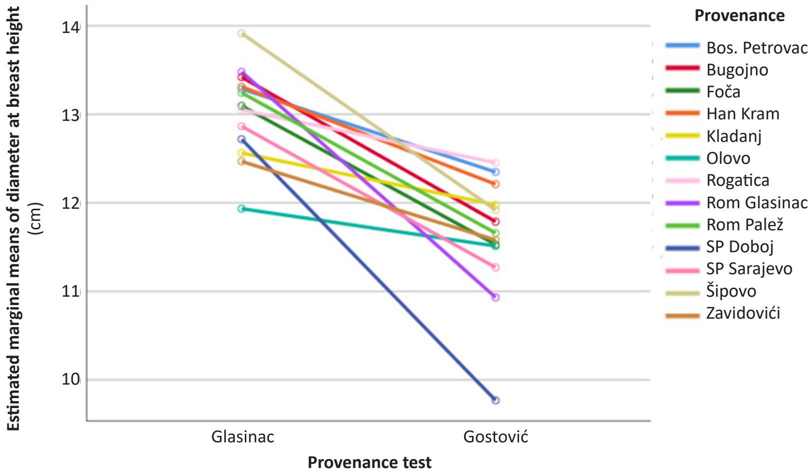

Figure 5. Graph of the interaction of effects of provenance and habitat conditions for diameter at breast height.

Table 4. Tests of between-subjects effects for trait of height.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4796.276[a]	25	191.851	54.368	0.000
Intercept	318609.332	1	318609.332	90290.226	0.000
Provenance test	4015.689	1	4015.689	1138.000	0.000
Provenance	311.826	12	25.986	7.364	0.000
P. test * Provenance	358.017	12	29.835	8.455	0.000
Error	12886.902	3652	3.529		
Total	342382.930	3678			
Corrected Total	17683.178	3677			
R Squared = .271 (Adjusted R Squared = 0.266)					

Table 5. Tests of between-subjects effects for diameter at breast height.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2970.403[b]	25	118.816	11.473	0.000
Intercept	552301.877	1	552301.877	53329.602	0.000
Provenance test	1824.163	1	1824.163	176.139	0.000
Provenance	768.520	12	64.043	6.184	0.000
P. test * Provenance	496.316	12	41.360	3.994	0.000
Error	37821.517	3652	10.356		
Total	599746.103	3678			
Corrected Total	40791.920	3677			
R Squared = .073 (Adjusted R Squared = 0.066)					

DISCUSSION

Investigating the interactions of the effects of provenances and environmental conditions can be important in the breeding strategy of Scots pine.

In this research, statistically significant interactions of effects of provenance and environmental conditions on experimental plots for both traits and some of the researched provenances were found. Provenance Romanija Glasinac had one of the highest estimated marginal means for height on the Glasinac plot, but one of the lowest marginal means on the Gostović plot. It could be explained by the vicinity of the provenance origin to the provenance test and similar ecological conditions. Provenances Zavidovići and Olovo had the lowest estimated marginal means for height on the Glasinac plot, but on the Gostović plot, their values were among the values of other provenances, which can also be explained by the vicinity of the provenances and similarity of their ecological conditions with the provenance test Gostović. Similar to the trait of height, provenance Romanija Glasinac had one of the highest estimated marginal means for diameter at breast height on the Glasinac plot, but one of the lowest marginal means on the Gostović plot. Provenance Rogatica had estimated marginal mean of diameter at breast height about average for all provenances on the Glasinac plot, but the highest estimated marginal mean on the Gostović plot. Provenance Olovo had the lowest estimated marginal mean for height on the Glasinac plot, but on the Gostović plot, its value was among the values of other provenances.

These results correspond to the results of other researchers. Eiche and Andersson (1974) investigated survival and growth in Scots pine in provenance tests in Northern Sweden. Their results showed the genecological variation of climatic hardiness, capacity for survival, and growth rate of different populations. They concluded that interaction for genotype and environment emerged quite obviously. Matheson and Raymond (1984, 1986) stated that the provenance by site interactions in forest trees are often detectable, but of small importance. Savva and Vaganov (2006) assessed genetic and environmental effects in Scots pine provenances planted in Central Siberia. They found that the main climatic factors controlling tree-rings formation differed slightly among different provenances. The genetically fixed ability of the provenances was not great (less than 15%), which proves the high adaptability of Scots pine to abrupt climatic change. The tree-ring formation of Scots pine provenances is mainly determined by environmental factors. Zhelev and Lust (1999) investigated Scots pine provenances in Belgium and found that the provenance by site interactions was of importance only for height growth. Alía et al. (2001) investigated 16 Spanish and 6 German provenances of Scots pine in a provenance test in Spain. Based on data for the height, diameter, the number of twigs at the fourth year whorl, and survival, provenance by site interaction was very significant ($P < 0.01$) for most traits.

Ballian et al. (2009) measured the diameter and height of the plants and calculated basal area and volume of plants in the provenance test of Scots pine Glasinac Sokolac, which is one of the provenance tests in this research. The provenance geographically closest to the provenance test showed the best results of productivity. Cvjetković et al. (2014) measured and calculated the same characteristics at the same plot in 2011. The results confirmed the existence of significant differences within and among provenances, and the provenance geographically closest to the provenance test showed the best results. In this research, provenance Romanija Glasinac, closest to the provenance test Glasinac Sokolac, showed the highest average height, but not the highest average of breast height diameter.

Gülcü and Bilir (2017) studied provenance x site interactions in thirteen-year-old Scots pine provenance tests at two sites in the southern part of Turkey, containing 30 provenances, based on height, diameter, and survival of plants. The results showed statistically significant provenance x site interaction ($p<0.05$). Memišević Hodžić et al. (2020) studied provenance x site interaction in two international provenance tests in Bosnia and Herzegovina, based on the data of heights and root collar diameter, and determined interaction between some of the researched provenances.

CONCLUSIONS

The results of this research showed interaction of effects of provenance genetic structure and habitat conditions for both researched traits (height and diameter at breast height). Considering the height, provenances Bugojno, Romanija Glasinac, and Šipovo had the highest, and provenances Olovo and Zavidovići the lowest values on the Glasinac provenance test. On the Gostović test, provenance Rogatica had the highest, and Seed plantation Doboj the lowest value of height. The highest values of breast diameter on the Glasinac provenance test had Šipovo provenance and the lowest Olovo provenance. On the Gostović test, provenance Bosanski Petrovac had the highest values of breast height diameter, and the lowest had Seed plantation Doboj. Except for provenance Romanija Glasinac on the Glasinac test for the trait of height, provenances originated from locations nearest to the provenance test locations did not show higher values of researched traits. Wilks' Lambda multivariate tests showed that values of heights and diameters at breast height are significantly dependent on provenance, habitat conditions on provenance tests locations, and interaction of provenance x habitat conditions on provenance tests locations. Graphical representation of estimated marginal means for both researched traits showed the presence of statistically significant interaction of effects of provenance and environmental conditions on provenance tests for some of the researched provenances. Tests of between-subjects effects for both traits showed a statistically significant interaction of effects of provenances and habitat conditions on provenance tests. The results of this study can be used in the process of Scots pine breeding and for its conservation by *in situ* and *ex-situ* methods.

Author Contributions

MMH, DB, conceived and designed the research, DB carried out the field measurements, DB performed measuring, MMH processed the data and performed the statistical analysis, DB supervised the research and helped to draft the manuscript, MMH wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Assessment of How Natural Stand Structure for Narrow Endemic *Cedrus brevifolia* Henry Supports Silvicultural Treatments for Its Sustainable Management

Elias Milios[1,*], Petros Petrou[2], Kyriakos Pytharidis[2], Andreas K. Christou[2], Nicolas-George H. Eliades[3]

(1) Democritus University of Thrace, Department of Forestry and Management of the Environment and Natural Resources, Pantazidou 193, GR-68200 Orestiada, Greece; **(2)** Ministry of Agriculture, Rural Development and Environment, Department of Forests, Loukis Akritas 26, CY-1414 Nicosia, Cyprus; **(3)** Frederick University, Nature Conservation Unit, P.O. Box 24729, CY-1303 Nicosia, Cyprus

***Correspondence**: emilios@fmenr.duth.gr

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ABSTRACT

Cedrus brevifolia Henry is a narrow endemic tree species of Cyprus flora. The objectives of this study are to develop silvicultural treatments for the conservation of the species formations based on the stand structure analysis of *C. brevifolia* natural forest and to present the characteristics of the first application of the treatments through silvicultural interventions. Six structural types were distinguished in *C. brevifolia* formations in the study area located in the state forest of Paphos. For each structural type, six circular plots of approximately 500 m^2 were established. In each plot, various measurements and estimations were recorded. Then, silvicultural interventions were applied in the plots of the mixed *C. brevifolia* formations. In the formations of *C. brevifolia* a great number of trees grow in the understory. In the very productive and in the poorly productive sites *C. brevifolia* occurs only in pure formations. The basal area of *C. brevifolia* in pure formations ranges from 19.04 $m^2 \cdot ha^{-1}$ in poorly productive sites to 38.49 $m^2 \cdot ha^{-1}$ in fairly productive sites. *Cedrus brevifolia* is the most competitive species of the study area as a result of both shade tolerance and the wide range of its site sensitivity behavior. The climax of the study area are the pure stands of *C. brevifolia* having an understory of *Quercus alnifolia* Poech and a sparse occurrence of *Pinus brutia* Ten., mainly in moderately productive sites. Forest practice has to, as much as possible, unite species formations in order to create extensive areas of *C. brevifolia* formations.

Keywords: Cyprus; shade tolerance; site sensitivity; thinning; marking rules

INTRODUCTION

Silvicultural interventions for the redistribution of the growing space in order to create certain conditions favor specific individuals or species (Oliver et al. 1996, Milios et al. 2019). In order to develop silvicultural guidelines for the long-term treatment of a forest ecosystem, a basic requirement is a thorough knowledge of the main ecological traits and characteristics of the constituting tree species. The main information needed is the site sensitivity determination (Oliver et al. 1996) of the constituting tree species and the knowledge of their light requirements. This information will be the basis for assessing the competitive ability of the species in the context of the ecosystem in question. Of course, the competitive ability of a species is not a constant trait, since it is also influenced by site productivity and by the competitive ability of the other competing species (Dafis 1986).

Stand height structure analysis combined with stand density and canopy cover data may supply crucial information on the light requirements of the species forming the different stories of the stand. Furthermore, comparative stand structure analysis in different site productivity areas is a significant tool in order to determine site sensitivity of the stand constituting species. Site productivity determines competitive superiority between species with different site sensitivity (Oliver et al. 1996), while the existence of trees in various stories in the vertical stand structure depends on the shade tolerance of the tree species (Oliver et al. 1996).

Hence, when the ecology of a tree species is not adequately known or understood, the stand structure analysis of the species formations in sites having different productivity can provide crucial information on its ecological requirements, site sensitivity and competition behavior. One such species is *Cedrus brevifolia* Henry (Cyprus cedar).

Cedrus brevifolia is a wind-pollinated conifer tree species of the Pinaceae family (Meikle 1977). It is an endemic species of the Cyprus flora, with narrow distribution, since it occurs in a sole population in the area of Paphos Forest. *Cedrus brevifolia* forest covers an area of 290 ha, which constitutes less than 0.2% of the high forest vegetation in Cyprus. From 1960 the Department of Forests has been implementing mass plantation of *C. brevifolia* plants at the boundaries of the natural forest of the species, covering today an area of ~130 ha (Eliades et al. 2019).

Cedrus brevifolia showed the highest stomatal conductance (Ladjal et al. 2005), while it is characterised by the lowest growth rate, but was found to be the least drought-sensitive among the cedar species (Ducrey et al. 2008). Although *C. brevifolia* is an island mountainous endemic species with narrow distribution, it revealed a high level of genetic diversity, most likely due to the long-term presence of the species in the mountains of Cyprus (Bou Dagher-Kharrat et al. 2007, Eliades et al. 2011). In addition, the unique population of *C. brevifolia* in Cyprus was not found to be genetically uniform, but rather showed significant genetic structure (genetic differentiation) among identified patches (Eliades et al. 2011). *Cedrus brevifolia* demonstrates phenotypic variation on its needle color, since two different types are observed, that is, trees with glaucous and trees with green phenotype (Meikle 1977). The conservation status of *Cedrus brevifolia* was defined in "The Red Data Book of the Flora of Cyprus" (Tsintides et al. 2007), where, based on the IUCN criteria, it was classified as a vulnerable species. In addition, the *C. brevifolia* forest has been coded and included in Annex I of Council Directive 92/43/EEC (The Habitats Directive) as a priority habitat type, namely "9590 **Cedrus brevifolia* forests (*Cedrosetum brevifoliae*)".

The lack of analytical studies on the ecology and stand structure of *C. brevifolia* has led to the absence of interventions in the formations of *C. brevifolia*. Moreover, the lack of ecological knowledge makes it difficult to determine the disturbances which would expose its formations to great risks.

In this context, the objectives of this study are: a) the stand structure analysis of *C. brevifolia* natural formations in the area of the species natural expansion, b) the development of silvicultural treatments for the conservation of the species natural formations, based on the acquired knowledge on the ecology of the species, and c) the presentation of the characteristics of the first application of the treatments through silvicultural interventions.

MATERIALS AND METHODS

Study Area and the Forest of *Cedrus brevifolia* in Cyprus

As already mentioned, the *C. brevifolia* forest covers an area of 290 ha, located in the top mountains of Paphos Forest (in Troodos mountain range). The species is characterized by limited altitudinal distribution from the upper limits of the meso-Mediterranean to the mid supra-Mediterranean zone (elevation of 900–1400 m above sea level) (Department of Forests 2005). The *C. brevifolia* forest in Cyprus shows discontinuous distribution (Figure 1), with the main patch of the forest occupying the peak area of Tripylos Mountain, while smaller patches also occur at four surrounding areas, namely: Mavroi Gremoi, Selladi tis Elias, Throni and Exo Milos (Eliades et al. 2019).

The pure *C. brevifolia* formations cover a total area of 106 ha, while the mixed formations occur in an area of 184 ha (data provided by Department of Forests); in both cases, these formations are scattered. The mixed formations include a wide range of areas in which *C. brevifolia* varies, from a few individuals up to a large number of trees that significantly contribute to the basal area of the formation.

Apart from *C. brevifolia*, the main species of the mixtures is *Pinus brutia* Ten. (Calabrian pine), while *Quercus alnifolia* Poech (golden oak) occurs in the lower stories in both pure and mixed formations (Delipetrou and Christodoulou 2016, personal observation). Moreover, there are areas with groups of *Q. alnifolia* sprouts (multi-stemmed plants) and seedlings – saplings of *C. brevifolia* growing in most cases under the above and side shade of *Q. alnifolia*; which is an evergreen sclerophyllous endemic shrub species of Cyprus with high ecological importance (Tsintides et al. 2002).

In the area where the natural forest of *C. brevifolia* is expanded, in most cases, the *C. brevifolia* formations alternate with formations of *P. brutia* (with the participation of *Q. alnifolia*) and, in some cases, with *Q. alnifolia* formations.

The parent material of the area is igneous rocks (diabase), the soil is slightly acidic and its texture is sandy loam to loam (Gatzogiannis et al. 2010). Soil profiles carried out in the *C. brevifolia* forest detected that the soil depth in the study area ranges from very shallow to very deep, with acidic pH (5-6.75) (Eliades 2015). The mean annual temperature in the wider area of Tripylos Mountain is 15.78˚C and the mean annual precipitation 668.7 mm (data availability for period 1981-2000) (Christou et al. 2001), while the dry period lasts from mid-April up to mid-October (Christou et al. 2001).

Methods

In order to address the scientific questions of the current study, fieldwork was carried out in 2017. The *C. brevifolia* natural formations were classified in structural types based on two main components: species composition of the formation and productivity of the site.

The species natural formations were classified into two types: pure formations of *C. brevifolia* (PRC), where *C. brevifolia* is the dominant species and composes at least 80% of the tree basal area, and mixed formations (MXC), where two dominant species exist (*C. brevifolia* and *P. brutia*).

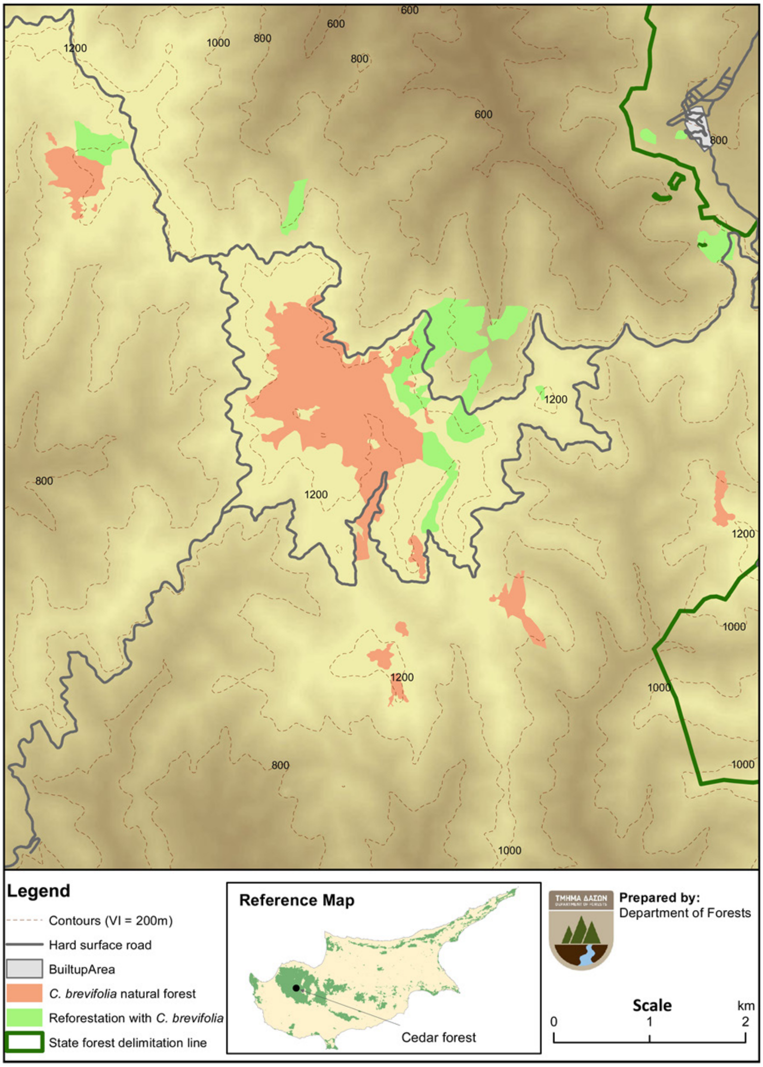

Figure 1. Distribution of *C. brevifolia* forest on Cyprus.

In addition, the classification of an area in a site productivity category was based on several criteria: soil depth, the form of the terrain (convex or concave) the existence of a stream (water) in the vicinity and the location of the area on the slope (base, middle, upper part, ridge) (Dafis 1986, Barnes et al. 1998, Papalexandris and Milios 2010, Adamopoulos et al. 2009, Stampoulidis et al. 2013, Petrou 2015, Petrou and Milios 2020). The form of the terrain was used as a surrogate of the total depth of the soil (Milios and Papalexandris 2008, Papalexandris and Milios 2010, Adamopoulos et al. 2009, Milios and Papalexandris 2019). Moreover, the location of the area on the slope can be used as a surrogate of the total soil depth (Dafis 1986, Barnes et al. 1998, Adamopoulos et al. 2009, Milios et al. 2012). The actual soil depth was measured (in soil profiles) in the very few cases where there were doubts regarding the classification of an area in a site productivity category.

The above approach of site productivity was based on the assumption that in Mediterranean areas with a dry period in summer, water availability is a significant factor of site productivity. In the same context, soil depth is related to site productivity since soil acts as a water reservoir and supplies the plant roots with water during summer (Dafis 1986, Hatzistathis and Dafis 1989, Papalexandris and Milios 2010). The different site productivity areas where *C. brevifolia* formations grow were easily distinguishable. The very productive sites (SA) are almost exclusively found on the banks of both sides of a local stream. On the contrary, the poorly productive sites (SD) are found only in ridges having narrow widths. In these ridges, soil is almost absent, while in most cases rocks (parent material) cover a great part of the terrain surface. The fairly productive sites (SB) occur mainly in concave areas in the middle and the upper part of the slope, while moderately productive sites (SC), are found mainly in the upper part of the slope and in medium width ridges having few or no appearances of rocks and deeper soil than SD. In a few cases, SC are found in the middle of the slope in mostly convex locations. Most of the *C. brevifolia* formations and the greatest area of the species distribution are found in moderately (SC) and poorly productive sites (SD), while in the very productive sites (SA) the species occurs in continuous areas in almost all cases. The SC covers the largest area in the study area.

Combining the species composition of the formation and productivity of the site, six out of eight different structural types were identified in *C. brevifolia* natural formations:

a) pure *C. brevifolia* formations found in very productive sites (PRCSA),
b) pure *C. brevifolia* formations found in fairly productive sites (PRCSB),
c) pure *C. brevifolia* formations found in moderately productive sites (PRCSC),
d) pure *C. brevifolia* formations found in poorly productive sites (PRCSD),
e) mixed *C. brevifolia* formations found in fairly productive sites (MXCSB) and
f) mixed *C. brevifolia* formations found in moderately productive sites (MXCSC).

The mixed structural types comprise only the rather closed formations where *C. brevifolia* constitutes a significant part of the basal area and not the open (having low tree density) mixed formations.

For each structural type six circular plots of approximately 500 m^2 (radius of 12.62 m) were randomly established in the area where the specific structural type occurs. In total, 36 plots were established. In each plot, the species, the diameter at breast height (dbh), (in cm -precision of one decimal), and the total height, (m - precision of 0.5 m) of all living trees with a height of over 1.3 m were recorded. The diameter measurements were made using diameter tape and the heights were measured using the Haga instrument. For each plot, the clustering of trees to the vertical distribution was done according to three categories: overstory trees, middlestory trees and understory trees (Dafis 1992). Overstory trees were defined as the trees taller than 2/3 of the predominant height (the average height of the tallest 100 trees·ha^{-1} – 5 tallest trees in the plot of 500 m^2). The trees with height equal or more than 1/3 but lower (or equal) than 2/3 of the predominant height were classified as middlestory trees, while those with height lower than 1/3 of the predominant height were classified as understory trees. Noticeably, for *Q. alnifolia* multi-stem individuals, only the dbh and the height of the dominant (tallest) stem were recorded.

Finally, for each plot, the canopy cover percentage was visually estimated as a percentage (maximum 100%) of the plot area, which was covered by the projection of the tree canopy.

Statistical Analysis

In the comparisons among the heights of the tallest *C. brevifolia* trees of the pure formation structural types (for each structural type the heights of the five tallest trees of each plot were used) the Dunnett T3 was used, since there was no homogeneity of variances. In the comparisons among the basal areas of the pure formations of *C. brevifolia* found in the different site productivity areas, the Duncan test was used.

For the diameter and height distributions of *C. brevifolia* in each structural type, the Anderson-Darling statistic was used for the examination of the typical distribution (lognormal, exponential, empirical, triangular, Weibull, gamma, normal, beta, uniform) that fits better to them (Milios et al. 2020). The closest fit is provided by the typical distribution having the lowest value of the Anderson-Darling statistic (Anderson and Darling 1954). A p-value is not available in all cases for all distributions that were tested; so the decision for the best-fitted distribution was based on the value of the Anderson-Darling statistic only (IBM 2012). The analyses were conducted using SPSS 21 (IBM 2012).

RESULTS

As previously mentioned, *C. brevifolia* forms mixed formations with *P. brutia* and *Q. alnifolia*. Apart from these tree species, woody species such as *Platanus orientalis* L., *Prunus avium* L. and *Arbutus andrachne* L. were also recorded in the established plots and were classified as "other species" (Figure 2 and 3).

In PRCSA from 623 trees·ha^{-1} of *C. brevifolia* 393 grow in the understory. In PRCSB, PRCSC and PRCSD the corresponding values are 480 – 173, 346 – 66 and 383 – 53. In MXCSB from 283 trees·ha^{-1} of *C. brevifolia* 137 grow in the understory, while in MXCSC the corresponding values are 200 – 56. In the case of *Q. alnifolia*, in all structural types, the trees grow in the understory and in the middlestory (Table 1).

The height of the tallest *C. brevifolia* trees in PRCSA is higher ($p<0.05$) than that of the rest of the structural types of pure formations, while the height of the tallest *C. brevifolia* trees in PRCSD is lower ($p<0.05$) than the corresponding heights of PRCSA, PRCSB and PRCSC. The height of the tallest *C. brevifolia* trees in PRCSB is higher than the height of the tallest *C. brevifolia* trees in PRCSC (Table 2). The tallest *C. brevifolia* tree measured in a plot has a height of 29 m and a breast height diameter of 57 cm, while the tree with the largest breast height diameter has a diameter of 109 cm and a height of 27 m. Both trees grow in plots of PRCSA.

The basal area of *C. brevifolia* in pure formations ranges from 19.04 m^2·ha^{-1} in poorly productive sites (PRCSD) to 38.49 m^2·ha^{-1} in fairly productive sites. The maximum canopy cover of *C. brevifolia* formations is 100% in very productive (PRCSA) and in fairly productive sites (PRCSB, MXCSB), while in moderately productive sites it is 85% in PRCSC, and 95% in MXCS. In poorly productive sites (PRCSD) it is 80% (Table 1).

Table 1. Structural data of the six structural types in *C. brevifolia* forest.

Species	Overstory (trees·ha^{-1})	Middlestory (trees·ha^{-1})	Understory (trees·ha^{-1})	Canopy cover range of all stories (%)	Basal area (m^2·ha^{-1})	N (trees·ha^{-1})
Pure formations in very productive sites (PRCSA)						
C. brevifolia	153	77	393		36.47	623
P. brutia	0	0	10		0.0017	10
Q. alnifolia	0	0	290		0.84	290
Other species	13	13	90		6.73	116
Total	166	90	783	90 - 100	44.04	1039
Pure formations in fairly productive sites (PRCSB)						
C. brevifolia	240	67	173		38.49	480
P. brutia	3	0	4		0.42	7
Q. alnifolia	0	30	266		1.25	296
Other species	0	0	3		0.002	3
Total	243	97	446	90 – 100	40.16	786
Pure formations in moderately productive sites (PRCSC)						
C. brevifolia	153	127	66		21.04	346
P. brutia	3	10	4		0.49	17
Q. alnifolia	0	47	186		0.34	233
Total	156	184	256	55 - 85	21.87	596
Pure formations in poorly productive sites (PRCSD)						
C. brevifolia	163	167	53		19.04	383
P. brutia	3	14	13		0.06	30
Q. alnifolia	0	33	110		0.20	143
Total	166	213	177	55 - 80	19.30	556
Mixed formations in fairly productive sites (MXCSB)						
C. brevifolia	73	73	137		11.81	283
P. brutia	57	26	0		12.32	83
Q. alnifolia	0	50	450		2.23	500
Total	130	149	587	85 - 100	26.36	866
Mixed formations in moderately productive sites (MXCSC)						
C. brevifolia	97	47	56		10.85	200
P. brutia	84	63	50		8.36	197
Q. alnifolia	0	100	143		1.13	243
Total	181	210	249	70 - 95	20.34	640

Table 2. Mean height of the tallest *C. brevifolia* trees in the structural types of pure formations.

Structural types of pure formations	Mean height of the tallest trees (m)	S.D.	Min	Max	n
PRCSA	24.37^{a}	3.054	16.0	29.0	30
PRCSB	17.72^{b}	3.175	13.0	23.0	30
PRCSC	10.30^{c}	2.524	6.0	16.0	30
PRCSD	7.50^{d}	1.520	5.0	10.0	30

Means are statistically different at p<0.05 when they share no common letter. The comparison was made using the Dunnett T3 test, S. D. = standard deviation, n = number of trees, 6 plots x 5 tallest trees = 30 trees.

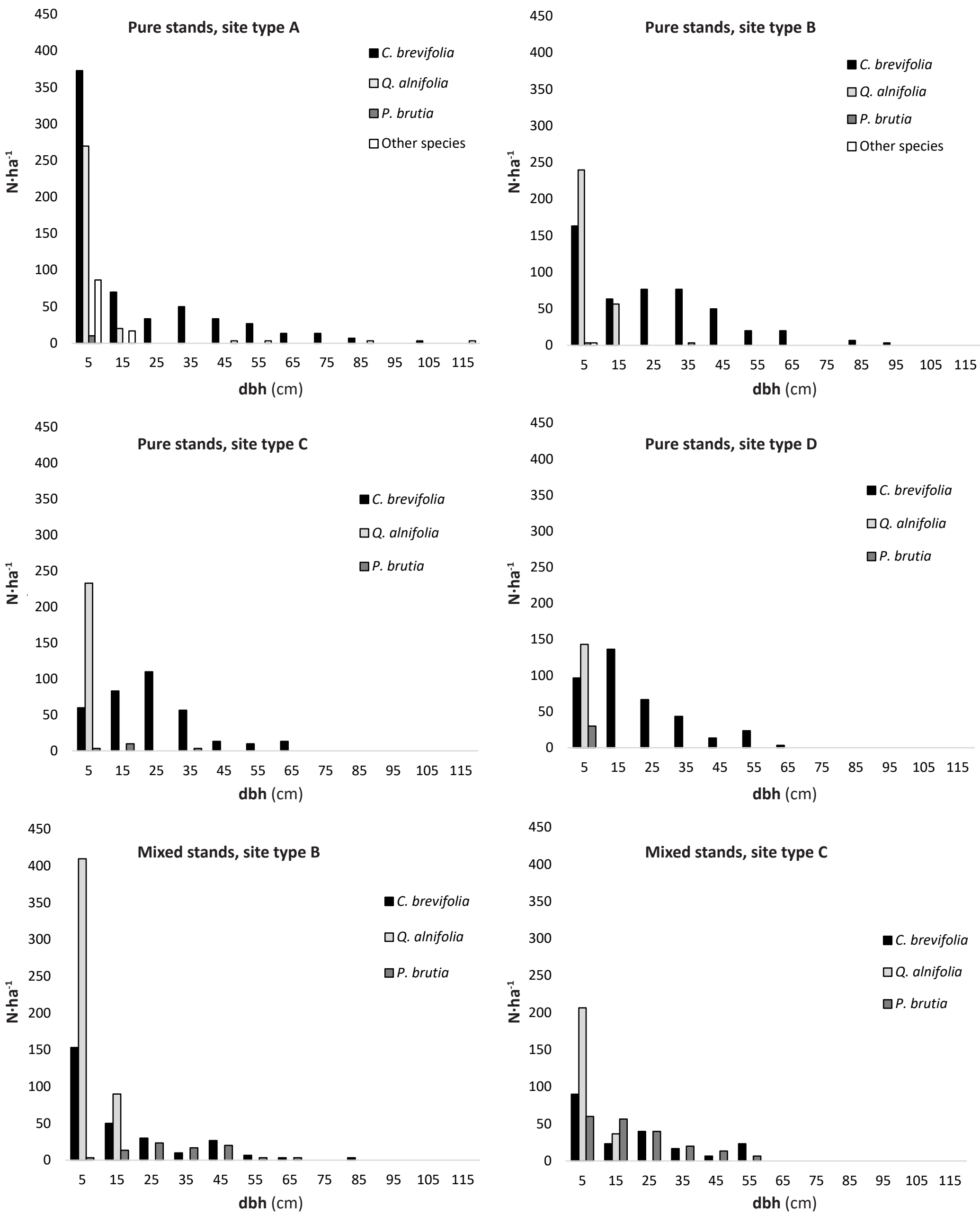

Figure 2. Distributions of tree diameters at breast height (dbh) in the six structural types.

The basal area in PRCSA is not different (p>0.05) compared to that of PRCSB and the basal area in PRCSC is not different (p>0.05) compared to that of PRCSD. However, the basal areas of PRCSA and of PRCSB are higher (p<0.05) than those of PRCSC and of PRCSD (Table 3).

In PRCSA, PRCSB, MXCSB and in MXCSC the diameter class of 5 cm (the lowest class) has more *C. brevifolia* trees compared to the rest diameter classes (Figure 2), while in PRCSA, PRCSB and MXCSB, the height class of 2 m (the lowest class) has more *C. brevifolia* trees compared to the rest height classes (Figure 3).

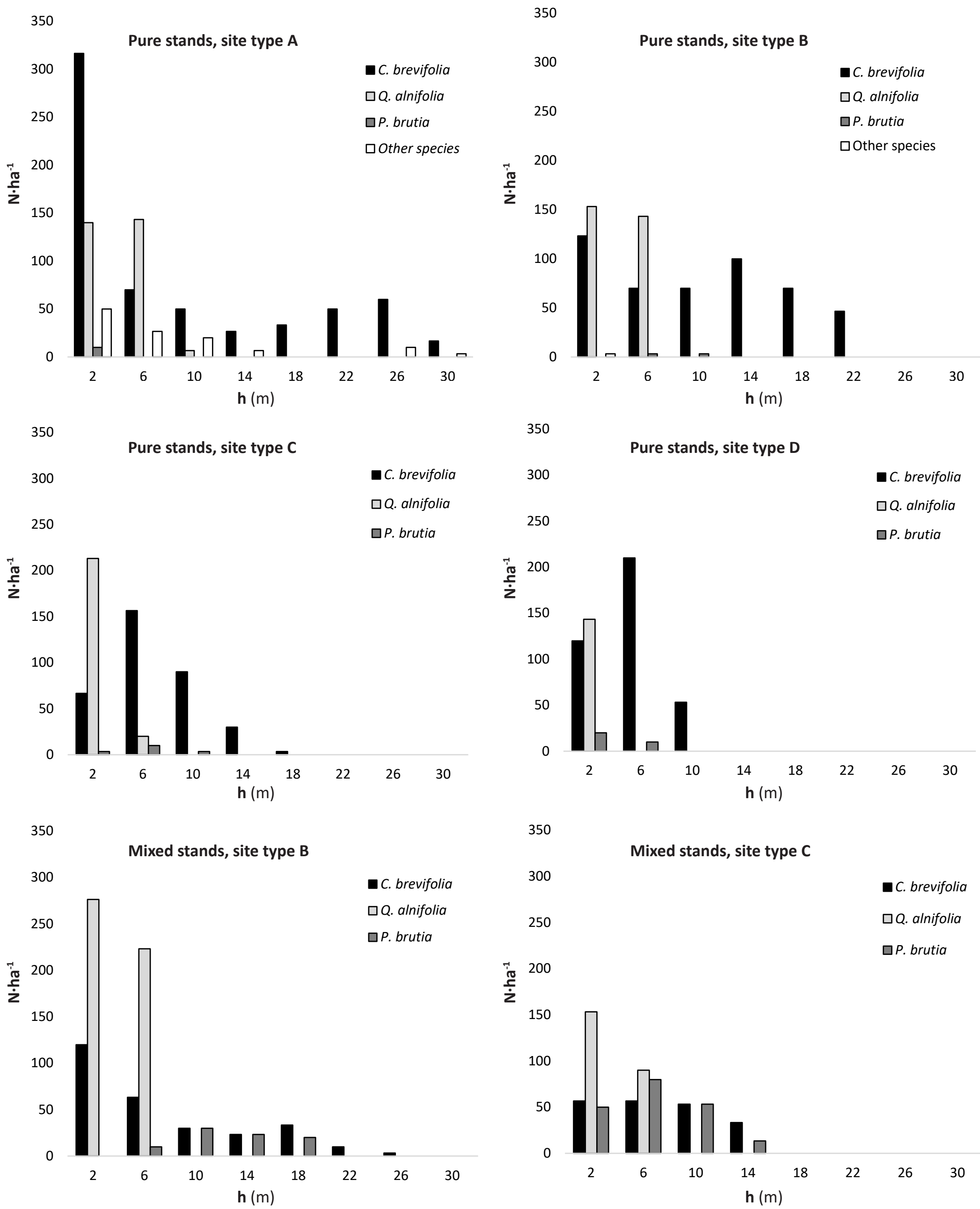

Figure 3. Tree height distributions in the six structural types.

The lognormal distribution fits better in the diameter distributions of *C. brevifolia* in PRCSA and in MXCSB structural types, while the triangular distribution fits better in the diameter distributions of the species in PRCSB and in MXCSC structural types. In the diameter distributions of *C. brevifolia* in PRCSC and in PRCSD the distributions that fit better are the normal and the uniform respectively (Table 4). In the height distributions of the species, the triangular distribution fits better in PRCSD, MXCSB and in MXCSC structural types. In PRCSB and PRCSC the distribution that fits better is the uniform one, while in PRCSA, lognormal distribution fits better (Table 4).

Table 3. Mean basal area of *C. brevifolia* trees for plots of each structural type of pure formations.

Structural types of pure formations	Mean basal area (m^2)	S.D.	Min	Max	n
PRCSA	1.83[a]	0.427	1.20	2.33	6
PRCSB	1.93[a]	0.450	1.13	2.28	6
PRCSC	1.05[b]	0.245	0.61	1.29	6
PRCSD	0.95[b]	0.296	0.62	1.44	6

Means are statistically different at p<0.05, when they share no common letter. The comparison was made using the Duncan test, S. D. = standard deviation, n = number of plots.

Table 4. Typical distribution that fits better in the diameter and height distributions of *C. brevifolia* in the different structural types using the Anderson-Darling statistic.

Structural type	Typical distribution	A (Anderson-Darling statistic)
	Diameter distribution	
PRCSA	Lognormal	0.23
PRCSB	Triangular	-0.22
PRCSC	Normal	0.45
PRCSD	Uniform	-0.15
MXCSB	Lognormal	0.27
MXCSC	Triangular	-0.76
	Height distribution	
PRCSA	Lognormal	0.42
PRCSB	Uniform	-0.62
PRCSC	Uniform	-0.97
PRCSD	Triangular	-1.59
MXCSB	Triangular	-0.64
MXCSC	Triangular	-2.11

DISCUSSION

In *C. brevifolia* forest, the diameter distributions of all structural types indicate uneven aged stands (O'Hara 2014) where the individuals with great dimensions are possibly the survivors of previous disturbances, especially in the moderately productive sites (SC) and poorly productive sites (SD) (Milios et al. 2007). On the other hand, in more productive sites (SA and SB) the great dimension of many of the large trees might have been the result of the more intense competition in combination with the favorable site conditions (Oliver and Larson 1996).

The differences of the heights of the tallest *C. brevifolia* trees in the different structural types of pure formations (Table 2) seem to support the classification of sites in relation to their productivity. However, the height of trees that were dominant for their entire life span is used as an index of the growth potential of a site in even-aged stands (Oliver and Larson 1996, Smith et al. 1997). Notably, the height of dominant trees should be compared at the same age. It could be assumed that the trees which comprise the tallest trees in the plots established in the pure formations of each site productivity category were dominant trees in an even-aged group, and at the time of measurement they were of more or less the same age. Under these assumptions, the observed statistically significant differences of the mean height of the tallest *C. brevifolia* trees (Table 2) verify the classification of the areas, where pure formations occur, in the different site productivity categories. This is an indication of correct site productivity classification.

Cedrus brevifolia trees can exhibit large dimension and can create stands with high basal area as in the case of pure formations in the SA and SB. In the PRCSA and PRCSB the basal area of the species is 36.47 and 38.49 $m^2 \cdot ha^{-1}$ respectively (Table 1). These values are higher compared to the value of *C. libani* basal area referred for stands in Tannourine Cedar Forest Reserve in Lebanon (Bassil et al. 2018), but they are lower than the basal area of pure *C. atlantica* forests in Theniet El Had National Park in Algeria (Sarmoum et al. 2018) and the values of *C. atlantica* basal area of most closed stands in the Moroccan Middle Atlas forests (Linares et al. 2011). In Cyprus, two groups of pure structural types are formed regarding basal area. The first group consists of PRCSA and PRCSB structural types and represents the productive sites, while the second group includes PRCSC and PRCSD structural types representing the less productive sites. The two structural types in each group do not exhibit a difference in basal area (p>0.05), while each of the structural types of the productive sites has higher ($p<0.05$) basal area compared to the structural types of the less productive sites (Table 3).

In the different structural types, the competition regime is differentiated as a result of different tree density and site productivity (Oliver and Larson 1996). This led to differences in tree diameter dimensions and in the form of distributions that consequently led to the great differences observed in the typical distribution that fits better in the diameter distributions of *C. brevifolia* trees in the structural types of the species formations (Table 4). In the case of *C. brevifolia* height distributions of the species formations there are three structural types in which the triangular distribution fits better in their height distribution compared to the other typical distributions that were checked. In two structural types the uniform distribution fits better and in one structural type lognormal distribution fits better (Table 4). The lower variability in the form of height distributions (compared to that of diameter distributions) in the different structural types is due to the factors that determine the height growth of trees. Hence, the competition regime created by the different densities of the formations does not influence significantly the height growth of the dominant trees, as in the case of their diameter. Tree height is mainly influenced and determined mainly by site conditions (Oliver and Larson 1996) and thus the range between the lowest and highest observed height of trees in all sites is reduced.

The shade tolerance of *C. brevifolia* was the decisive factor which determined both diameter and height distributions of the species in the different structural types, since it led to the development of the “robust” lowest diameter and height distribution classes. *Cedrus brevifolia* exhibits shade tolerance. This is obvious from both the diameter and height distributions of all structural types (Figure 2 and 3). Especially, in PRCSA, PRCSB and MXCSB structural types where the greatest canopy cover percentage is observed, most of the *C. brevifolia* trees of the lowest classes in both diameter and height distributions were established and grew under shade conditions. Moreover, a great percentage of *C. brevifolia* trees grow in the understory of their plot in most structural types (Table 1).

Cedrus brevifolia is more shade-tolerant than its main tree species competitor in the study area, *P. brutia*. *Pinus brutia* is a light-demanding (Korakis 2015) and fast-growing species (Kitikidou et al. 2011, Kitikidou et al. 2012). The few *P. brutia* tress with small dimensions (height and diameter) found in PRCSA and PRCSB grow in the edges of their plots (and formations), reaching adequate side (or top) light for their survival. On the other hand, in the PRCSC, PRCSD and MXCSC structural types, the light condition, as a result of the rather low canopy cover percentage created in many locations, allows the establishment and survival of some *P. brutia* trees in the understory (Table 1). In harsh conditions in medium elevation of central Cyprus, *P. brutia* seedlings can be established and survive at least for one growing season under the facilitation of mature individuals of the species (Petrou and Milios 2012, 2020).

The most significant result of this study is that in the worst site conditions there is only one structural type of the species formations (PRCSD), a pure one, as in the case of the very productive sites (PRCSA). Even though *P. brutia* is a site-insensitive species (Korakis 2015), *C. brevifolia* is more competitive compared to *P. brutia* in the worst site conditions. *Pinus brutia* has a very sparse occurrence in poorly productive sites (SD) and this is not the result of unfavorable light conditions, as in the cases of the pure formations of other sites (mainly PRCSA and PRCSB structural types), since the vegetation in the SD formations is more or less sparse in many cases. It seems that *P. brutia* cannot create even very sparse formations in SD. Possibly another reason for the dominance of *C. brevifolia* in SD is the probable larger lifespan of the species compared to *P. brutia*. Thus, *C. brevifolia* is the most competitive species of the study area, owing to both shade-tolerance and the wide range of its site sensitivity behavior. This wide range of the site sensitivity may be the outcome of a significant genetic heterogeneity observed among the different site populations of the species (Eliades et al. 2011).

Quercus alnifolia cannot be considered as a strong competitor of *C. brevifolia*, since it is a shrub or small tree reaching a height of up to 10 m in the plots of this study, while Petrou et al. (2015) measured heights up to 11.60 m in their study for the construction of site index curves for *Q. alnifolia* in Cyprus. The competition among *C. brevifolia* and *Q. alnifolia* trees for light ends when *C. brevifolia* trees reach the height of a few meters.

Regardless of the fact that *Q. alnifolia* grows in the understory exhibiting shade tolerance, it cannot prevent the establishment of *C. brevifolia* trees as it can be concluded from the height and diameter distributions of PRCSA, PRCSB and MXCSB structural types where the greater canopy cover percentage is observed, while many of the understory trees of *C. brevifolia* had a height of up to 2 m in all structural types.

Based on the above analysis, the climax of the study area are the pure stands of *C. brevifolia* that have an understory of *Q. alnifolia* and a sparse occurrence of *P. brutia* mainly in moderately productive sites (SC).

Development of Silvicultural Treatments

Small scale disturbances, which release a small amount of growing space, will not influence the succession in the area. Even in the case of the establishment of a *P. brutia* individual in the free-growing space, the reoccupation of the growth space from the adjacent *C. brevifolia* trees (mainly in SA and SB mainly and secondly in SC) in combination with the increase in light requirements of the *P. brutia*, as it becomes older and bigger in dimensions (Dafis 1986), will lead to the death of the *P. brutia* tree due to low light availability. In the case of SD, the unfavorable site conditions will not probably allow even the establishment of a *P. brutia* tree.

Disturbances which release large growing space, killing many trees, like forest fires, act against the dominance of *C. brevifolia*, since *P. brutia* as a pioneer and bradychorous species (Thanos and Marcou 1991, Spanos et al. 2000, Thanos and Daskalakou 2000, Boydak 2004) will have a competitive advantage. Thus, if no intense disturbances take place in the study area, the succession process will lead to the dominance of *C. brevifolia* in mixed formations and the development of pure *C. brevifolia* formations. Moreover, *C. brevifolia* will be established gradually in areas adjacent to species formations and will finally dominate in almost entire study area. However, apart from the prevention of large-scale disturbances like forest fires, forest practice can accelerate succession in the area through the favoring of *C. brevifolia*.

As it is referred in the study area section, in the area where the natural forest of *C. brevifolia* is expanded, in most cases, the *C. brevifolia* formations alternate with formations of *P. brutia* (with the participation of *Q. alnifolia*) and, in some cases, with *Q. alnifolia* formations. Forest practice has to unite, as much as possible, species formations in order to create extensive areas of *C. brevifolia* formations. These extensive areas will exhibit high stand structure differentiation as a result of the different age of *C. brevifolia* trees and different site productivity and therefore higher biodiversity (Lindenmayer and Franklin 2002). The treatments proposed to favor the species relate to the removal through cuttings and thinning of individuals of other species (see Figure 4).

Based on the emerged knowledge from this study a workflow was developed, with specific silvicultural treatments for *C. brevifolia* formations. A detailed description of each of the three silvicultural treatment types that have been developed for *C. brevifolia* formations is presented in Figure 4, which also presents the structural types of *C. brevifolia* formations where each silvicultural treatment should be applied.

The silvicultural treatments of Figure 4, are applied through silvicultural interventions (tree cut, thinning etc.). A silvicultural intervention may combine two silvicultural treatments since it can cause different effects in different *C. brevifolia* trees or regeneration plants. For example, from the cutting of a *P. brutia* tree an overstory *C. brevifolia* tree (silvicultural treatment type ii – see Figure 4), as well as two regeneration *C. brevifolia* plants that are growing under the shade of the cut pine, can be favored simultaneously (silvicultural treatment type i- see Figure 4).

The interventions (treatments) aiming to favor *C. brevifolia* should not be restricted to only one application. They should be periodically applied. Their characteristics as well as the time of each application (or the need of a new application) should be defined according to structure and competition conditions of the formations. The achievement of even a relatively simple goal, such as the reduction of the intensity of competition, faced by individual *C. brevifolia* trees through the removal of neighbouring competitors belonging to other species, in most cases cannot be accomplished by a single intervention.

The main reasons for that are: (a) the abrupt removal of competition can lead to a drastic change in the conditions of growth for those individuals we want to favor with potentially negative consequences for their growth, even for their survival. Therefore, the redistribution of the growing space should be done gradually with more interventions depending on the prevailing characteristics of competition and (b) the change in competition conditions due to the increment of dimensions of potential competitors. For example, a plant that, in the first intervention, does not compete with the *C. brevifolia* tree, that is to be favored, over time becomes a strong competitor that should be removed. In addition, the need for periodic interventions arises from the different conditions created by the change in structure characteristics and more generally in competition regime. These changes create new needs for redistribution of the growing space. These needs should be assessed and the necessary measures should be taken each time.

The proposed treatments are referred to the present structure of natural *C. brevifolia* formations. Potentially, after many decades, in some cases the silvicultural treatments that should be applied to closed natural *C. brevifolia* formations will be moved towards the concepts of the classical silvicultural systems and new silvicultural guidelines should be developed.

Besides, general principles were developed (Box 1) that could be adopted for the sustainable management of *C. brevifolia* forest, while they are valid for all silvicultural interventions. Hence, in the case of formation structures that have not been analysed or consist of a combination of structures of some of the previously mentioned structural types, the analysed silvicultural treatments, in combination with the general principles which are presented below, provide the information and tools for the application of the proper silvicultural interventions – treatments in order to achieve the goals that were set. The mentioned principles (Box 1) are also valid for the analysed structural types. The term of light intensity is referred to the degree of change of light conditions. Consequently, an intervention is considered as intense when it causes a great increase in light intensity in the forest floor (see below).

Since *C. brevifolia* is the keystone species for the ecosystem in the highest elevations of Paphos Forest (Tripylos Mountain and the neighboring hills), a rational management of the *C. brevifolia* forest is needed in order to conserve and enhance the ecosystem biodiversity. Along with the proposed silvicultural treatments, forest practice in the area should incorporate the following principles, related to the enhancement of biodiversity, in the silvicultural interventions (Box 1). The proposed principles are based mainly on Lindenmayer and Franklin (2002).

Box 1. General guidelines for silvicultural interventions.

General principles valid for all silvicultural interventions

a) <u>Edges</u>: Canopy-formation edges should not retreat or "open" in a great extent as a result of the silvicultural interventions.
b) <u>Ridges – convex areas – not productive sites</u>: Silvicultural interventions in ridges, convex areas and in non-productive sites should be light and applied only where judged essential.
c) <u>Logging debris:</u> Large-scale material (d>10cm) resulting from forestry operations, except for a small percentage, should not remain in the formations to avoid insect damage.
d) <u>Cutting of the top – pruning of trees of various dimensions that compete with *C. brevifolia* plants</u>: It is a way to reduce competition and it is recommended in cases where, in parallel with competition, a positive influence exists. This cutting can be done and in parallel the canopy density in the micro-locations where *C. brevifolia* plants grow is maintained and the widening of existing gaps is avoided.
e) <u>Low intensity interventions</u>: The interventions in *C. brevifolia* formations should be of light intensity except in cases where the participation of *C. brevifolia* trees is low and the objective is to drastically favor the *C. brevifolia* trees even if a rather wide growing space is released. In these cases, the interventions can be intense. In general, inner (closed) forest conditions should be maintained or disturbed to the smallest extent possible in the closed formations where *C. brevifolia* occurs at a satisfactory rate.

Principles for the conservation and enhancement of biodiversity

a) Retention of standing dead *C. brevifolia* trees (large dimension dead trees as a priority).
b) Retention of *C. brevifolia* fallen trees on the forest floor.
c) Retention of stumps, having a height of 70–100 cm, originated from the cutting of rather large-dimension trees.
d) Identification and favoring of *C. brevifolia* individuals having a phenotype with glaucous color of needles.
e) Retention of some living *P. brutia* trees having large dimensions.
f) Retention of few *P. brutia* trees in fairly productive sites (SB) and moderately productive sites (SC) (at a later stage, when *C. brevifolia* dominates in those sites).
g) Favoring of *P. orientalis* individuals, as well as individuals of other broadleaved species, growing mainly inside or on the side banks of the stream in SA, through the cutting of trees, which intensely compete them.
h) Retention of some gaps inside the *C. brevifolia* expansion area.

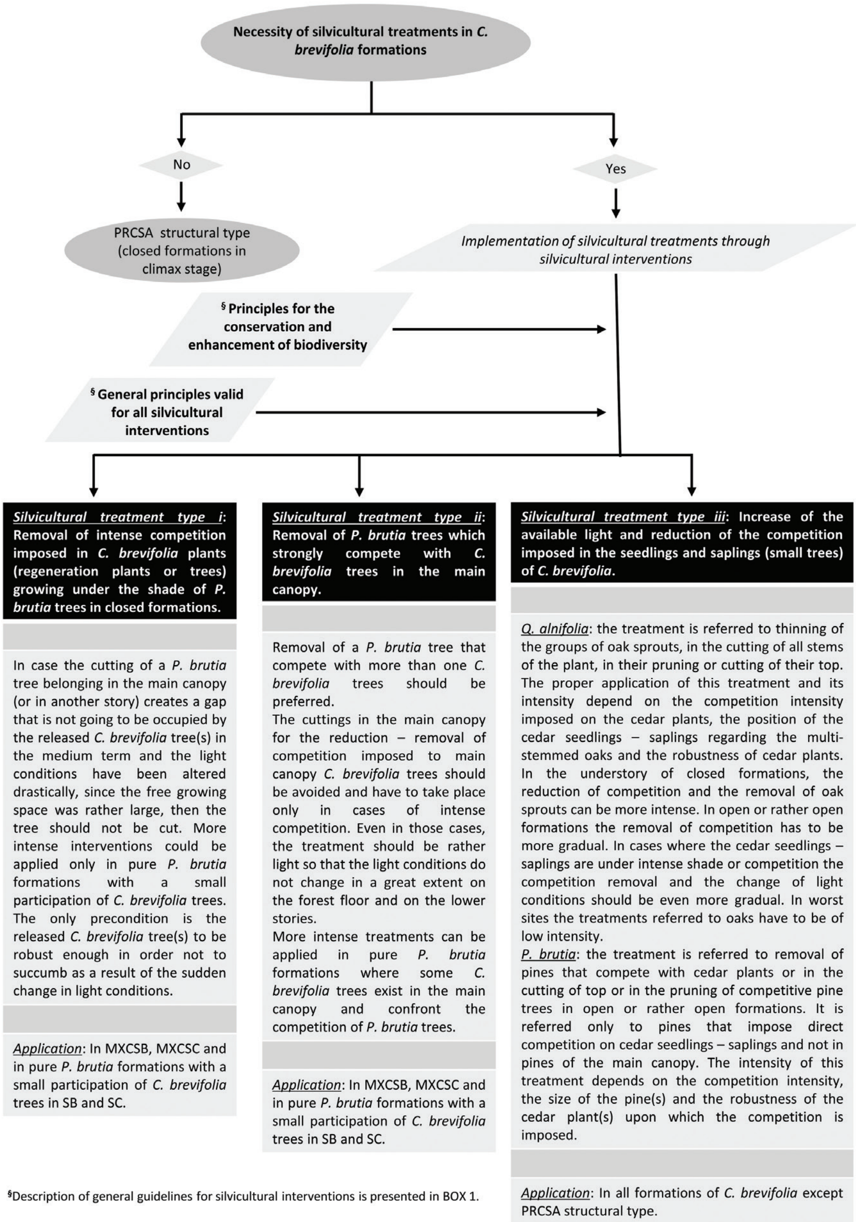

Figure 4. Workflow of silivicultural treatments in *C. brevifolia* formations.

Application of the Proposed Silvicultural Treatments

Silvicultural interventions were applied in the plots of the mixed formations (MXCSB, MXCSC) in 2018 (see Box 2). For each silvicultural intervention application, the following data was recorded: a) the type of implemented treatment or treatments, since a cutting of a tree may combine the characteristics of more than one treatment, b) the species of the tree, in which the intervention was applied, and c) the number of the *C. brevifolia* trees and regeneration plants (having a height of between 0.1 m to 1.3 m), which were favored by the intervention.

One improvement developed during the application of the interventions was the killing through girdling (at their base) of large *P. brutia* trees which competed or suppressed *C. brevifolia* trees. This was done in order to avoid the creation of large gaps, while, at the same time, the competition or the suppression upon *C. brevifolia* plants were removed.

Box 2. Silvicultural interventions in mixed formations of *C. brevifolia.*

Structural type	Silvicultural treatments through silvicultural interventions in *C. brevifolia* formations
MXCSB	In total 18 (60 ha^{-1}) trees and 62 (207 ha^{-1}) regeneration plants of *C. brevifolia* were favored by the cut or kill of eight (27 ha^{-1}) (seven were cut and one was killed) *P. brutia* trees and the stem thinning (or cut) in 18 (60 ha^{-1}) *Q. alnifolia* trees in the six plots of MXCSB. In the case of two cut *P. brutia* trees, *C. brevifolia* plants were favored in the frame of two silvicultural treatment types.
MXCSC	In the plots of MXCSC, 10 (33 ha^{-1}) trees and 54 (180 ha^{-1}) regeneration plants of *C. brevifolia* were favored by the cut or kill of 14 (47 ha^{-1}) (13 were cut and one was killed) *P. brutia* trees and the stem thinning (or cut) of eight (27 ha^{-1}) *Q. alnifolia* trees. From the cutting of two *P. brutia* trees, *C. brevifolia* plants were favored in the frame of two silvicultural treatment types.

Characteristics and results of silvicultural interventions from which the silvicultural treatments were implemented in the plots of mixed *C. brevifolia* formations. The numbers in parentheses are referring to values per hectare.

Structural type	Species of the trees to which the intervention was implemented	Number of the trees to which the intervention was implemented	Number of *C. brevifolia* trees which were favored	Number of *C. brevifolia* regeneration plants which were favored
MXCSB	*P. brutia*	8 (27)	15 (50)	23 (77)
	Q. alnifolia	18 (60)	3 (10)	39 (130)
MXCSC	*P. brutia*	14 (47)	10 (33)	26 (87)
	Q. alnifolia	8 (27)	0 (0)	28 (93)

In the plots of mixed formations in SB about 25% of the *P. brutia* basal area was removed (trees were cut – killed). This represents approximately 12% of the total basal area. The corresponding percentages of mixed formations in SC are approximately 16% (basal area of *P. brutia*) and 7% (total basal area). These interventions were intense in terms of *P. brutia* basal area removal, but they did not lead to a substantial increase in light intensity in the forest floor. The killing, instead of cutting, of the *P. brutia* trees worked in that direction.

CONCLUSIONS

Cedrus brevifolia trees can achieve large dimension and can create stands with high basal area, while they exhibit shade tolerance. *Cedrus brevifolia* is the most competitive species of the study area as a result of both shade tolerance and the wide range of its site sensitivity behavior. Regardless of the fact that *Q. alnifolia* grows in the understory exhibiting shade tolerance, it cannot prevent the establishment of *C. brevifolia* trees.

The climax of the study area are the pure stands of *C. brevifolia* having and understory of *Q. alnifolia* and a sparse occurrence of *P. brutia* mainly in moderately productive sites. Forest practice should, as much as possible, unite species formations in order to create extensive areas – formations – stands of cedar. The treatments proposed to favor the species relate to the removal of individuals of other species.

Author Contributions

EM, PP, N-GHE conceived and designed the research; EM and PP designed the methodology in the field; PP and KP processed the data; EM performed data analyses; AKC and N-GHE secured the project funding and supervised the project implementation; EM, PP, KP, AKC, N-GHE wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Tree Species Diversity and Spatial Distribution of Aleppo Pine Stands in Northeastern Algeria

Insaf Hani [1,*], **Malika Rached-Kanouni**[1], **Ammar Menasri**[2]

(1) University of Larbi Ben M'hidi, Faculty of Exact Sciences and Life Sciences and Nature, Department of Life Sciences and Nature, Laboratory of Functional Ecology and Environment (F.E.E.L), 1st November 1954 Street, Oum el Bouaghi 04000, Algeria; **(2)** Abbes Laghrour University, Department of Agronomic Sciences, Road of Oum-El-Bouaghi, PB 1252 Khenchela 40000, Algeria

*** Correspondence:** e-mail: insaflyne@gmail.com

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ABSTRACT

The spatial pattern of species is one of the key studied parameters in ecology so as to better understand the ecological processes and the functioning of forest ecosystems. This paper describes the classification of structural indices measuring the alpha diversity and examines typical representatives of the classification groups such as the Shannon's index, aggregation index by Clark and Evans, the mingling index, the diameter differentiation index and the coefficient of segregation by Pielou. The tree inventory made it possible to count 7 species that are divided into six (06) families. Only *Pinus halepensis* Mill. trees were taken into account via calculation in spatial distribution. Western exposure shows the most regular tree patterns (1.6±0.1) according to the aggregation index by Clark and Evans, while the species mingling index for south- and east-facing stands indicates segregation of *Pinus halepensis* Mill. groups. The diameter differentiation index for the majority of the studied stands is assumed through estimated values within the range that starts from 0.4 to 0.9 for the four exposures. The distribution shows that western and eastern exposures belong to the fourth class of differentiation (very large differentiation), which means that the trees with the smallest DBH have less than 30% of the size of the neighbouring trees since the diameter differentiation index for the two exposures is 0.9±0.05 and 0.7±0.2.

Keywords: tree species diversity; spatial distribution; Clark and Evans index; mingling index; the diameter differentiation

INTRODUCTION

The characteristics of forest stand structure are of a great interest to various groups of stakeholders. Moreover, the monitoring of tree diversity and forest structure is a crucial prerequisite for understanding and maintaining forest habitats. Structural indices have been widely accepted as sound measures for biodiversity conservation purposes (Motza et al. 2010).

Biodiversity is a key element for evaluating the stability of the system in managed forests as well as in old-growth ecosystems (Kimmins 1997). Forest structure as a term has multiple meanings (Indir et al. 2013). According to Kimmins (1997), the structure of plant community is viewed in terms of vertical and horizontal spatial organization. The majority of indices quantifying forest structure can be divided into two major groups; distance-independent and distance-dependent measures (Tomé et al. 1989, Sylvie 1998, Pommerening 2002). While the first group evaluates stand structure without any spatial reference (Tomé et al. 1989, Pommerening 2002, Cordonnier et al. 2012, Pommerening and Grabarnik 2019), the second group can be subdivided into individual or single tree parameters based on neighbourhood relations (Pommerening 2002, Pommerening et al. 2006). Accounting for small-scale differences in biodiversity, distance-dependent measures describe forest stand structure at the stand level (Indir et al. 2013).

In the present study, diversity was evaluated at stand level (α diversity) which represents the number of species in the stand, their proportion, as well as their distribution (Rached-Kanouni et al. 2020a). Three of the distance-dependent stand structure measures were thus used; the aggregation index by Clark and Evans, the species mingling index and the diameter differentiation index. The results are discussed with referring to some simulated references and suggestions are provided to show how these methods could be applied for *Pinus halepensis* Mill. in Beni Oudjana forest (Algeria).

MATERIALS AND METHODS

Study Area

The study was conducted in Beni Oudjana forest (Figure 1), which is part of a forest and pastoral area of the Aures Massif (eastern Algeria) located between longitude (X1: 6°58’07", X2: 6°42’34") and latitude (Y1: 35°28’22", Y2: 35°19’04") (Hani et al. 2020). The altitude of the sample plots ranges from 1024 m to 1472 m above sea level. The climate of this forest massif is characterized by a long dry and hot summer season and an increasing number of years with less rainfall. Rainfall is generally low and irregular. The rainfall gradient decreases from north to south (Bentouati 2006, Goubi et al. 2019). Average annual temperatures range from 13.6 to 14.9°C (Bentouati 2006, Goubi et al. 2019, Rached-Kanouni et al. 2020b). The substratum is of marly and marly-limestone type for the pine forest. From a bioclimatic standpoint, most of the pine forests have a north and north-west orientation and they are located in the sub-humid stage during cold winters (Bentouati 2006, Hani et al. 2020). This forest area is composed of several softwood and hardwood species, namely Aleppo pine (*Pinus halepensis* Mill.), holm oak (*Quercus ilex* L.), cade juniper (*Juniperus oxycedrus* L.), Phoenicean juniper (*Juniperus phoenicea* L.), atlas cedar (*Cedrus atlantica),* mastic pistachio (*Pistacia lentiscus* L.), narrow-leaved mock privet (*Phillyrea angustifolia* L.) and rosemary (*Rosmarinus officinalis* L.) (Hani et al. 2020).

Field Measurements

The experimental trial has 16 plots distributed in the area of Aleppo pine with the regeneration of other species stands (Figure 2). The study plots were randomly selected in relation to different cardinal exposures (east, south, west and north). Vegetation data were collected in rectangular plots of 25 m × 20 m (500 m^2) and their characteristics are illustrated in Table 1. On each plot, the tree species were distinguished, and the diameters of all trees with DBH>5.0 cm. In order to calculate Clark and Evans index, DBH differentiation (T_{ij}) and species mingling (M_i) indices, the distance between the nearest trees in relation to the referent tree should be measured. X and Y coordinates were recorded for each tree in each of the 16 plots.

Data Analysis

Tree Species Diversity

At the scale of a stand, biodiversity indicators are usually placed into one of two categories; those that are based on the identification of key tree species and on the identification of key structures (Lindenmayer et al. 2000, McElhinny et al. 2005).

One of the first diversity indices was species richness (SR). This index evaluates the number of tree species in the stand (Gonçalves et al. 2010). Though it enables to distinguish diversity as a function of the number of species, it does not give any information regarding the weight of each species in the mixture. Thus, two stands have the same number of species, where one has a similar number of individuals per species and the other has a much higher number of individuals of one of the species which are classified in the same type (Gonçalves 2003).

The Shannon’s index (H’) (Equation 1) was used to evaluate tree species diversity at different plots (Shannon et al. 1949). Its computation was performed through employing the following equation:

$$H'(P1, P2, \dots Pn) = -\sum_{j=1}^{n} Pj\ .\ Ln\,(pj) \qquad (1)$$

where P_j is the probability of a randomly selected tree belonging to tree species j; and n is the number of tree species in the forest. If there is only one species recorded on the subplot, the Shannon’s index H’ is equal to zero. For k species with equal proportions, H’ corresponds to ln(k) (Keren et al. 2020). A similar index (Equation 2), also working with probabilities, was developed by Simpson (1949) and based on the heterogeneity, measuring the probability of two individuals randomly chosen belonging to the same species (Pierrat 1995, Gaines et al. 1999, Gonçalves et al. 2010). It ranges from 0 to 1, and decreases with the increase of the number of species and with the proximity of the species frequencies (Simpson 1949).

$$Ds = 1 - \sum \frac{[ni(ni-1)]}{[N(N-1)]} \qquad (2)$$

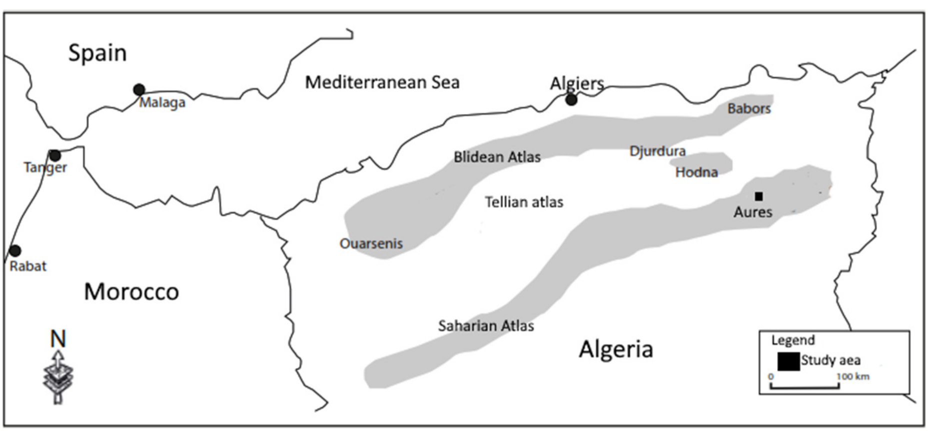


Figure 1. Geographical location of the study area (Bentouati 2006).

Figure 2. Mixed stand of Aleppo pine exposed to the north (plot N1).

where ni is number of individuals in species i; and N is the total number of individuals.

Spatial Distribution

For each individual sample plot, the aggregation index by Clark and Evans (*R*) (Equation 3) was calculated with no correction for edge effects. The aggregation index by Clark and Evans and numerical variables were developed to describe aspects of the variability of tree location in forest stands by a signal value (Evans 1950-1960). One example is the aggregation index by Clark and Evans (1954) which is defined as follows:

$$R = \frac{\bar{r}\,observed}{E\,(r)} \qquad R[0;\ 2,1491] \qquad (3)$$

where $$E(r) = \frac{1}{2\sqrt{\frac{N}{A}}}$$

where $\bar{r}$ observed stands for the mean of the distances from the trees to their nearest neighbours in a given forest stand, while E(r) is the mean nearest neighbour distance in the stand with completely random tree locations of intensity λ=N/A with A = area of the forest stand and N= number of trees (Pommerening and Stoyan 2006, Pommerening and Uria-Diez 2017). Usually, the interpretation of R values is as follows: R>1 if the pattern tends regularity, R=1 if it is completely random and R<1 if there is clustering in the pattern (Clark and Evans 1954).

Mingling index (M_i) (Equation 4) gives for each individual tree i the proportion of its n nearest neighbours that do not belong to the same species as the reference tree i (Gadow 1993). Figure 3 illustrates the index for the case n = 4. The mingling index can only take one of a limited number of values. For example, when n = 4 neighbours there are n + 1 = 5 possible values of M_i, calculated as k/n, with k = 0, 1, …, n: (0,00; 0,25; 0,50; 0,75; and 1,00) (Pommerening and Stoyan 2006, Indir et al. 2013, Pommerening and Uria-Diez 2017). Using these scores, all trees of the stand can be individually classified and the overall stand structure can be characterized by the distribution of the values of M_i. The mean population mingling can be expressed as follows:

$$M_i = \frac{1}{n}\sum_{j=1}^{n} v_{ij} \qquad M_i[0;1] \qquad (4)$$

M_i: is the species mingling index; n: is the number of the nearest neighbouring trees (3 or 4) V_{ij} = 1, if the reference tree i and the neighbour j are different tree species; V_{ij} = 0, otherwise (Pommerening 2002, Pommerening and Grabarnik 2019).

The examination of the DBH differentiation index (T_{ij}) (Equation 5) indicates the range of the difference in size of the 4 nearest neighbouring trees and describes the spatial distribution of tree sizes (Pretzsch 2009, Indir et al.2013, Keren et al.2020) which was calculated through the application of the following formula:

$$T_{ij} = 1 - \frac{1}{n}\sum_{j=1}^{n} \frac{min(\,DBH\,i\,, DBHj\,)}{max(\,DBH\,i\,, DBHj\,)}\ ;\ \ T_{ij}[0\,;1] \qquad (5)$$

where T_{ij} represents DBH differentiation index; DBH = diameter at breast height (in cm) thereby, i stands for a reference tree, j refers to the closest neighbour trees. Therefore, the DBH differentiation index was computed by using four closest neighbour trees around each reference tree (Pommerening 2002).

Pielou's coefficient of segregation (S') (Equation 6) describes the degree of mixing for a two species tree (Pommerening and Grabarnik 2019). This coefficient is defined as:

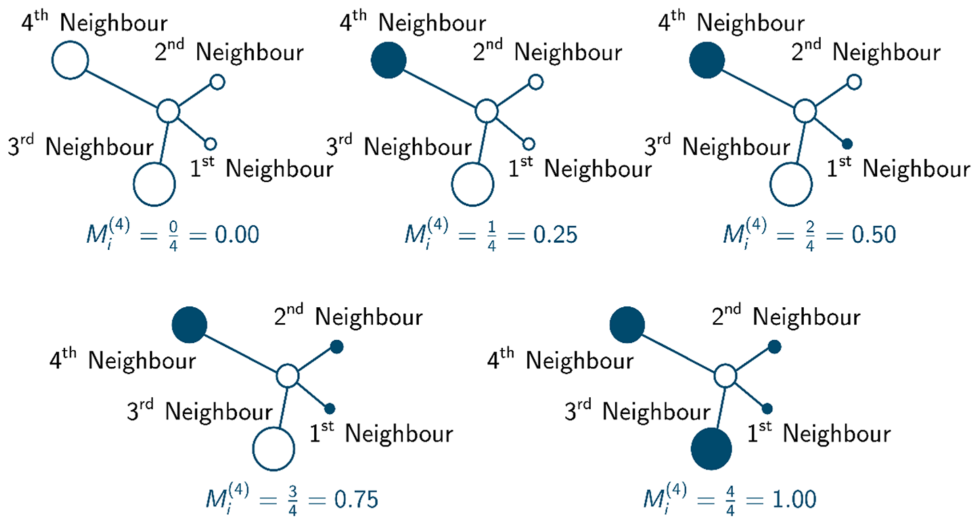


Figure 3. Illustration of the mingling index for n=4 neighbours (Gadow 1993).

$$S' = 1 - \frac{N(b+c)}{m.s + n * r} \quad ; \quad S'[-1;1] \tag{6}$$

If the nearest neighbours are always of the same species as the reference trees, then S'=1. If all neighbours are of a different species, then S'=-1. In the case of complete randomness of species distribution, one can expect values around 0 (Pielou 1977).

RESULTS

The results of this study provide significant information concerning the variation in tree species diversity and the spatial distribution of Aleppo pine stands in Beni Oudjana forest. The tree species inventory gave the reported results in Table 1 (families and species). Seven species were divided into six (06) observed families. The flora of this area is mainly dominated by *Pinaceae* and *Cupressaceae*, followed by *Fagaceae*, while *Lamiaceae* and *Anacardiaceae* are the least frequent families.

The values of *H'* index vary depending on the exposure of the studied plots. It varies from 0.9±0.3 for the northern exposure to 0.5±0.3 for the western one. Simpson's Diversity Index is very small for stands with western exposure 0.4±0.3, whereas it is much larger for stands with northern exposure (0.8±0.09).

Spatial Distribution

Only *Pinus halepensis* Mill. trees were taken into consideration via the calculation of the aggregation index (R), the mixing index (M_i) and the diameter differentiation index (T_{ij}).

The aggregation index (R) describes the horizontal spatial arrangement of tree positions (Pommerening 2002). It was calculated for all sixteen (16) plots. According to the aggregation index, western exposure shows the most regular tree patterns (1.6±0.1) (Figure 4). The east and south-facing stand also appears to be quite regular with 1.3±0.1 and 1.3±0.3, respectively. The R index for the north-facing plots was 1.2±0.1 as plots show only slight tendency towards regularity.

The mingling index (M_i) was calculated for each tree separately. The overall index value for the plot/stand was derived through the average indices of individual trees. When 4 nearest neighbouring trees were considered, the results showed index values ranging from 0.3 to 0.8.

The diameter differentiation index (T_{ij}) was calculated for all trees. For the overall plot's value it was derived as an average index of individual trees on the plot. When the 4 nearest neighbours were observed, the results showed that the diameter differentiation in the western and eastern exposures was almost the same as a very large differentiation index, 0.9±0.1 and 0.7±0.3, respectively, which in fact presented a very large differentiation (0.7<TI<1.0) because the tree with the smallest DBH is 30% thinner than that of the reference tree's size. The (T_{ij}) index indicates a large differentiation level in the south-facing plots with 0.6±0.2. The index value was same as the average index only in the northern exposure (0.4±0.1)

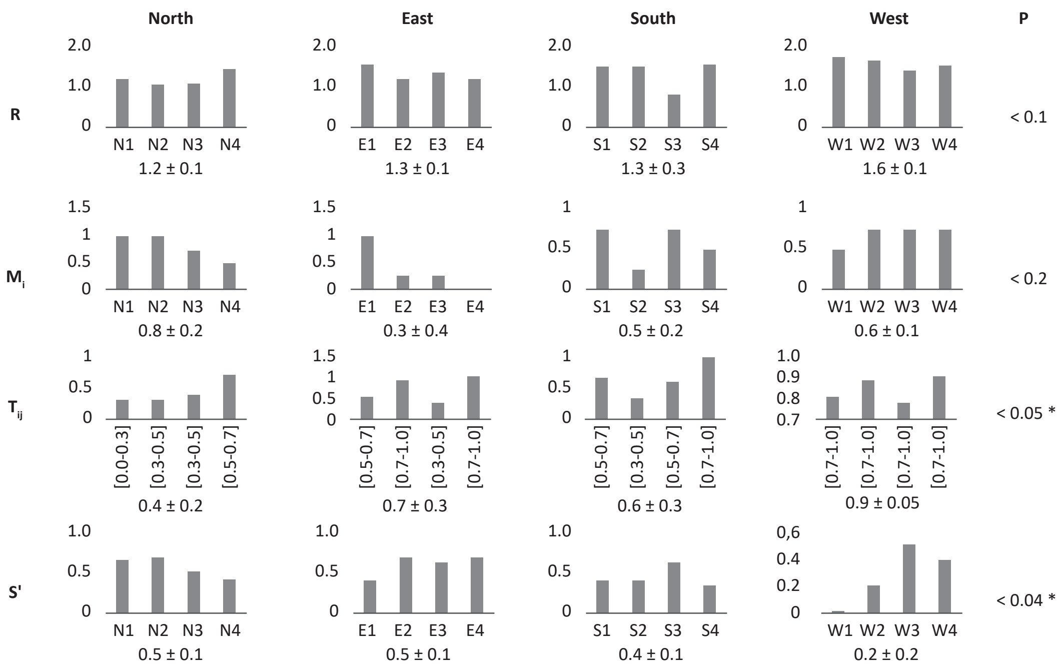
The mean distance-dependent measure of segregation (S') by Pielou varies significantly (P<0.04) depending on the exposure of the studied plots. It varies from 0.2±0.2 for the western exposure to 0.56±0.12 for the northern exposure.

The ANOVA statistical test is significant for the diameter differentiation index (T_{ij}) and Pielou's segregation index (S'). On the other hand, there is no significant difference between plots in the forest in terms of the aggregation index (R') and the mingling index (M_i) (Figure 4).

Table 1. Plot characterisation, Species richness (RS), Species Density (N), Simpson (D_s) and Shannon's index (H') per plot.

Exposition	Plots	Altitude (m)	SR	Species	N (Ind/Ha)	H'	D_s
North	**N1**	1024	4	*Pa ; Ju ; Qu ; Ph*	720	1.20	0.864
	N2	1121	4	*Pa ; Ju ; Qu ; Ph*	1360	1.23	0.888
	N3	1106	3	*Ju ; Pl ; Ph*	860	0.77	0.701
	N4	1314	2	*Ju ; Ph*	780	0.62	0.890
East	**E1**	1140	4	*Pa ; Ju ; Qu ; Ph*	900	0.69	0.496
	E2	1333	3	*Ju ; Qu ; Ph*	1200	0.97	0.882
	E3	1292	3	*Ju ; Qu ; Ph*	1520	0.94	0.857
	E4	1399	3	*Ju ; Qu ; Ph*	1460	1.02	0.926
South	**S1**	1383	3	*Ju ; Qu ; Ph*	1200	0.74	0.669
	S2	1446	3	*Ju ; Qu ; Ph*	1660	0.74	0.672
	S3	1240	3	*Ju ; Qu ; Ph*	940	1.04	0.946
	S4	1339	2	*Ju ; Ph*	880	0.54	0.773
West	**W1**	1472	2	*Ca ; Ph*	4080	0.03	0.045
	W2	1186	3	*Pa ; Qu ; Ph*	1600	0.42	0.385
	W3	1434	3	*Ju ; Qu ; Ph*	1500	0.87	0.791
	W4	1284	3	*Ju ;Ro ; Ph*	2080	0.70	0.639

Pa - Phillyrea angustifolia L.; *Ju - Juniperus oxycedrus* L.; *Qu - Quercus ilex* L.; *Ph - Pinus halepensis* Mill.; *Ro - Rosmarinus officinalis* L.; *Pl - Pistacia lentiscus* L.; *Ca - Cedrus atlantica;* Ind/ha – individuals/hectare.



R - The aggregation index; M_i - The mingling index; T_{ij} - The diameter differentiation index; S' – Pielou's segregation; P – p value; * - significant differences according to the ANOVA.

Figure 4. A quantitative description of the structure of the four exposures by means of variables (R, M_i, T_{ij} and S').

DISCUSSION

The analysed stands were originally mixed *Pinus halepensis* Mill. stands that were developed into multi-species structures. The evolution of these stands originates from different structures that can be already noticed in terms of diversity. The tree species richness varies from 2 to 4 probably due to ecological variations, namely site and seed source. In fact, plots with more species have nearby stands of the regenerated species and the plots with fewer species are surrounded by pure *Pinus halepensis* Mill. stands.

Each of the four used stand structure indices quantifies spatial relations in a specific way. The aggregation index by Clark and Evans (R) observes the regularity of the spatial arrangement of trees. The species mingling index (M_i) strives to describe the biodiversity, because of the amount of different species sharing the habitat. The diameter differentiation index (T_{ij}) observes the dimensions (DBH) of the nearest neighbouring trees and shows the level of their differentiation while coefficient of segregation (S') by Pielou (1977) describes the degree of mixing of trees in a forest.

The Clark and Evans aggregation index (R), according to the results shown in Figure 4, would increase with the plot density. It can be said that plots with a large number of individuals are the most regular, the west-facing plots are the densest and most regular with 9260 individuals/ha (Table 1) where the index of aggregation (R) varies from 1.5 to 1.7 (Figure 4), but the stands facing east and south also seem to be regular and can be dense with 5080 and 4680 individuals/ha respectively and an aggregation index of 1.3 for both exposures. The north-facing plots are the least dense with 3720 individuals/ha and show a slight tendency towards regularity with an aggregation index equal to 1.2.

The current state of a forest may be more effectively described using the distribution of the mingling variable (Füldner 1995, Pommerening 1997, Albert 1999). The bigger the mean mingling (M_i) is, the more different tree species are intermingled. Small values indicate large groups of only one tree species and therefore segregation (Pommerening 1997). According to the findings in Figure 4 which showed that the index had values from 0 to 1 in all 16 plots, this result can be related to anthropogenic action in the study area such as the illegal cutting of *Quercus ilex* L. and *Juniperus oxycedrus* L. that were observed on all the east-facing plots. Holm oak is a symbol of strength and longevity and has been intensively exploited for heating, tannin and charcoal. It is even considered to be one of the best fire woods as it allows one of the best calorific yields. The use of *Juniperus oxycedrus* L. wood in the form of fence posts is widespread throughout the studied area. It can be also seen that planting in the exploited plots is necessary.

The index of diameter differentiation according to the results shown in Figure 4 failed to provide any firm conclusion about any trend. Contrary to expectations, this index perhaps increases with the age of Aleppo pine stands where the majority of which are not even-aged stands. The diameter differentiation index (T_{ij}) for the majority of the studied stands assumed approximate values within the range from 0.3 to 1.0 for the four exposures. According to Pommerening 2002, these values represent the mean differentiation of diameters. Facing south stands that belong to the third class of differentiation (large differentiation), which means that their immediate neighbours have a diameter of 50% and mainly more than 70% of their own diameter. On the other hand, in western and eastern exposures the trees with the smallest DBH are less than 30% of the size of the neighbouring one because the diameter differentiation index for the two exposures is 0.9±0.05 and 0.7±0.3 respectively which represents a very large differentiation (0.7<TI<1.0); an average differentiation level (0.3<TI<0.5) in the northern exposure (0.4±0.2), where the tree with the smallest DBH is 50 to 70% of the reference tree's size. Pielou's segregation index (S') shows that *Pinus halepensis* Mill., *Juniperus oxycedrus* L. and *Quercus ilex* L. tend to segregate.

CONCLUSION

The results describe the reference state of Beni Oudjana forest; an "ecological state" that is determined in a quantifiable sense through the silvicultural parameters of *Pinus halepensis* Mill. From the findings, it can be seen that the diversity analysie as function of the horizontal and vertical spatial distribution measures are complementary. The first distribution indicates the proportion of the species present in the stand, and the second shows the way they are arranged in the horizontal plane, while the third indicates the way they are distributed in the vertical plane.

Aleppo pine forests are a natural barrier against the advance of the desert towards the north of the country. Therefore, it is very important to estimate the spatial distribution of Aleppo pine stands all over Algeria and to know their current state for the application of planting programs which are unfortunately inapplicable as the calculation of the distance between trees for the whole Algerian forest is very expensive. However, this study has shown that it could be applicable for small scales.

For a successful tree or shrub planting and for a development program to be successful, the present and future needs of the local population have to be taken into consideration. Because there is competition between agriculture, animal husbandry and wood consumption, the local population must be convinced that these programs (which only attain promising results after a few years) are necessary. The relatively high costs of some management programs and the necessary technical skills can also be obstacles. On the other hand, the lack of understanding of the role of trees and shrubs in the enrichment of the environment or the rejection of change can hinder efforts to combat desertification in the Aures region.

Author Contributions

IH conceived and designed the research, carried out the field measurements, and processed the data and performed the statistical analysis, MR-K and AM supervised the research and helped to draft the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Comparative Analysis of Wood Fuels Consumption in Households in the Federation of Bosnia and Herzegovina

Dragan Ratko Čomić[1,*], Branko Dragoš Glavonjić[2], Nemanja Duško Anikić[3], Mersudin Hamid Avdibegović[4]

(1) University of Banja Luka, Faculty of Forestry, Department of Forest Economics and Organization, Bulevar vojvode Stepe Stepanovića 175a, BA-78000 Banja Luka, Bosnia and Herzegovina **(2)** University of Belgrade, Faculty of Forestry, Kneza Višeslava 1, RS-11030 Belgrade, Serbia **(3)** Master of Forestry, Dr Danice Perović 12, BA-78000 Banja Luka, Bosnia and Herzegovina **(4)** University of Sarajevo, Faculty of Forestry, Zagrebačka 20, BA-71000 Sarajevo, Bosnia and Herzegovina

*** Correspondence:** e-mail: dragan.comic@sf.unibl.org

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ABSTRACT

Analysis of the consumption of wood energy from wood-based fuels in households in the Federation of Bosnia and Herzegovina was the main purpose of this paper. A survey on wood fuel consumption was first conducted using the Wood fuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology of the Food and Agriculture Organization (FAO) of the United Nations (UN). These results were compared to the results published by official statistics. The survey was conducted in ten cantons in the Federation of Bosnia and Herzegovina, namely in 5,475 households, 2,669 urban and 2,806 other households. The results of the research showed that wood fuels were used in 516,334 or 71.59% of the total number of households. Firewood was used in 497,139 households or in 96.28% in relation to the total number of households in the Federation of Bosnia and Herzegovina that used wood fuels. The surrounding countries showed similar trends. The estimated consumption of firewood in households using the WISDOM methodology is 4.10 (when compared to the official statistical data on total felled timber in and outside public and private forests) to 4.93 times higher than the official statistical data (when compared to the official statistical data on the sale of firewood in state forests), i.e. 4.52 times higher in average. This research indicates the need to apply a new methodological approach for the collection and analysis of data on the consumption of wood fuels in households for energy purposes. Some of the shortcomings of the existing official statistics are the neglect of statistically unregistered production of firewood from private forests and from areas not categorized as forests and forest land, as well as incomplete coverage in terms of conducting a survey on consumption of all categories of wood fuels and all major consumer categories. All the aforementioned, in addition to the economic consequences, has a negative impact on the fulfilment of commitments arising from international agreements in terms of the share of energy from renewable sources and greenhouse gas emissions in total energy consumption in Bosnia and Herzegovina. In addition, incomplete knowledge of the realistic supply and consumption of wood fuels can affect the reliability of planning documents in forestry, with many negative consequences for sustainability of a complex forest ecosystem.

Keywords: renewable energy sources; households; wood fuel; woody biomass; WISDOM methodology; Federation of Bosnia and Herzegovina

INTRODUCTION

Renewable energy sources have become an inevitable topic of scientific and professional discussions regarding energy and climate change. Biomass is the most commonly used renewable energy source in the world (Toklu 2017). Global energy trends, the growing impact of climate change and the need for energy security, make the transition to sustainable and efficient energy systems necessary due to their low greenhouse gas (GHG) emissions without (or with minimal) negative impact on the environment (Ladanai and Vinterbäck 2009, Rosillo-Calle 2016). Increased use of energy from renewable sources is an important part of the package of measures needed to reduce greenhouse gas (GHG) emissions and meet the commitments defined by the Paris Agreement on Climate Change (UNFCCC 2016). Future perspectives of the European Union indicate that the use of renewable energy shall be mostly market-oriented and, by 2030, the share of energy from renewable sources in the EU should be at least 27%. Some Member States may set more ambitious national targets (Bürgin 2015, European Commission 2015). The constant growth of energy demand at the global level has raised attention to renewable sources. Increasing the consumption of this type of energy in the EU aims to reduce dependence on fossil fuel imports, thus making energy production and consumption sustainable (Saint Akadiri et al. 2019). Woody biomass is a clean, renewable energy source that could dramatically improve our environment, economy and energy security, with significantly lower GHG emissions, reduced waste and reduced dependence on fossil fuels (Gokcol et al. 2009). According to a survey which included 11 post-transition EU countries, changes in renewable energy consumption per capita have a statistically significant impact on economic growth. Should the consumption of renewable energy increase by 1%, GDP growth is expected to be 0.68% (Fatur-Šikić 2020). Biomass and renewable waste, with a share of 64.2% in primary renewable energy production, are the most important energy sources in the EU (Parobek et al. 2016). In order to fully exploit the potential of biomass, it is necessary to encourage greater sustainable mobilization of wood resources together with the development of new systems of sustainable forestry (European Parliament 2018).

More than a half of the felled wood globally is used as an energy source, thus supplying 9% of global primary energy production (Bailis et al. 2015). More than a fifth (21.6%) of roundwood production in the EU in 2016 was used as fuel wood (Eurostat 2018). Despite the fact that wood is the most important source of thermal energy in the Western Balkans, the sustainability of use largely depends on the improvement of existing practices, primarily related to improving the regulatory framework, finding new sources of funding and increasing commercially available biomass (Stojadinović et al. 2017). An important trend in the region is the use of significant amounts of woody biomass, with the established practice of combustion in conventional inefficient furnaces (Dunjić et al. 2016). Although some progress has been made, foreign authors have previously stated that countries such as Bosnia and Herzegovina (BiH) and Serbia have serious deficits in the promotion of renewable energy sources (RES), which lack more specific obligations in relation to the use of RES. Their growing demand for energy is mostly satisfied by fossil fuels, despite the fact that they are aware of the importance of RES, their usefulness and the need for their integration, development and use (Karakosta et al. 2012).

The Energy Community (2012a) published a study on biomass consumption in households, industry and tertiary sector in the Community member countries, using Eurostat methodology and demand-based approach determined by the survey (Robina and Lončarević 2017). The research and data analysis within this paper were conducted using Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology, which is based on the same principles. The research using WISDOM methodology was made for all countries of the Western Balkans, namely for Slovenia for the heating season 2003/2004 (Drigo and Veselić 2006), Croatia for the heating season 2007/2008 (Segon et al. 2009), Serbia for the heating season 2009/2010 (Glavonjić 2011, Glavonjić et al. 2015), Montenegro for the heating season 2011/2012 (Marinović et al. 2013, Statistical Office of Montenegro 2013), Bosnia and Herzegovina for the heating season 2015/2016 (Glavonjić et al. 2017) and Macedonia for the heating season 2015/2016 (Trajanov et al. 2018). The research for Bosnia and Herzegovina, in addition to the above mentioned, included the consumption of certain fuels in households with the aim of improving the national energy balance (Robina and Lončarević 2017) and assessing the financial and environmental sustainability of woody biomass to replace conventional heating (Kyriakopoulos et al. 2010). Various other studies on the potentials of biomass usage were conducted in Bosnia and Herzegovina, resulting in very useful internet platforms that have been developed for some of them (e.g., http://atlasbm.bhas.gov.ba/) (Pfeiffer et al. 2019, Karabegović and Ponjavić 2020). The research on the consumption of energy in households, services and industry in Bosnia and Herzegovina (hereinafter abbreviated as BiH) was also conducted by the Energy Institute "Hrvoje Požar" in 2008, and the results were estimated for the national level, but also for twenty different energy consumption zones (Robina and Lončarević 2017).

Firewood, alone or in combination with other fuels, was the main energy source used for heating in households in BiH (Glavonjić et al. 2017). Out of the total number of households, 74% or 860,228 used solid fuels for heating purposes, among which 70.3% of households used only firewood, 23.2% used firewood with coal, 3.3% used firewood with other fuels. The remaining 3.2% used pellets, briquettes, wood processing residues or combined these fuels with other types of fuel. Apart from the fact that energy presents the basis of future economic and social development (Dias et al. 2004), and that biomass is the most common renewable energy source (Toklu 2017, Parobek et al. 2016), even some of the European countries and Energy Community (EC) contracting parties have no harmonized statistics on energy from biomass (Robina and Lončarević 2017). This is the reason why official data in some EU countries may be prejudiced, as indicated by a research in Greece, where empirical data indicate results and trends different from official statistics (Arabatzis and Malesios 2011). Namely, the officially published data show a decrease in the consumption of firewood due to the decreasing population in rural areas, a better life standard and the replacement of firewood with other energy sources. In contrast, empirical research indicates that, due to the economic crisis (2008) and rising oil prices, firewood consumption has increased, all indicating the importance of empirical research in collecting and presenting reliable statistics on energy consumption.

Households are an important consumer of energy from biomass, especially firewood, but these amounts of energy have rarely been officially recorded (Robina and Lončarević 2017). This is as well confirmed by the World Bank research on biomass consumption for heating conducted for the countries of the Western Balkans (Stojadinović et al. 2017). The authors state that the use of biomass is not recorded due to the practice of statistical institutes to collect and publish data only on official trade in woody biomass. The use of wood biomass for heating in local communities located near forest areas and the use of wood by private forest owners is not recorded. This leads to the research question of whether the official statistical data represent the real consumption of biomass in BiH, primarily wood fuels. The relevance of data on actual wood fuel consumption is always limited by various variables, from a complex cross-sectoral character (forestry, agriculture, energy and rural development) to limited institutional and human resources. A complex state structure of BiH, including a large number of administrative units, further affects the complexity of collecting relevant and reliable official statistics. The application of methods that do not provide a realistic estimate of wood fuel consumption leads to incorrect conclusions, which further negatively affects the drafting of sectoral policies and decision-making on the use of wood-based energy. Further negative impact also relates to the fulfilment of current and future commitments, such as those related to the use of renewable energy sources within the Energy Community (Energy Community 2012b).

This paper is based on the results of research on the consumption of firewood and wood fuels in BiH in 2015, which was conducted from February to June 2016 within the project "Using wood energy to improve sustainable economic rural development and meet the 2020 renewable energy targets for the Western Balkans". The project was funded by the Food and Agriculture Organization (FAO) of the United Nations (UN). The aim of the research was to collect data on the types, quantities and values of wood fuels produced, imported, exported and consumed in Bosnia and Herzegovina. In addition, the research also provided data on the sources of wood fuel supply as well as on devices used for their combustion, which will be published in one of the following papers.

The paper performs a comparative analysis of the obtained results with the official statistical data for the Federation of BiH and with the data on wood fuel consumption in the surrounding countries, which indicates the (non)relevance of existing data with recommendations for improving the existing situation.

The main and auxiliary hypotheses of this paper are defined following the above, and are as follows:

- Main hypothesis: Actual consumption of firewood in households in BiH is higher than the one presented in official statistics.
- Auxiliary hypothesis 1: Consumption of firewood in households in BiH determined using the WISDOM methodology indicates similar trends to the consumption in the countries of the region.
- Auxiliary hypothesis 2: The collection and analysis of official statistics on wood fuel consumption in BiH needs to be improved to reflect the actual consumption.

MATERIALS AND METHODS

The following scientific methods and techniques were used in this paper: content analysis and desk research (qualitative analysis of the existing literature used for theoretical framework), classification (quality data management), analysis and synthesis (detailed analysis of the available data on wood fuel consumption and their merging), deduction (determining wood fuel consumption in households based on the consumption in cantons), induction (deriving a general conclusion on the consumption based on the results for specific spatial units) and comparison (comparing the consumption within specific spatial units and comparing with official statistical data). A survey was used as an appropriate scientific research technique for field data collection.

The results on the consumption of wood fuels in the Federation of BiH presented in this paper were collected for the entire BiH within the aforementioned project by using the WISDOM methodology. WISDOM is a GIS-based methodology developed in collaboration between FAO and the Center for Ecosystems Research at UNAM University in Mexico (Sánchez-García et al. 2015). WISDOM enables the spatial representation of supply and demand for wood fuels, using data structured in three established modules, namely: SUPPLY (data related to the supply of wood fuels), DEMAND (data related to the demand/consumption of wood fuels) and INTEGRATION (related to merging and mapping of all data) (Masera et al. 2006). This enables the integration of available information regarding the supply and demand of woody biomass that can be used for energy purposes, at different administrative levels.

Data obtained by WISDOM provide strategic decision-making in the woody biomass supply and wood-based energy, including the identification of sites (in terms of effectiveness and biomass sources' availability) suitable for specific activities in order to valorise the potential of wood biomass as an energy source (Marinović et al. 2013).

This paper presents the results related to the demand module, for the Federation of BiH. Since the research was conducted within the same project for BiH (which consists of two entities - the Federation of Bosnia and Herzegovina and the Republic of Srpska), the WISDOM methodology was also used to obtain data on wood fuel consumption in the Republic of Srpska, which is presented in another scientific paper.

Sample and Methodology for Field Survey

Basic element of the demand module development was the empirical field research of the consumption of firewood and other wood fuels through conducting the survey in the heating season 2015/2016. The research was conducted in households, commercial facilities (bakeries, shops, car services, hairdressers, hotels, shopping malls, banks, etc.), public facilities (schools, health centers and clinics) and large consumers such as woody biomass district heating systems.

Preliminary results of the 2013 census (Agency for Statistics of Bosnia and Herzegovina 2013) were used as a basis for determining a representative sample for household surveys. Due to the fact that the WISDOM methodology includes those households that use solid fuels for heating purposes, it was necessary to conduct preliminary research and collect data on the number of households in all cantons (Federation of BiH), mesoregions (Republic of Srpska) and District Brčko which use other fuels for heating purposes, such as electricity, gas, heating oil, as well as the number of households using a district heating system.

For these purposes, the questionnaire method was used to collect data from all relevant fuel suppliers in BiH. The households that use other heating fuels/energy generating products such as electricity, gas, district heating system and oil products were excluded from the total number of households according to the census in BiH (i.e. 1,163,387 households). WISused solid fuels (wood fuels and coal) as the main heating energy source, and the sample for the survey was 1% of that number or 8,602 households.

Other authors indicate a similar number of households that use wood-based energy in BiH. Thus, the number of 869,349 households in BiH that used wood as an energy source was determined within the research conducted by the Agency for Statistics of BiH for the reference period of 12 months in 2014 (Robina and Lončarević 2017). Methodological procedures for determining the sample size for each canton, mesoregion and District Brčko were defined, along with the distribution of *urban* and *other* households. Surveys within households were conducted from 15 March 2016 to 22 April 2016 in 109 cities/municipalities throughout BiH, i.e. in the entities of the Republic of Srpska and Federation of BiH, as well as in District Brčko. A total of 8,500 households for the whole territory of BiH were surveyed, namely 3,912 households in urban settlements and 4,588 households in other settlements; 102 households less than planned were surveyed, primarily due to the lack of cooperation of respondents in some areas.

The questionnaire for households contained 22 questions, 2 of which were related to the structure of households, 11 related to the characteristics of residential buildings, 6 related to the consumption of wood fuels and 3 related to heating systems.

The survey in the Federation of BiH was conducted in 5,475 households, namely in 2,669 urban and 2,806 other households. Distribution of households by cantons is presented in Table 1.

After the conducted survey and the data entry into the web application, the entered data were checked together with the logical control of consumption. Furthermore, the data were processed, and their classification and recalculation from the sample level to the whole level were performed. The results of wood fuel consumption in households in the Federation of BiH and specific cantons are presented below.

RESULTS

Distribution of Households that Use Certain Types of Wood Fuels for Heating Purposes in the Federation of BiH

The obtained research results indicate that firewood and other wood fuels were used in 516,334 households at the level of the Federation of BiH. Firewood was used in 497,139 or 96.28% of the total number of households that used wood fuels, slabs from sawmills were used in 5,693 households or 1.10%, wood pellets in 12,383 households or 2.40%, wood briquettes in 264 households or 0.05%, logging residues in 751 households or 0.15%, and sawdust in 104 households or 0.02% (Figure 1).

When the consumption is observed by specific cantons in the Federation of BiH, the distribution and percentage share of households in the consumption of wood fuels is shown in Figure 2. The percentages refer to the relative share of households where firewood was used.

The above presented data indicate that firewood is the prevailing energy source, with a share of more than 95% in all cantons in the Federation of BiH, except in Canton 10, where the use of firewood was approximately 85%.

Observing the distribution of households by certain types of wood fuels, the data were as shown in Table 2. The

Table 1. Distribution of surveyed households by cantons in the Federation of BiH.

Canton	Total number of surveyed households	Urban households	Other households
Bosnian-Podrinje Canton	65	36	29
Herzegovina-Neretva Canton	518	239	279
Canton 10	182	57	125
Posavina Canton	103	38	65
Sarajevo Canton	1,133	990	143
Central Bosnia Canton	600	203	397
Tuzla Canton	1,153	453	700
Una-Sana Canton	601	239	362
West Herzegovina Canton	191	44	147
Zenica-Doboj Canton	929	370	559
Total Federation of BiH	**5,475**	**2,669**	**2,806**

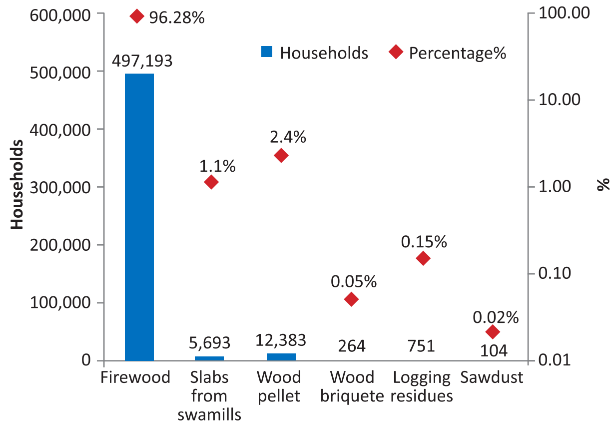

Figure 1. Distribution of households using certain types of wood fuels for heating purposes in the Federation of BiH in the heating season 2015/2016.

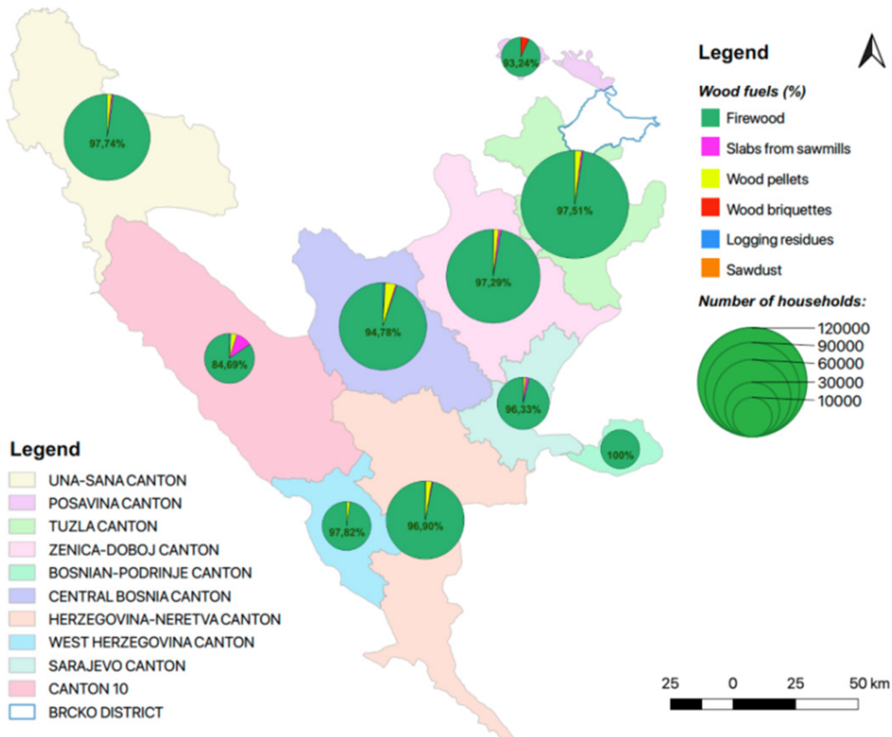

Figure 2. Distribution of households using wood fuels in each canton of the Federation of BiH in the heating season 2015/2016.

upper fields indicate the absolute amount of consumption, while the lower ones refer to the relative amount of the share of each canton in the total consumption of that fuel at the level of the Federation of BiH.

Firewood was used in 497,139 households, as follows: Tuzla Canton (114,344 or 23%), Zenica-Doboj Canton (86,212 or 17.34%), Una-Sana Canton (73,255 or 14.74%), Central Bosnia Canton (73,156 or 14.72%), Herzegovina-Neretva Canton (59,487 or 11.97%), Sarajevo Canton (26,388 or 5.31%), West Herzegovina Canton (23,615 or 4.75%), Canton 10 (21,481 or 4.32%), Posavina Canton (11,630 or 2.34%) and Bosnia-Podrinje Canton (7,571 or 1.52%).

Slabs from sawmills were used in 5,693 households in seven cantons, predominantly in Canton 10 (2,655 or

46.64%), followed by Zenica-Doboj Canton (799 or 14.03%), Tuzla Canton (626 or 11%), Sarajevo Canton (539 or 9.47%), Una-Sana Canton (470 or 8.26%), Central Bosnia Canton (369 or 6.48%) and Herzegovina-Neretva Canton (235 or 4.13%). This type of wood fuel was not consumed in Bosnia-Podrinje Canton, Posavina Canton and West Herzegovina Canton.

Out of a total of 12,383 households that used wood pellets, the highest consumption was in households in Central Bosnia Canton (3,028 or 24.45%) and Tuzla Canton (2,291 or 18.50%), followed by households in Herzegovina-Neretva Canton (1,565 or 12.64%), Zenica-Doboj Canton (1,478 or 11.94%), Una-Sana Canton (1,222 or 9.87%), Canton 10 (997 or 8.05%), Posavina Canton (843 or 6.81%), West Herzegovina Canton (526 or 4.25%) and Sarajevo Canton (433 or 3.50%). This type of wood fuel was not consumed in households in Bosnia-Podrinje Canton.

Wood briquettes were consumed in 264 households in only three cantons, namely in Zenica-Doboj Canton (122 or 46.21%), Central Bosnia Canton (110 or 41.67%) and Sarajevo Canton (32 or 12.12 %). This type of wood fuel was not consumed in households in other cantons.

Logging residues were used in 751 households, predominantly in households in Central Bosnia Canton (519 or 69.11%) and Canton 10 (232 or 30.89%), while this type of wood fuel was not consumed in households in other cantons.

Sawdust was consumed in 104 households in Herzegovina-Neretva Canton, while it was not consumed in households in other cantons.

The total number of households using wood fuels for heating in each canton in the Federation of BiH is shown in Figure 3.

Consumption of Wood Fuels in Households at the Level of the Federation of BiH and in Each Canton

Consumption of wood fuels in households in each canton and at the level of the Federation of BiH for the heating season 2015/2016 is presented in Table 3. The upper fields indicate the absolute amount of consumption, while the lower ones refer to the relative amount of the share of each canton in the total consumption of that fuel at the level of the Federation of BiH.

Of the total consumption of firewood, which was 2,937,340 m^3, the highest consumption was in Una-Sana Canton (560,433 m^3 or 19.08%), Central Bosnia Canton (538,544 m^3 or 18.33%), Tuzla Canton (499,768 m^3 or 17.01%) and Zenica-Doboj Canton (494,959 m^3 or 16.85%), followed by Herzegovina-Neretva Canton (295,188 m^3 or 10.05%), Canton 10 (174,529 m^3 or 5.94%), Sarajevo Canton (153,472 m^3 or 5.22%), West Herzegovina Canton (103,259 m^3 or 3.52%), Posavina Canton (77,883 m^3 or 2.65%) and Bosnia-Podrinje Canton (39,305 m^3 or 1.34%).

Slabs from sawmills were consumed in a total volume of 12,339 m^3, predominantly in Canton 10 (4,811 m^3 or 38.99%), which is further followed by Herzegovina-Neretva Canton (2,166 m^3 or 17.55%), Sarajevo Canton (1,653 m^3 or 13, 40%), Una-Sana Canton (1,442 m^3 or 11.69%), Tuzla Canton (1,022 m^3 or 8.28%), Central Bosnia Canton (689 m^3or 5.58%) and Zenica-Doboj Canton (556 m^3 or 4.51 %).

The total consumption of wood pellets was 55,566 tonnes, of which almost a third was consumed in Central Bosnia Canton (16,299 t or 29.33%), followed by Tuzla Canton (9,422 t or 16.96%), Zenica-Doboj Canton (7,751 t or 13.95%), Canton 10 (5,564 t or 10.01%), Herzegovina-Neretva Canton (4,689 t or 8.44%), Una-Sana Canton

Table 2. Distribution of households using wood fuels in each canton in the Federation of BiH in the heating season 2015/2016, by certain types of wood fuels (Source: FAO project "Using wood energy to improve sustainable economic rural development and meet the 2020 renewable energy targets for the Western Balkans").

Wood fuel	Bosnian-Podrinje Canton	Herzegovina-Neretva Canton	Canton 10	Posavina Canton	Sarajevo Canton	Central-Bosnia Canton	Tuzla Canton	Una-Sana Canton	West Hercegovina Canton	Zenica-Doboj Canton	TOTAL Federation of BiH
Firewood	**7,571**	**59,487**	**21,481**	**11,630**	**26,388**	**73,156**	**114,344**	**73,255**	**23,615**	**86,212**	**497,139**
	1.52%	11.97%	4.32%	2.34%	5.31%	14.72%	23.00%	14.74%	4.75%	17.34%	100.00%
Slabs from sawmills	**0**	**235**	**2,655**	**0**	**539**	**369**	**626**	**470**	**0**	**799**	**5,693**
	0.00%	4.13%	46.64%	0.00%	9.47%	6.48%	11.00%	8.26%	0.00%	14.03%	100.00%
Wood pellets	**0**	**1,565**	**997**	**843**	**433**	**3,028**	**2,291**	**1,222**	**526**	**1,478**	**12,383**
	0.00%	12.64%	8.05%	6.81%	3.50%	24.45%	18.50%	9.87%	4.25%	11.94%	100.00%
Wood briquettes	**0**	**0**	**0**	**0**	**32**	**110**	**0**	**0**	**0**	**122**	**264**
	0.00%	0.00%	0.00%	0.00%	12.12%	41.67%	0.00%	0.00%	0.00%	46.21%	100.00%
Logging residues	**0**	**0**	**232**	**0**	**0**	**519**	**0**	**0**	**0**	**0**	**751**
	0.00%	0.00%	30.89%	0.00%	0.00%	69.11%	0.00%	0.00%	0.00%	0.00%	100.00%
Sawdust	**0**	**104**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**104**
	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%

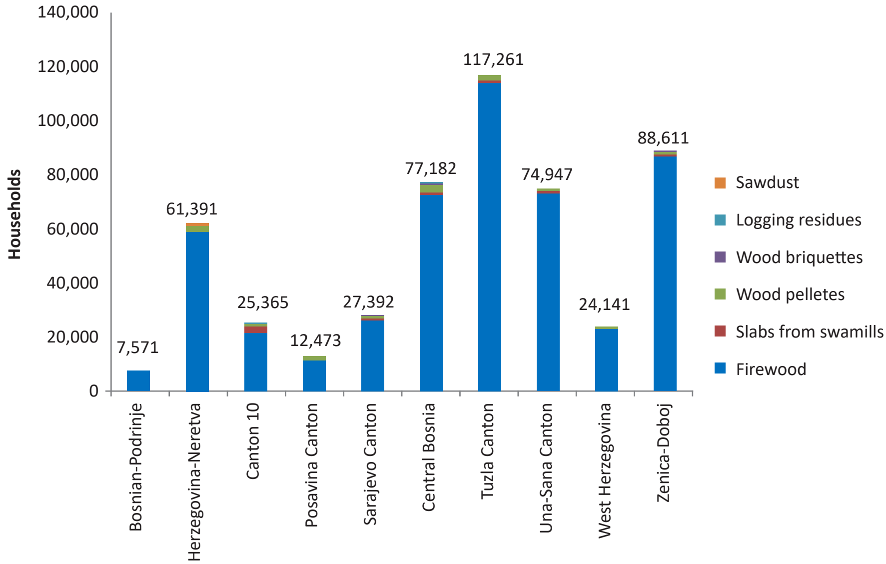

Figure 3. Total number of households using wood fuels for heating in each canton in the Federation of BiH in the heating season 2015/2016.

Table 3. Consumption and relative share of some cantons in the total consumption of wood fuels in households in the Federation of BiH in 2015/2016.

Canton	Firewood (m³)	Slabs from sawmills (m³)	Wood pellets (tonnes)	Wood briquettes (tonnes)	Logging residues (m³)	Sawdust (m³)
Bosnian-Podrinje	39,305	0	0	0	0	0
	1.34%	0.00%	0.00%	0.00%	0.00%	0.00%
Herzegovina-Neretva	295,188	2,166	4,689	0	0	11
	10.06%	17.55%	8.44%	0.00%	0.00%	100.00%
Canton 10	174,529	4,811	5,564	0	121	0
	5.94%	38.99%	10.01%	0.00%	4.27%	0.00%
Posavina	77,883	0	4,107	0	0	0
	2.65%	0.00%	7.39%	0.00%	0.00%	0.00%
Sarajevo	153,472	1,653	1,448	95	0	0
	5.22%	13.40%	2.61%	20.79%	0.00%	0.00%
Central-Bosnia	538,544	689	16,299	220	2,713	0
	18.33%	5.58%	29.33%	48.14%	95.73%	0.00%
Tuzla	499,768	1,022	9,422	0	0	0
	17.01%	8.28%	16.96%	0.00%	0.00%	0.00%
Una-Sana	560,433	1,442	4,448	0	0	0
	19.08%	11.69%	8.00%	0.00%	0.00%	0.00%
West Herzegovina	103,259	0	1,838	0	0	0
	3.52%	0.00%	3.31%	0.00%	0.00%	0.00%
Zenica-Doboj	494,959	556	7,751	142	0	0
	16.85%	4.51%	13.95%	31.07%	0.00%	0.00%
Total Federation of BiH	2,937,340	12,339	55,566	457	2,834	11
	100%	100%	100%	100%	100%	100%

(4,448 t or 8%), Posavina Canton (4,107 t or 7.39%), West Herzegovina Canton (1,838 t or 3.31%) and Sarajevo Canton (1,448 t or 2.61%).

Wood briquettes were consumed in the total amount of 457 tonnes in the Federation of BiH, with the highest consumption in Central Bosnia (220 t or 48.14%), followed by Zenica-Doboj Canton (142 t or 31.07%) and Sarajevo Canton (95 t or 20.79%).

Logging residues were consumed in the total amount of 2,384 m^3 in only two cantons the Federation of BiH, namely in Central Bosnia Canton (2,713 or 95.73%) and Canton 10 (121 or 4.27%).

Sawdust was used as an energy source only in Herzegovina-Neretva Canton, in the amount of 11 tonnes.

DISCUSSION

Firewood is the most common wood fuel in all cantons in the Federation of BiH and was used in more than 96% of households that use wood fuels. The remaining 4% of households used other types of wood fuels. The total consumption of firewood in households of all cantons of the Federation of BiH was 2.94 million m^3. The highest consumption was in the following cantons: Una-Sana, Central Bosnia, Tuzla and Zenica-Doboj, which cover more than 71% or approximately 2.1 million m^3. The consumption of this type of wood fuel shall be discussed more thoroughly in the second part of this chapter.

Approximately 82% slabs from sawmills were used during the heating season 2015/2016 in households in Canton 10, Herzegovina-Neretva Canton, Sarajevo Canton and Una-Sana Canton, in the total amount of more than 10 thousand m^3. Total consumption of this type of wood fuel in the Federation of BiH was 12.34 thousand m^3. Relatively low consumption in households can be explained by the fact that slabs are used as an energy source at the place of their origin (in wood-processing plants), as well as a raw material for obtaining more attractive wood fuels, primarily wood pellets.

Total consumption of wood pellets in households in the Federation of BiH during the heating season 2015/2016 was 55.6 thousand tonnes, with more than 60% being used in the Central Bosnia, Tuzla and Zenica-Doboj cantons. Even greater share of wood fuels in the total consumption is expected in the future, due to all the advantages related to simplicity, comfort in use and the advancement of combustion technology, as well as the advantages in the supply and use of this energy source, in addition to lower heating prices compared to some other energy sources (Thomson and Liddell 2015). However, neutral impact on the environment in the future may become one of the key factors for the selection of this type of fuel for heating, not only for environmental but also for economic reasons (for example, in case of limitation or introduction of a tax on greenhouse gas emissions or increased subsidies to meet commitments for the participation of renewable energy sources). The EU experiences show that, along with the assumption of commitments for the participation of renewable energy sources, the consumption of wood pellets has increased (Flinkman et al. 2018). On the other hand, relatively high initial investments in equipment, pellet prices volatility, supply uncertainty, lack of subsidies and favorable credit lines for the procurement of equipment, as well as insufficient environmental education of the population, can be serious barriers to more intensive use in BiH households. Econometric models based on research conducted for seven EU countries indicate that GDP is less important, while the prices of wood pellets and alternative energy sources are of great importance for the use of wood pellets (Flinkman et al. 2018). Consumption will certainly be affected by market categories such as production, import and export. Official FAO statistics data (FAO 2021) indicate that the production of pellets in BiH increased from 83,000 tonnes in 2012 to 270,000 tonnes in 2016, which is followed by a declining trend to 230,000 tonnes in 2019. Imported quantities within the same period were significantly lower and ranged to a maximum of 14,240 tonnes in 2017. However, data on significant exports of this wood fuel, which had an upward trend in the period 2012-2014 (from 73,000 to 172,000 tonnes), followed by the declining trend between 2015 and 2019 (from 137,350 to 69,900 tonnes), indicate potential problems in available quantities in the future. The fact is that the difference in profits made in the domestic and foreign markets will play a significant role in creating the preconditions for increased consumption of this wood fuel in the entire BiH.

Wood briquettes were significantly less used compared to wood pellets. Total amount of 457 tonnes was used in only three cantons, almost half being used in Central Bosnia Canton. This wood fuel was used in Zenica-Doboj and Sarajevo cantons as well. Two main reasons caused a low consumption of briquettes, as compared to pellets. Significant quantities of briquettes produced in BiH are exported. In addition, since wood pellets represent a more comfortable fuel that burns in furnaces and boilers with automatic control, a large number of households decided to use this type of wood fuel instead of briquettes, coal and firewood. This does not mean that briquettes will no longer be used in households, but the assumptions are that consumption will have a declining trend since pellets, as a wood fuel, are easier to use.

Total consumption of logging residues was 2.8 thousand m^3, namely in only two cantons, of which predominantly in Central Bosnia Canton (more than 95% of the total consumption). This can be related to different approaches in some cantons in terms of enabling the local population to collect logging residues (so-called *collection*). In addition, this represents quite a difficult way to provide heating products, which can be a limiting factor due to the lack of labor in countryside, which is caused by the departure of young people to cities and migration outside BiH. Finally, almost all forestry companies in BiH are FSC certified, and therefore obliged to leave some logging residues in forests as organic matter necessary for soil fertilization, thus ensuring the stability of soil regime.

Sawdust was even less present as an energy source, with the total amount of 11 tonnes used only in Herzegovina-Neretva Canton. The reason for such low consumption is understandable, since sawdust is used as a raw material for obtaining wood pellets and briquette.

Since the official statistics for the Federation of BiH provide data for firewood, discussion shall primarily be focused on firewood consumption, given the fact that it is the most common energy source in households (more than 96%). Data on firewood consumption in each canton in the Federation of BiH, obtained within this research, are presented in Figure 4.

Analyzing the available data issued by the Institute for Statistics of the Federation of BiH, the only data on firewood quantities in 2015 were identified in the Statistical Bulletin 226 (Institute for Statistics of the Federation of BiH 2016). This includes data on sales of firewood originating from state forests, which amounted to 653,450 m^3 in 2015.

Research by Glavonjić and Čomić (2016) indicates that 91.48% of firewood in the Federation of BiH was consumed in households. If this amount is observed in correlation with the official statistical data, it can be concluded that firewood sold from state forests was used in the amount of 597,776.06 m^3. Further analysis and data on firewood consumption, indicating consumption in 497,139 households, show that the average consumption per household in the heating season 2015/2016, according to the official statistics on the sale of firewood originating from state forests, was 1.20 m^3 or 1.68 stacked cubic meters. The Statistical Bulletin (Institute for Statistics of the Federation of BiH 2016) provided no data on the sale of firewood originating from private forests, which are certainly a significant source of firewood for households, especially for those households outside urban areas.

More realistic data are obtained when considering the official statistical data on total felled timber in and outside state and private forests. Comparing the data on the total mass of 780,325 m^3 (Institute for Statistics of the Federation of BiH 2016) with the previously adopted assumptions about the percentage share in consumption and the number of households, it can be concluded that the average consumption in the heating season 2015/2016 per household was 1.44 m^3 or 2.02 stacked cubic meters. Using the same assumptions, the average consumption of firewood per household in cantons in the Federation of BiH according to the official statistics is as follows: Bosnia-Podrinje Canton 3.19 m^3 or 4.46 stacked cubic meters; Herzegovina-Neretva Canton 0.98 m^3 or 1.37 stacked cubic meters; Canton 10 – 5.55 m^3 or 7.78 stacked cubic meters; Posavina Canton 0.10 m^3 or 0.14 stacked cubic meters; Sarajevo Canton 2.45 m^3 or 3.43 stacked cubic meters; Central Bosnia Canton 1.11 m^3 or 1.55 stacked cubic meters; Tuzla Canton 0.58 m^3 or 0.81 stacked cubic meters; Una-Sana Canton 2.74 m^3 or 3.84 stacked cubic meters; West Herzegovina Canton 0.22 m^3 or 0.31 stacked cubic meters; Zenica-Doboj Canton 1.86 m^3 or 2.60 stacked cubic meters.

On the other hand, observing the total number of households using firewood and the total consumption of firewood, the research presented in this paper using the WISDOM methodology indicates that the average consumption of firewood in households in the Federation of BiH was 5.91 m^3, i.e. 8.27 stacked cubic meters, in particular: Bosnia Podrinje Canton 5.19 m^3 or 7.27 stacked cubic meters; Herzegovina-Neretva Canton 4.96 m^3 or 6.94 stacked cubic meters; Canton 10 – 8.12 m^3 or 11.37 stacked cubic meters; Posavina Canton 6.70 m^3 or 9.38 stacked cubic meters; Sarajevo Canton 5.82 m^3 or 8.14 stacked cubic meters; Central Bosnia Canton 7.36 m^3 or 10.31 stacked cubic meters; Tuzla Canton 4.37 m^3 or 6.12 stacked cubic meters; Una-Sana Canton 7.65 m^3 or 10.71 stacked cubic meters; West-Herzegovina Canton 4.37 m^3 or 6.12 stacked cubic meters; Zenica-Doboj Canton 5.74 m^3 or 8.04 stacked cubic meters (Figure 5).

Based on all the above, it can be concluded that data on the estimated consumption of firewood in households using the WISDOM methodology is 4.10 (when compared to the official statistics on total felled timber in and outside state and private forests) to 4.93 (when compared to the official statistics on the sale of firewood in state forests) times higher, i.e. in average 4.52 times higher in relation to the official statistical data.

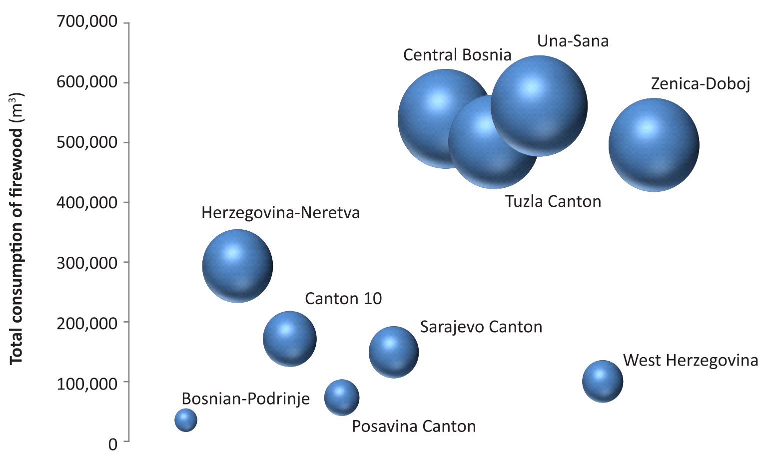

Figure 4. Total and relative consumption of firewood in the Federation of BiH cantons in the heating season 2015/2016.

The difference in average household consumption between the official statistics and data obtained using the WISDOM methodology is graphically presented in Figure 6.

Considering the above, it is evident that official statistical data often do not show the realistic situation. Since the average consumption of firewood per household in four cantons was less than 1 m³, namely in two cantons 0.1 m³ and 0.22 m³, the relevance of official statistical data is questionable.

If the results obtained using the WISDOM methodology in the Federation of BiH are compared with the average consumption of firewood in the countries of the region estimated by using the same (WISDOM) methodology, they are as follows: 5.49 m³·household⁻¹ (7.67 stacked cubic meters) in Montenegro (Marinović et al. 2013), 7.30 m³·household⁻¹ (10.22 stacked cubic meters) in Serbia (Glavonjić 2011, Glavonjić et al. 2015), 6.50 m³·household⁻¹ (9.10 stacked cubic meters) in Slovenia (Drigo and Veselić 2006) and 6.31 m³ (8.84 stacked cubic meters) in Macedonia (Trajanov et al. 2018). It is evident that the data are similar. As for comparison, Granic et al. (2008) state that average consumption in the Federation of BiH was 8.6 m³, while Robina and Lončarević (2017) state that households in BiH used an average of 7.7 m³ of solid biofuels per year.

Analyzing the relative differences between the data obtained using the WISDOM methodology and official statistical data for the Federation of BiH, similar trends with the surrounding countries are evident. Using the WISDOM

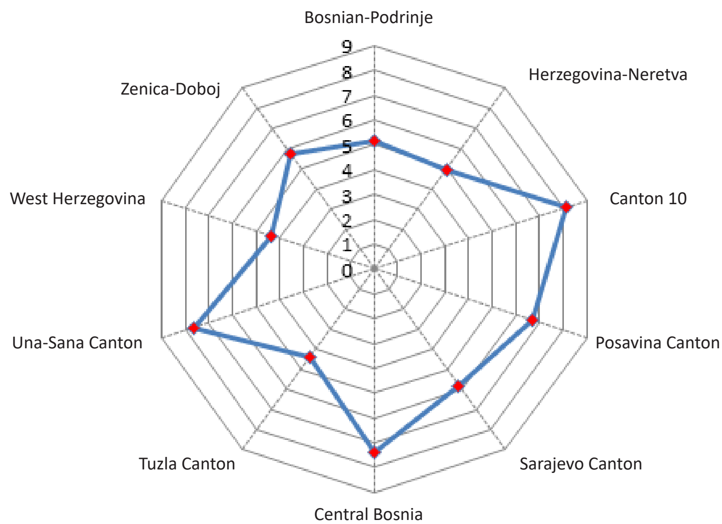

Figure 5. Average consumption of firewood in the Federation of BiH cantons according to the WISDOM methodology ($m^3 \cdot household^{-1}$).

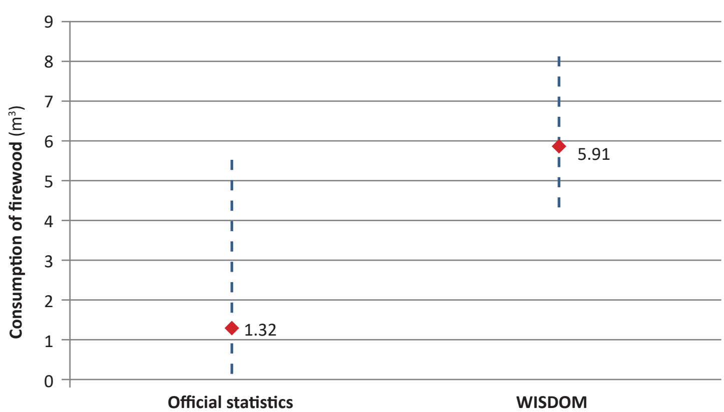

Figure 6. Consumption of firewood per household in the Federation of BiH according to the official statistical data and data obtained using the WISDOM methodology ($m^3 \cdot household^{-1}$).

methodology, 4.9 times higher consumption of firewood was determined in households in Serbia in the heating season 2010/2011 compared to official statistics (Glavonjić 2011), even 5.1 times higher consumption in Montenegro in the heating season 2011/2012 (Glavonjić and Krajnc 2013), and 1.7 times higher in Macedonia in the heating season 2015/2016 (Trajanov et al. 2018, State Statistical Office of the Republic of Macedonia 2016).

Considering the above research results and relevant bibliography, the relevance of official statistical data on the consumption of firewood, i.e. the share of registered consumers of firewood in total consumption, is questionable. Previous research (Granić et al. 2008) indicates that there were approximately 60% of registered consumers of firewood in BiH, while Robina and Lončarević (2017), referring to other research and studies, indicate that data on actual biomass consumption in households may differ significantly from those officially recorded. The authors further stated that most official reports on biomass consumption consider only firewood originating from state forests, but that in most cases households use wood from their own forests and do not officially report the amount of wood logged and used for energy purposes.

The use of biomass is not registered since statistical offices collect and publish data only on official trade in wood biomass, while the use of wood biomass for heating local communities located near forest areas and the use of wood by private forest owners is not recorded, which was confirmed by the research conducted for the World Bank (Stojadinović et al. 2017). This is followed by the land registry issues, unresolved property ownership rights and strict legal regulations, due to which some private forest owners cannot legally use firewood and other types of wood from their own forests since it is impossible to obtain valid proof of ownership documents. The problem of private forest ownership, including restrictions related to more effective mobilization of wood from private forests, has been covered in detail by PRIFORT project research (Glück et al. 2010).

A key precondition for improving the current state in private forests in all Western Balkan countries are the associations of private forest owners, namely the readiness of forest owners to form such associations. Although there are no consistent empirical data on the scope and type of illegal activities in forestry, the differences in the results on firewood consumption obtained using the WISDOM methodology and data available to the Institute for Statistics of the Federation of BiH can be partly explained by this problem. Forestry experts believe that the lack of adequate measures to combat corruption is one of the most serious problems in the forestry sector in the Federation of BiH (Avdibegović et al. 2014).

Survey which is described as a new research approach (Robina and Lončarević 2017), on which the WISDOM methodology is based, has indicated that the consumption of solid biofuels was 52.62% in 2009 and 52.02% in 2010, in relation to the consumption in 2014. They further state that the data on this almost double increase are the result of the application of a new research approach, and that they do not represent a real increase in the consumption of solid biofuels. Previously (refers to 2009 and 2010), data on solid biofuel consumption were based on statistical and other data of relevant institutions and organizations. Actual data (refers to 2014) on wood fuel consumption in households for energy purposes were obtained after the adoption of a new approach and comprehensive research on the consumption of wood fuels for heating in households. Considering all the above, the authors (Robina and Lončarević 2017) conclude that data on the consumption of energy obtained from solid biofuels in the past were not relevant, which was confirmed by the results of research under FAO project presented in this paper.

CONCLUSIONS

Firewood and other wood fuels are an important renewable energy source and very important economic resource that enables the development of the entire economy. Although large amounts of biomass are not used effectively, sustainable energy supply in the Western Balkans countries is essential for the regional economic growth and meeting EU accession commitments (Stojadinović et al. 2017). Sustainable and more efficient use of wood fuels for heat energy will contribute to increasing the share of renewable energy by using local energy sources, which are CO_2 neutral and at the same time have a positive economic impact and effects on employment. Considering a carbon-neutral source, it must be emphasized that in an effort to reduce CO_2 emissions by using energy from biomass, the environment must not be endangered since uncontrolled logging can cause forest degradation (Sulaimanet et al. 2020).

Lack of reliable data on available wood biomass, wood fuels and their supply and demand/consumption in households, public institutions, industry and other categories of consumers prevents the application of various measures and instruments (regulatory, financial, planning, promotional and other) for the sustainable use of available energy potentials based on wood. The results presented in this paper indicate that the use of the WISDOM methodology enables overcoming of the lack of relevant information on wood fuel consumption. In addition, the WISDOM provides an assessment of the potentials and contribution of wood-based energy to meet national and international targets and plans for the participation of renewable sources in total energy consumption. Relevant data on wood fuel consumption represent the basis for future strategic planning in the energy sector and the use of renewable energy sources, as well as in forestry, environmental protection and related sectors.

Considering the main goal of determining the actual consumption of wood fuels in households in the Federation of BiH, by comparing the results of research obtained by the WISDOM methodology with official statistics on the recorded consumption, it can be concluded that the consumption of firewood in households was higher, as follows:

- 4.10 times when compared to the official statistical data on total felled timber in and outside state and private forests,
- 4.93 times when compared to the official statistical data on the sale of firewood in state forests, i.e.,
- 4.52 times in average.

Given the absolute amounts, the average consumption of firewood in households in the Federation of BiH in the heating season 2015/2016 was 5.91 m^3, or 8.27 stacked cubic meters. This type of wood fuel was present in more than 96% of households in the Federation of BiH that use wood fuels. On the other hand, official statistics show an average consumption of 1.32 m^3 (1.85 stacked cubic meters) per household.

The results obtained using the WISDOM methodology show a lack of reliability of the existing official statistics. Some of the causes are the neglect of statistically unrecorded production of firewood from private forests (to a large extent) and from areas not categorized as forests and forest land. In addition, incomplete coverage is evident in terms of conducting consumption research in all the most important categories of consumers and all categories of wood fuels. The above will, in addition to the negative economic consequences, affect the (im)possibility of providing relevant evidence of fulfilment of commitments in terms of the participation of renewable energy sources and greenhouse gas emissions. One of the greatest consequences is the impossibility of drafting relevant planning documents in forestry, with further negative consequences for the sustainability of the complex forest ecosystem.

Based on the results of research related to the consumption of wood fuels in the Federation of BiH, the most important recommendations for improving the current situation in this area are as follows:

- As stated in the Energy Community Study (2012a), consumption surveys should be included as one of the basic tools for collecting data on energy consumption in all consumption sectors. Annual specific surveys on biomass consumption would be the best way to ensure reliable statistics for estimating biomass consumption in households.
- Entity statistical offices, as well as the Agency for Statistics of Bosnia and Herzegovina, should be more involved in the implementation of the defined and implemented WISDOM methodology in future surveys of wood fuel consumption.
- Relevant institutions in the field of forestry should further encourage sustainable production of wood biomass, thus making a significant contribution to the faster development of its production.
- It is necessary to intensify efforts to apply various instruments (financial, regulatory, planning and promotional) and to find new models with the use of good foreign practices, such as "small scale cooperatives", energy plantations, combination with carbon credits etc. for the increased use of wood biomass.
- To initiate a discussion at the state (BiH) and entities' levels regarding potential incentives for producers and/or discouraging the export of wood fuels (by encouraging domestic consumption), as a carbon neutral and renewable energy source, which would indirectly increase domestic consumption.
- Competent state, entity and local institutions, in cooperation with international organizations, should support the implementation of projects to replace fossil fuels with wood fuels, in order not to export the largest quantities of produced wood fuels in Bosnia and Herzegovina, but to use them. A wider framework includes measures such as incentives, subsidies and special purpose credit lines ("green credit lines"), as well as strategic programs of environmental education and strengthening public awareness.
- To intensify activities on establishing and strengthening the official national association for biomass as one of the urgent tasks in the future.

Author Contributions

DRČ, BDG, MHA conceived and designed the research; BDG, DRČ, MHA carried out the field measurements; BDG, DRČ and NDA processed the data and performed the statistical analysis; BDG and MHA supervised the research and helped to draft the manuscript; DRČ wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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The Network Structure of the Forestry Research as a Scientific Field in Turkey between 1999 and 2019

Hamid Dervis[1], Sezgin Ayan[2]*

(1) Kastamonu University, Faculty of Science and Literature, Department of Information Management & Records, Kuzeykent Campus, TR-37100 Kastamonu, Turkey; **(2)** Kastamonu University, Faculty of Forestry, Silviculture Department, Kuzeykent Campus, TR-37100 Kastamonu, Turkey

*** Correspondence:** e-mail: sezginayan@gmail.com

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ABSTRACT

This study aims to analyse and map the network structure of the scholarly communications in the realm of forestry research between 1999 and 2019 in Turkey using bibliometric analysis and social network analysis methods of the articles published within Clarivate Analytics' Web of Science (WoS). A total of 8689 records, including their bibliographic data, were extracted from WoS. The analysis of each sub-period shows that the number of international collaboration of Turkish authors has increased globally from 23 countries in the first sub-period to 113 countries in the last sub-period within forestry publications. Also, the annual percentage rate of publications has increased from 58 articles in 1999 to 1016 in 2019 in the realm of forestry alongside with their received average citations in each sub-period. Multi-author articles precede single-author articles in the field of forestry in each sub-period. This research is the first analysis of forest research production using bibliometric and network analysis in Turkey. According to the results biomass, remote sensing and climate change were current trends on forest research in Turkey. Incidentally, the research findings can be used by policymakers regarding future investments in forestry research development.

Keywords: bibliometric; social network analysis; forestry publication; forestry science mapping

INTRODUCTION

Forestry education in Turkey has a long history. Technical training and education in forestry began with the establishment of the first Forestry School in Istanbul, on 17th November 1857 (Gumus 2016), which became the first Faculty of Forestry under the Istanbul University (IUFF) in 1948 (Ozdonmez and Ekizoglu 1996, Ekizoglu 2001). From the point of view of the country, the primary objective of the forestry education at the beginning was to train human resources for the forestry organization. The second Forestry Faculty of the Black Sea Technical University was started and specialized in forest industry after its establishment in 1971. After 1993, 10 more new forestry faculties were established in different regions in Turkey (Yurdakul Erol and Sahin 2016). Four specialization fields at bachelor level education, which are forest engineering, forest industry engineering, wildlife management and landscape architecture, have been established. Graduate studies are provided under more than 20 different programs presently.

The priority-setting problem in forestry research projects in Turkey has been an important issue mainly since 1994, when the Forestry Research Master Plan (FRMP) was prepared as a part of the Turkish Agricultural Research Project (TARP) supported by the World Bank. Usually a monetary analysis is conducted to assess research output (Dasdemir 2005). The majority of current forestry research projects in Turkey are proposed, funded and carried out by the MAF and its 13 Forestry Research Institutes (FRIs) and scientific research funds of universities and the scientific and technological research council of Turkey (TUBITAK). Furthermore, the activities of well-established non-governmental organizations such as Chamber of Forestry Engineers, The Foresters' Association of Turkey etc., have contributed to the scholarly communications of the forestry sector.

Admittedly, as well as an increase in the number of forest faculties in Turkey, the objectives they pursue are diversified and proliferated in need of the day. The function of forest faculties is no longer limited to education of professionals for forestry management and organization; their function now includes producing information, raising public awareness, supporting sustainable development, and playing an effective role in the formation of related policies. On the other hand, following the change in the science of forestry education, Turkey and the rest of the world have adapted to the changing needs and priorities in forestry and forestry direction, which has provided dynamism in Turkish forestry education (Erdas 2008). Particularly, Bologna Process including Turkish Higher Education has been effective on the renewal and reorganization of the curriculum of the program since the beginning of 2000s. In Turkey, research topics, publications, and scientific events such as conferences, symposia, and congresses of the world directly affected forestry and environmental policies. Periodically, biodiversity, combating desertification, sustainability, participatory management, ecosystem-based planning, climate change, climate change mitigation and migration have been the dominant themes.

In the last few decades, the attention to the scientific productivity of researchers and research institutions in the world has increased (Abramo and D'angelo 2014). Similar to other scientific fields, Chirici (2012) reported two main approaches for evaluating scientific productivity for forestry development in Italy: (i) peer review, a qualitative evaluation in which a group of experts evaluates the research output, and (ii) bibliometric evaluation, where quantitative analysis of publications and citations is performed.

Evaluation of researchers' work and careers has increasingly transitioned from peer review to bibliometric evaluation (Rogers 2002, Cameron 2005). Bibliometric analysis, along with its gradual widening of applications, plays a significant role in finding scientific indicators for policy-makers and the executive branch. Pritchard (1969) defined bibliometric studies as a quantitative analysis of written publications by using statistical and mathematical applications. Similar to other scientific fields, forestry is studied by data scientists to measure its performance in terms of growth, structure, productivity, and interrelationship.

Hazarika et al. (2003) in a bibliometric analysis conducted in India based on the journal The Indian Forester for the period between 1991 and 2000 stated that multiple authorship was dominant (64.6%). Miah et al. (2013) conducted a bibliometric analysis of forestry research (1977-2007) in Bangladesh and established a strong increase of forestry papers from 1998 to 2000, but they started to decrease in 2001 and again increased in 2005 due to various factors. Most of the published papers were multi-authored in a bibliometric analysis of forestry researchers in Tanzania, and the majority (88.1%) of the publications were multiple-authored (Sife et al. 2013). There are some studies on forestry publications from bibliometric viewpoint: covering bibliometric analysis of global forest ecology (Song and Zhao 2013), co-term and citation analysis of evolution of Mediterranean forest research (Nardi et al. 2016), bibliometric productivity of forest scientists in Italy (Giannetti et al. 2016), bibliometric analysis of Open Access forestry research (Peiró 2018).

On the other hand, social network analysis (SNA) is a method derived from sociology to measure network structure (Otte and Rousseau 2002). SNA conceptualizes social structure as nodes and links connecting these nodes. Moreover, SNA quantifies the relationships between nodes within a network structure. Anthropologists, psychologists, sociologists, physicists, economists, and mathematicians utilize social network analysis methods to measure the relationship between people, organizations, or even nations. For example, Jacob L. Moreno (1934), a psychologist who mapped the social interaction of elementary school children, was instrumental in spreading the SNA methodology in scientific research. He named his map sociogram. SNA utilizes sociogram and mathematical graph theory to analyse the network structure (Scott 2000), where a sociogram shows the interaction among people within a group. One of the models within SNA is a small-world phenomenon that indicates each node (actor) in a random network structure which is connected to another node through an acquaintance (link) (Milgram 1967).

Literature defines co-authorship as a collaboration of two or more scientists in a research activity. Rogers (2003) stated that social interactions in multidisciplinary scientific areas and practitioners are instrumental in disseminating knowledge. Co-authorship among authors in the field of forestry reveals the network's indicators within each period, which is instrumental in diffusion of knowledge inside the scientific endeavour. Bibliometric methods such as co-occurrence have been utilized to conduct social network analysis; for example, co-word analysis (Leydesdorff and Vaughan 2006), maps of the collaborators (Wagner and Leydesdorf 2005) and co-authorship (Glanzel 2002) were applied to create social network structure of scientific collaboration among universities. Romanelli and Boschi (2019) for instance used Science Citation Index Expanded within online WoS database to measure the legacy of Elinor Ostrom on common forest research using bibliometric and network analysis methods. They used the co-occurrence of words to map the cognitive development in the network formation. Besides, Romanelli and Boschi utilized VOSviewer (Van Eck and Waltman 2010) to undertake the task.

Although there are numerous articles exploring forestry as a research field using bibliometric analysis (Song and Zhao 2013, Nardi et al. 2016), limited studies have been focused on social network analysis of the subject domain (Giannetti et al. 2016). This study explores forestry research development at the macro and micro levels in Turkey using bibliometric and SNA techniques.

MATERIALS AND METHODS

To delineate records properly, we used the "thesaurus "of Forestry Compendium CAB Abstracts database to define the search terms. We extracted terms from CAB Abstracts thesaurus based on the word "forestry," including their narrower terms and related terms. With the help of an expert in the forestry field, we finalized a compound text query (See Appendix A).

To conduct the research (Retrieved 24.12.2020), a total of 8689 records from Science Citation Index Expanded (SCI/EXPANDED) of all document types in all languages were downloaded from Web of Science (WoS) Clarivate Analytics (online academic database) using a compound text query between 1999 and 2019, having at least a country/regional Turkish collaborator. Clarivate Web of Science (WoS) was selected as a database covering inclusively referred journals. WoS was selected as a database since it covers inclusive referred journals. Descriptive analysis and bibliometric analysis were used to evaluate scholarly communications within forestry journals in WoS. According to WoS, scientific publications gained momentum starting in the past two decades; we chose 1999 as the starting year and divided the last two decades into four periods to gradually monitor research development.

The total record was divided into four sub-periods (1999-2003, 2004-2008, 2009-2013 and 2014-2019). Descriptive analysis was conducted using Bibliometrix (Aria and Cuccurullo 2017), an R package was used to create and to compare indicators for each period. Secondly, Bibexcel was used to make co-occurrence frequency matrix from bibliographic data extracted from WoS (Persson et al. 2009). VOSviewer was used to map the co-occurrence analysis. Gephi (Bastian et al. 2009) software analysed the network's properties within scholarly communication in the field of forestry.

The social network analysis approach presents scientific collaboration in the field of forestry research. SNA conceptualizes the network structure using centrality measures in terms of betweenness, closeness, and degree. Betweenness centrality measures a node's ability to connect other nodes in the network, whereas closeness centrality measures how fast a node can access another node in the system. Degree centrality measures the number of connections a node has with other network structure nodes (Scott 2000). The clustering coefficient indicates an inclination to aggregate a subgroup within a group (Newman 2001). Using SNA and descriptive analysis mentioned above, we have addressed the following research questions for the network structure of the forestry in Turkey: (i) Does the flow of knowledge in the network structure depict growth in publications' rate?, (ii) Which of the most prolific universities are publishing in the forestry research field, thus stimulating knowledge diffusion?, (iii) What are the research topics within forestry?, (iv) Who are the prolific authors, and do they collaborate more frequently? (v) What does network structure look like?

RESULTS

Research questions have been answered as follows:

(i) Does the flow of knowledge in the network structure depict growth in publications' rate?

A total of 8702 articles were extracted from WoS from 1999 to 2019. Description analysis is shown in Table 1. The number of records, average citation per article, the total number of authors, authors of single-authored articles, authors of multi-authored articles, authors per item, and co-authors per reports have increased for each sub-period, except for average citations per document and annual percentage growth rate.

For instance, the total average citation decreased from 33.73 in 1999-2003 to 28.68, 20.91, and 9.31 in other three periods respectively. Although the total number of articles has grown steadily from 371 in the first period (1999-2003) to 4020 in the last period (2014-2019), the annual percentage growth rate for each period fluctuates between 19.93% and 19.30%, and 3.07% and 12.82%, respectively (Table 1). These results confirm that the increasing number of research institutions in Turkey in the last three decades have triggered the number of researchers and the number of articles.

Figure 1 shows that the number of publications has increased from 58 articles in 1999 to 1016 articles in 2019, and about eighteen folds in the scholarly publications in the realm of forestry. A steady increase in the number of articles has been determined. The study findings indicate that forestry researchers in Turkey produced an average of 414.4 articles per year between 1999 and 2019.

(ii) The next question to be answered is which of the most prolific universities are publishing in the forestry research field, thus stimulating knowledge diffusion?

Table 2 shows the aggregated publications produced by the 15 most productive universities, producing 275, 875, 2004, and 2247 articles, which yields 74%, 67%, 66%, and

Table 1. Descriptive analysis of articles for each period.

Descriptive Analysis				
Period	**1999-2003**	**2004-2008**	**2009-2013**	**2014-2019**
Documents	371	1294	3017	4020
Ave citations per docs	33.73	28.68	20.91	9.31
Authors	866	2791	7301	15420
Authors of single-authored docs	47	143	322	376
Authors of multi-authored docs	830	2648	6979	15044
Single-authored docs	69	219	415	438
Authors per docs	2.36	2.16	2.42	3.8
Co-Authors per docs	2.94	3.26	3.82	5.37
Annual percentage growth rate	19.93%	19.30%	3.07%	12.82%

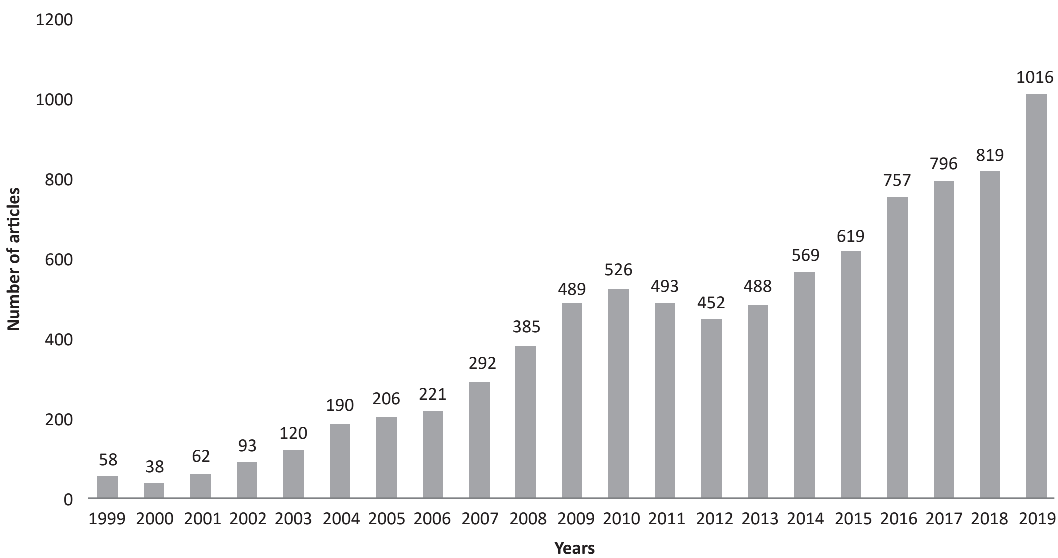

Figure 1. Number of publications in forestry: 1999-2019.

56% of scholarly publications in each sub-period respectively. As seen in Table 2, the 15 most productive universities in forestry scientific publications increased in each subsequent period. It was determined that Istanbul University and Karadeniz Technical University, the oldest forestry faculties in Turkey, were the most productive universities in terms of the publication number in the four subsequent periods. Although almost the same prolific universities appear in each sub-period with some fluctuation, for example, Bulent Ecevit University appears in the first and second sub-period, it has lost its position in the third and fourth sub-sequent period. This is because after 2007 Bartin Faculty of Forestry separated from Bulent Ecevit University and continued its academic life as an independent university under the Bartin University. Bartin University appears in the third and fourth periods at 12th and 7th rank respectively. Similarly, Kahramanmaras Sutcu Imam University appears in the first, second, and third sections respectively; however, it does not appear in the last period.

Kastamonu University, in terms of the number of publications in the last period, ranked 6th with a total number of 131 articles. Until 2006, the Kastamonu Forestry faculty continued its academic activities as a faculty affiliated with Gazi University.

With 41 publications within 1993-2003, Istanbul University is followed by Karadeniz Technical University with 134 publications for 2004-2008. Concurrently, Istanbul University succeeded with 295 scientific publications for 2009-2013 and 263 for 2014-2019. Although there are no forestry faculties or forestry research institutions, it can be seen from Table 2 that publications related to forestry are produced at universities such as Ege University, Middle East Technical University, Hacettepe University, Istanbul Technical University, and Yildiz Technical University, which indicates the multidisciplinary nature of the research development in the realm of forestry in Turkey.

(iii) What are the research topics within forestry?

VOSviewer calculated and created the keywords' co-occurrence from bibliographic data with a minimum threshold of 2 occurrences of the keywords. One can say that the network structure consists of 7 clusters where each cluster is made of distinct keywords. The links between nodes indicate the strength of co-occurrence of words between clusters. As it can be seen in Figure 2, biomass with the highest centrality is located in the centre of the graph, followed by pyrolysis and supercritical fluid extraction in the upper left side of the network. Within the second sub-period (2004-2008), the total number of keywords increased to 477, with a minimum of 2 occurrences of each keyword, making 25 clusters. In this period, remote sensing and mechanical properties are centralized, and logging, accumulation, hidden Markov models are periphery. Parallel to growth in publications during the 2009-2013 sub-period, the total number of keywords has increased to 1243 with the same criteria mentioned for the previous periods. Although remote sensing still stands with the highest centrality located in the centre of the network of the graph, biodiversity, climate change, and recycling started to appear within the network structure. Finally, climate change has become the latest research topic in the last sub-sequence.

(iv) Who are the prolific authors, and do they collaborate more frequently?

The answer to the question of who the prolific authors are, and whether they collaborate more frequently is depicted in Figure 3, which indicates a productive university generating prolific authors. The 10 most productive authors in each sub-period are also shown in Figure 3. Although some authors are present in each sub-period, most of them do not repeat in different sub-periods. For example, a few authors appeared in the first and second sub-period, and one appeared in the third and fourth sub-period in the same location, with over fifty publications (Figure 3).

Table 2. Top 15 Turkish universities with highest number of publications in each sub-sequence.

N	1999-2003			2004-2008			2009-2013			2014-2019		
1	Istanbul Uni. (41)			Karadeniz Tech Uni. (134)			Istanbul Uni. (295)			Istanbul Uni. (263)		
2	Karadeniz Tech Uni. (39)			Istanbul Uni. (127)			Karadeniz Tech Uni. (214)			Istanbul Tech Uni. (260)		
3	Istanbul Tech Uni. (37)			Istanbul Tech Uni. (91)			Istanbul Tech Uni. (191)			Karadeniz Tech Uni. (232)		
4	Hacettepe Uni. (27)			Bülent Ecevit Uni. (62)			Suleyman Demirel Uni. (161)			Middle East Tech Uni. (178)		
5	Kahramanmaras Sutcu Imam Uni. (21)			Gazi Uni.(54)			Ege Uni. (149)			Suleyman Demirel Uni. (147)		
6	Ankara Uni. (19)			Selcuk Uni. (54)			Duzce Uni. (134)			Kastamonu Uni. (131)		
7	Middle East Tech Uni. (16)			Ankara Uni. (52)			Middle East Tech Uni. (122)			Bartin Uni. (129)		
8	Akdeniz Uni. (12)			Hacettepe Uni. (51)			Gazi Uni. (112)			Duzce Uni. (124)		
9	Dokuz Eylul Uni. (11)			Kahramanmaras Sutcu Imam Uni. (51)			Kahramanmaras Sutcu Imam Uni. (104)			Yildiz Tech Uni. (119)		
10	Çukurova Uni. (10)			Ege Uni. (46)			Hacettepe Uni. (99)			Cukurova Uni. (118)		
11	Gazi Uni. (10)			Middle East Technical Uni. (45)			Ankara Uni. (97)			Hacettepe Uni. (118)		
12	Ege Uni. (9)			Sulyman Demirel Uni. (45)			Bartin Uni. (90)			Gazi Uni. (115)		
13	Ondokuz Mayıs Uni. (9)			Çukurova Uni. (42)			Ministry of Forestry Water Affairs of Turkey (86)			Ankara Uni. (109)		
14	Bulent Ecevit Uni. (7)			Abant İzzet Baysal Uni.(39)			Dokuz Eylul Uni. (77)			Ege Uni. (109)		
15	Marmara Uni. (7)			Düzce Uni. (37)			Cukurova Uni. (76)			Mugla Sıktı Kocman Uni. (95)		
Total	(N)	(n)	(%)	(N)	(n)	(%)	(N)	(n)	(%)	(N)	(n)	(%)
	371	275	74	1294	874	67	3017	2004	66	4020	2247	56

Note: Number in the parenthesis shows the total number of publications at each university in each sub-period. (N): Corresponds to the total of publications in each sub-period; (n): Corresponds to the sum of publications by the 15 most productive universities in each sub-period, and (%): Corresponds to the percentage of publications by the 15 most productive universities each sub-period.

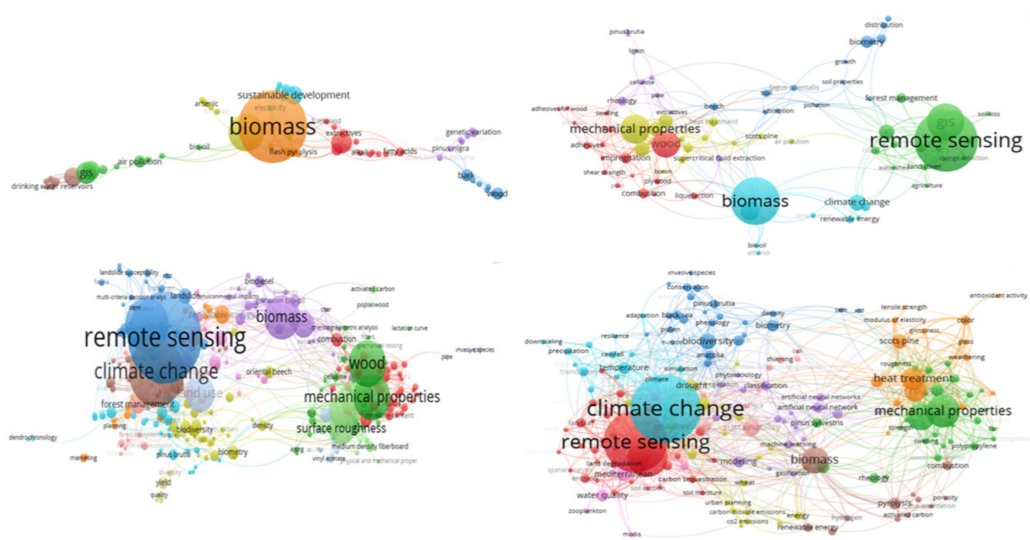

Figure 2. Keyword co-occurrence: 1999-2003 (upper left), 2004-2008 (upper right), 2009-2013 (lower left), 2014-2019 (lower right).

(v) Finally, what does network structure look like?

Degree centrality coefficients rose slightly from 0.027 in 1999-2003 to 0.033 in 2004-2008, and 0.059 in 2009-2013, but to some extent dropped marginally from 0.059 in 2009-2013 to 0.047 in 2014-2019 sub-periods, correspondingly. The number of authors increased in each period; the betweenness centrality increased slightly in each period from 0.00098 to 0.104, which means that the growth in publications within the second sub-period affected the flow of information among authors, resulting in higher betweenness centrality. However, high closeness centrality coefficients indicated the over 50% of sub-networks within the whole network are connected. Besides, growth in the clustering coefficients in each period is an indication of the small-world phenomenon in the network structure (Table 3).

VOSviewer calculated the total strength of the co-authorship link for each selected country with a threshold of one number of the article for each subsequence. For instance, Turkish researchers in the field of forestry collaborated with 23 countries during the first sub-period; in Figure 4, international collaboration is depicted as a center-periphery network structure. Similarly, Turkish scientists in the realm of forestry as in the first sub-period collaborated with the United States of America, the United Kingdom and Wales on the one hand, and Slovenia, Germany, Belgium and Finland on the other, located in the left of the network close to the center, too. However, Italy, the Czech Republic and Japan are located in the periphery of the network. The total number of collaborates raised three folds from 23 to 69 in just five years. New collaborations have entered the network - Denmark, New Zealand, India in the same cluster close to the center; Russia, Bulgaria, Sweden, Jamaica, and Egypt are nearer to center then Finland, which is located in the periphery. Compared to the previous period, slightly increased network in the third sub-period from 69 to 84 resulted in new collaborations with countries.

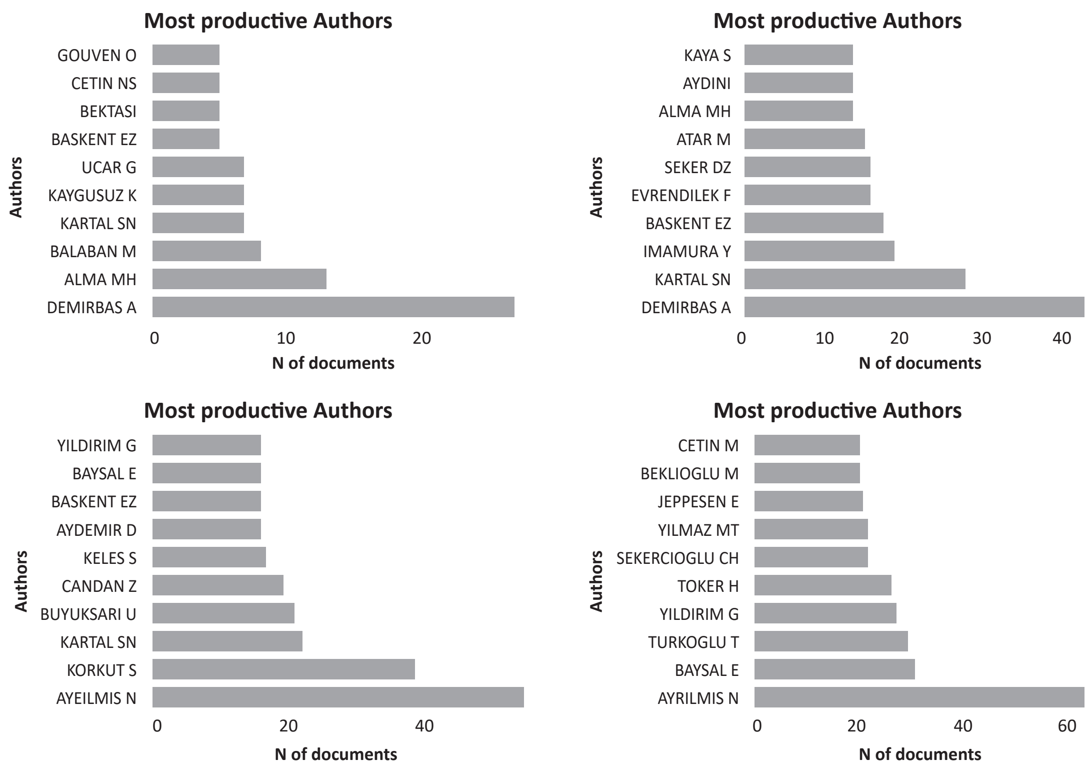

Figure 3. The most productive authors in each sub-sequence: 1999-2003 (upper left), 2004-2008 (upper right), 2009-2013 (lower left), 2014-2019 (lower right).

Table 3. Network measures of forestry in each sub-sequence.

	1999-2003	2004-2008	2009-2013	2014-2019
Degree centrality	0.027	0.033	0.059	0.047
Betweenness	0.00098	0.067	0.117	0.104
Closeness	0.606	0.879	0.553	0.546
Clustering coefficient	0.284	0.221	0.265	0.301

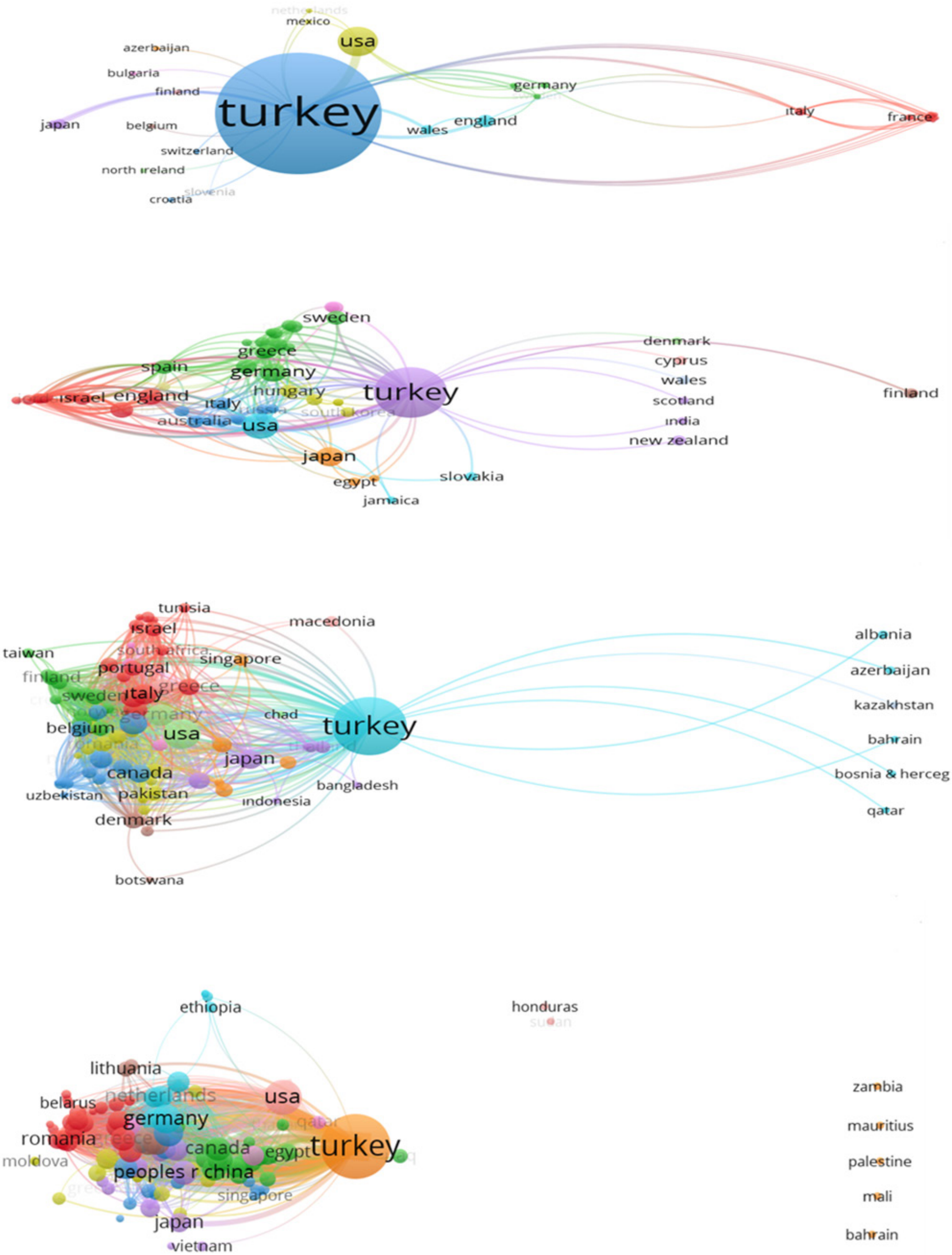

Figure 4. Number of international collaborations with Turkey in each period from top to bottom: 1999-2003, 2004-2008, 2009-2013, 2014-2019.

For example, a broad spectrum of countries from the African continent, such as Botswana, Morocco, Algeria, and from the Middle East, such as Iran, Saudi Arabia and Lebanon, as well as Albania, Chile, The People's Republic of China, Serbia, and, finally from central Asian countries (Kazakhstan, Azerbaijan) are new international collaborators, only a few to name. The highest collaborations in the last sub-period reached 113 countries. It can be seen that there are candidates from almost each continent participating in the network collaboration (Figure 4). It can be conjectured that as scientific collaborations have increased, the number of publications has increased too. Therefore, there is a positive correlation between scientists' collaboration and growth in publications internationally and locally.

DISCUSSION

According to Giannetti et al. (2016), the total number of scientific papers of forestry research employs 0.06% of the whole scholarly publications worldwide. Measuring research strength is considered essential for a modern country's ongoing innovative and competitive capacity at the global level. A country's success in science, technology, and research determines its ability to compete for increasingly mobile resources and investment capital and to participate in global knowledge-sharing networks (Anonymous 2006). In this context, it can be say that in forestry, being one of the scientific fields, scholarly communication has been booming since 1999 in Turkey. WoS's retrieved data revealed that international collaboration in co-authorship is a fast-growing research activity in forestry as a research field in Turkey (Figure 3). To start with, 23 countries with a minimum of one co-authorship on an article raised to 113 countries in 2014-2019 in Turkey. The growth in scientific collaboration has increased in the past decade. According to Elsevier (2013), the rate of co-authorship among different countries increased from 14% in 2003 to 17% in 2011. Especially, during the third period (2009-2013), Turkey's development of more intensive cooperation with countries from Central Asia, Middle East and Africa also affected the cooperation in academic publications. Furthermore, after the 2010s, young researchers with language competence who have completed their master's and doctorate studies abroad, especially in the USA and the UK, have returned to Turkey and achieved momentum both in producing international publications and in developing international cooperation (Cetinsaya 2014). Geographical proximity is not an obstacle to collaborative studies among scientists. According to WoS, the number of scientific publications has increased steadily; the number of average citations has gradually shrunk in each sub-period. However, the overall citations have increased from 1999 to 2019. Nevertheless, further studies are needed to determine the extent to which the cited articles are either purely local or international. Topical analysis using co-word analysis indicated that cognitive development started with biomass at the beginning, and eventually changed to remote sensing, biodiversity and climate change in the second and third sub-sequence, and to climate change in each sub-sequence.

Properties of the network structure of scholarly forestry papers authored by Turkish scientists between 1999 and 2019 indicate that the degree of collaboration at the international levels gradually increased in each period (Figure 4). The number of nodes in the network has increased steadily in the second and third period (1999-2003, 2004-2008), yet the network is not well connected. The centrality coefficients of the network structure revealed that sub-clusters within the social network structure are more connected at the micro-level than that at the macro level. The betweenness coefficients' centrality remained low in each sub-period, whereas the closeness centrality increased in each period. The closeness centrality stayed above almost 50% in all sub-periods, which is an indication of the small-world phenomenon in the network structure. There was a 90% increase in the number of publications compared to the third period (2009-2013). The increasing number of publications in the fourth sub-period (2014-2019) shows the concrete repercussions of the academic incentive application implemented in 2016 by Higher Education Council (YÖK) and changes in academic upgrade criteria made by the Inter-University Council (UAK).

CONCLUSIONS

The results are of major importance for determining Turkey's higher education strategies in the field of forestry, quality management and key indicators. In addition, the research findings can be used by policymakers regarding future investments in forestry development.

Appendix A

Terms mentioned below were extracted from CAB Thesaurus within Forestry Compendium, a comprehensive, encyclopaedic resource for forestry information. The co-author, an expert in forestry, reviewed and selected the words finally for correctness.

"agroforestry" OR "community forestry" OR "farm forestry" OR "forest policy" OR "private forestry" OR "seed orchards" OR "silviculture" OR "social forestry" OR "urban forestry" OR "afforestation" OR "amelioration of forest sites" OR "amenity forests" OR "amenity value of forests" OR "artificial regeneration" OR "controlled burning" OR "coppicing" OR "degraded forests" OR "demonstration forests" OR "dendrochronology" OR "disturbed forests" OR "farm woodlands" OR "felling" OR "fire detection" OR "fire prevention" OR "fire suppression" OR "forest administration" OR "forest economics" OR "forest inventories" OR "forest management" OR "forest plantations" OR "forest products" OR "forest railways" OR "forest taxation" OR "forestry development" OR "forestry engineering" OR "forestry law" OR "forestry machinery" OR "forestry practices" OR "forestry workers" OR "forests" OR "fuel appraisals" OR "fuel plantations" OR "increment" OR "irrigated stands" OR "linear plantations" OR "logging" OR "mensuration" OR "national forests" OR "pollarding" OR "primary sector" OR "protection forests" OR "protection of forests" OR "pulpwood production" OR "reserved forests" OR "selection forests" OR "silvicultural systems" OR "stand improvement" OR "state forests" OR "stumpage value" OR "wood") "forest ecosystem" OR "forest planning" OR "sustainable forest" OR "participatory forestry" OR "forest harvesting" OR "Climate change" OR "assisted migration" OR "forest biodiversity" OR "Mediterranean forest" OR "conservation forestry" OR "reforestation" OR "desertification" OR "forest restoration" OR "forest rehabilitation" OR "fast growing species" OR "natural regeneration" OR "non-wood forest products" OR "biomass production" OR "forest fire" OR "timber production" OR "soil conservation" OR "forest certification" OR "Silva pastoral systems" OR "forest regeneration methods" OR "coppice forest" OR "high forest" OR "provenances trials" OR "introduced tree species" OR "tree improvement" OR "forest genetics" OR "exotic species" OR "invasive species" OR "short rotation forestry" OR "old-growth forest" OR "energy forestry" OR "forest inventory" OR "forest conversion" OR "sub alpine forest" OR "tree migration" OR "stand structure" OR "relict tree species" OR "Peripheral population" OR "marginal population" OR "relict forest" OR "genetic pollution" OR "forest tree seed" OR "seedling propagation" OR "forest entomology" OR "forest fragmentation" OR "forest villagers" OR "un-even aged forest" OR "Even-aged forest" OR "bio energy" OR "carbon sequestration" OR "clear cutting" OR "chain of custody" OR "ecosystem services" OR "endangered species" OR "forestland" OR "forest type" OR "forest management plan" OR "deciduous trees" OR "land use" OR "remote sensing" OR "biometry" Or "marketing" OR "multiple use" OR "pure stand" OR "mixed stand" OR "seed tree" OR "seed tree cut" OR "rotation period" OR "seed year" OR "site index" OR "conifer" OR "softwood" OR "thinning"

Author Contributions

HD and SA conceived, designed the research, and wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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A Viral Pathogen from Pine Processionary Moth, *Thaumetopoea pityocampa* (Denis & Schiffermuller, 1775) (Lepidoptera: Notodontidae)

Mustafa Yaman[1,*]

(1) Bolu Abant İzzet Baysal University, Faculty of Arts and Science, Department of Biology, TR- 14030 Bolu, Turkey

*** Correspondence:** e-mail: muyaman@hotmail.com

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ABSTRACT
Pine processionary moth, *Thaumetopoea pityocampa* (Den. & Schiff.) is a serious defoliator in pine forests. Its larvae cause defoliation by eating leaves mainly on coniferous species, *Pinus brutia, P. nigra, P. pinaster*, and *P. pinea* in Turkey. Cypovirus is the most common entomopathogen in *T. pityocampa* populations. In this study, the ultrastructure of the cypovirus of *T. pityocampa* was observed in the intestine lumen of the predatory beetle, *Calasoma sycophanta* L. (Coleoptera: Carabidae), which supports the hypothesis of possible transmission of the virus to *T. pityocampa* populations by the predatory beetle. Polyhedral occlusion bodies (OBs) and virions were examined by electron microscopy. OBs of the virus were of irregular shape and 2.1 µm (1.2-3) in diameter, and each of them included up to 50 virions in a cross-section. Virions were icosahedral and 78.3 (65-90) nm in size and each virion had surface spikes. Smaller OBs, larger virions and a high number of virions per cross-section were the main features of the cypovirus in *T. pityocampa.* Our observations make us conclude that the predator beetle, *C. sycophanta*, may disseminate OBs of cypovirus when preying upon infected *T. pityocampa* larvae**.**

Keywords: predatory beetle; *Calasoma sycophanta*; cypovirus; prey; transmission; biological control

INTRODUCTION

While insects have many beneficial roles in research (Takov et al. 2020), medicine and agriculture (Demirözer et al. 2020), the number of different plant-damaging insects is considerably high (Kanat et al. 2005, Erkan 2018, Kuyulu and Genç 2020, İnal and Kandemir 2020). Pine processionary moth, *Thaumetopoea pityocampa* (Den. & Schiff.), is native to southern Europe, North Africa and parts of the Middle East. This pest extends its geographical distribution, currently ranging from North Africa to central Europe (de Boeer and Harvey 2020). Its larvae cause defoliation by eating leaves mainly on coniferous species, *Pinus brutia, P. nigra, P. pinaster,* and *P. pinea* in Turkey (Atakan 1991, Kanat et al. 2005), as well as central in southern Europe and North Africa (Trematerra et al. 2019). Climate change stimulates the pine processionary moth caterpillars to increase their attacks in pine forests (Hodar et al. 2003). The processionary moth defoliation can have a significant impact on the growth rate of the infested trees by decreasing the activity of needles and their availability for photosynthesis (Hodar et al. 2003, Jacquet et al. 2012, Erkan 2018). The effect of defoliation on tree growth occurs not only in the current year but also over years. Erkan (2018) determined the five-year effect of defoliation on the tree growth in *Pinus brutia* forests and found significant relationship between added total defoliation rate and total diameter for five years. According to this study, defoliation in trees damaged by *T. pityocampa* has increased, and diameter growth loss rate also has also increased significantly. Jacquet et al. (2012) found that mean relative tree growth loss increased with the rate of defoliation under the processionary moth attack and the damage was significantly higher for young trees than for old trees. Repeated defoliation weakens trees and makes them more susceptible to secondary pests such as bark beetles and may result in death of trees (Jacquet et al. 2012). *T. pityocampa* also causes the health risks to people, pets and livestock due to their urticating hairs (Trematerra et al. 2019). Possible treatment options include chemical pesticides application, mechanical removal, use of predator insects and entomopathogenic organisms (Kanat and Özpolat 2006, Goertz and Hoch 2013). However, the chemical pesticides used can harm people and the environment as well as non-target organisms (Arıkan and Turan 2020). The predatory beetle *Calosoma sycophanta* L. (Coleoptera: Carabidae) has been used for the biological control of *T. pityocampa* in Turkey (Kanat and Özpolat 2006). Currently this beetle is mass produced in 35 rearing laboratories and released for biological control of *T. pityocampa* in different regions in Turkey (Ceylan et al. 2012).

In the pest control strategies against *T. pityocampa* larvae, chemical insecticides are mainly used. Entomopathogenic microorganisms such as viruses, bacteria, protists, fungi and nematodes are promising for pest control (Avtzis 1998, Er et al. 2007). Although cypovirus (Cytoplasmic Polyhedrosis Virus (CPV)) is the most common entomopathogen in *T. pityocampa* populations (Tsankov et al. 1979, İnce et al. 2007), studies on this pathogen are very limited.

In this study, the ultrastructure of the cypovirus of *T. pityocampa* observed in the intestine lumen of the predatory beetle, *C. sycophanta*, has been documented for the first time. Furthermore, the infection was confirmed in the *T. pityocampa* larvae, and the virus was compared with cypovirus recorded previously in *T. pityocampa* as well as other lepidopteran pests to support the hypothesis that the transmission of the virus in *T. pityocampa* populations by the predatory beetle is possible.

MATERIALS AND METHODS

C. sycophanta adults and *T. pityocampa* larvae were collected in the rearing laboratories in Agean and Mediterranean region of Turkey. Samples of both insects were dissected in Ringer's solution (Merck) for microscopic examination according to Yaman (2019). The midgut lumen of *C. sycophanta* and the different organs such as intestine, fat body, hemocoel and Malpighian tubules of *T. pityocampa* were examined for the occlusion bodies (OBs) of *T. pityocampa* cypovirus. When OBs were observed, part of intestinal material or infected tissues was used for ultrastructural studies. Ultrastructural studies were carried out according to Yaman and Radek (2019). Characteristics of the viral particles from both insect species were compared to confirm that the virus in the midgut lumen of *C. sycophanta* shows the same characteristics as *T. pityocampa* cypovirus.

RESULTS AND DISCUSSION

A cypovirus was observed in the midgut lumen of the predator beetle *C. sycophanta* that was reared with the larvae of *T. pityocampa*, and in the gut tissue of dead *T. pityocampa* larvae showing typical viral infection symptoms. OBs and virions were examined by electron microscopy (Figure 1). Polyhedral occlusion bodies (OBs) were of irregular shape (Figure 1a, b) and 2.1 µm (1.2-3) in diameter and each of them included up to 50 virions in a cross-section (Figure 1c). Virions were occluded by a deposition of a polyhedrin matrix (OB) (typically up to 50 virions per OB) (Figure 1a, b). Virions were icosahedral and 78.3 (65-90) nm in size (Figure 1c) and each virion had surface spikes (Figure 1d).

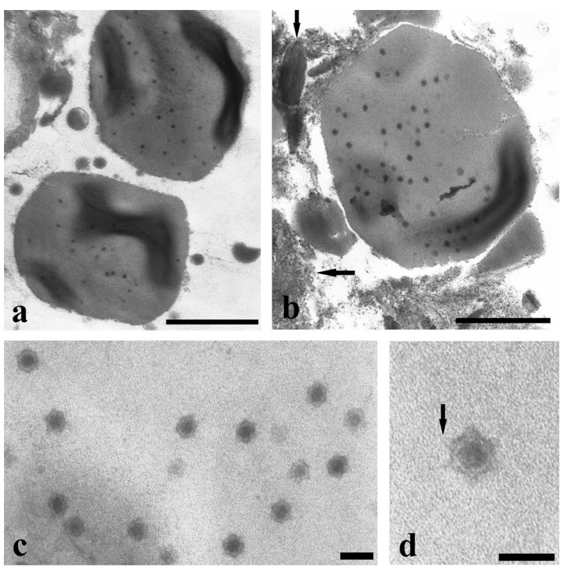

Figure 1. Ultrastructure of polyhedral occlusion bodies (OBs) of a cypovirus (CPV) of *T. pityocampa*; **(a)** Two occlusion bodies including different virions in a cross-section; **(b)** A whole inclusion body including up to 50 virions in a cross-section, surrounded by intestinal nutrient residues (arrow indicates); **(c)** A number of icosahedral virions occluded in polyhedrin matrix. **(d)** A virion exhibiting surface spikes (arrow indicates). Bars: 1 µm (Figure 1a, b) and 100 nm (Figure 1c, d).

The cypovirus of *T. pityocampa* has been recorded in a number of studies from different countries, as a possible microbial pathogen against *T. pityocampa* (Tsankov et al. 1976, Sidor et al. 1982, İnce et al. 2007). However, no detailed ultrastructural studies of this virus were published. İnce et al. (2007) analyzed a cypovirus from *T. pityocampa* by light and electron microscopes and electrophoretic RNA genome. Unfortunately, that study does not include any ultrastructural characteristics. Cross-sections of OBs in this study showed that they contain a high number of virions (up to 50) (Figure 1a, b). A high number of virions per OBs is desirable to control pest insect populations. All cypoviruses have similar tissue specifications, infecting only gut of insects. Therefore, shape and size of OBs and virions, and the number of the virions per OB are important morphological and ultrastructural characteristics to compare cypoviruses by adding more supportive data to molecular and biochemical comparison. In the literature, ultrastructural characteristics of some cypoviruses of lepidopteran pests have been documented. In order to characterize the *T. pityocampa* cypoviruses, we compared its morphological and ultrastructural features with other cypoviruses from lepidopteran pests. İnce et al. (2007) noted that the OBs of cypovirus isolated from *T. pityocampa* had larger size, 2.4 x 5.3 µm. Zeddam et al. (2003) observed relatively small OBs (between 1 and 3 µm) in *Norape argyrrhorea*, and Zhou et al. (2014) recorded similarly sized OBs in *Dendrolimus punctatus*, approximately 1.2 µm.

The results confirmed that the cypovirus in this study has considerably smaller OBs than that recorded from the same host by İnce at al. (2007). However, it has bigger OBs than those of *N. argyrrhorea* (Zeddam et al. 2003) and *D. punctatus* (Zhou et al. 2014). The cypovirus shows differences also in the diameter (78.3 nm) of virions from the cypovirus (70 nm) of *N. argyrrhorea* (Zeddam et al. 2003) and the cypovirus (50 nm) of *D. punctatus* (Zhou et al. 2014). As a result of the study, smaller OBs, larger virions and a high number of virions per cross-section were the characteristics of the cypovirus in *T. pityocampa* from different localities. Some strains of virus isolated from different localities may present better insecticidal activities (Murillo et al. 2001).

During the microscopic observation of this study, the cypovirus was observed firstly in the gut lumen of one predator beetle, *C. sycophanta*, and then confirmed in the larvae of the prey, *T. pityocampa*. As seen in Figure 1a, b, the occlusion bodies were not disturbed by the gut contents of the predatory beetle. Entomopathogenic organisms transmit in different ways between insects populations (Yaman 2020). This result speculates that the predator beetle, *C. sycophanta*, disseminates OBs of cypovirus when preying upon infected *T. pityocampa* larvae. Similar judgments were proved by Capinera and Barbosa (1975), Vasconcelos et al. (1996) and Goertz and Hoch (2013). Capinera and Barbosa (1975) found that field-collected or laboratory-fed *C. sycophanta* adults defecated nucleopolyhedrovirus polyhedra in sufficient quantity to infect 3rd-stage gypsy moth *Lymantria dispar* (Lepidoptera: Lymantridae) larvae. Vasconcelos et al. (1996) showed that carabids transmit sufficient baculovirus into the soil to cause death in larvae of the cabbage moth *Mamestra brussicae* L. (Lepidoptera: Noctuidae). Goertz and Hoch (2013) demonstrated that *C. sycophanta* can disperse viable spores of the microsporidian species, *Nosema lymantriae* and *Vairimorpha disparis.* Furthermore, they observed that both microsporidian species did not infect the beetles after feeding on infected prey.

CONCLUSION

Shape and size of OBs and virions, and the number of virions per OB are important morphological and ultrastructural characteristics to compare cypoviruses by adding more supportive data to molecular and biochemical comparison. As a result of the study, smaller OBs, larger virions and a high number of virions per cross-section are the characteristics of the cypovirus in *T. pityocampa* from a different geography of Turkey. Turkey is a potential source of new and interesting entomopathogens. Observations of this study make us conclude that the predator beetle, *C. sycophanta*, may disseminate OBs of cypovirus when preying upon infected *T. pityocampa* larvae and therefore play a role in the transmission success of the pathogen. Future studies should be focused on the role of the predator beetle in the transmission of the virus in *T. pityocampa* populations.

Author Contributions

MY designed the research, collected the samples, carried out microscopic analysis and wrote the manuscript.

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Conflicts of Interest

The author declare no conflict of interest.

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REVIEW PAPER

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Juniperus L. for Restoration of Degraded Forest Lands in Turkey

Cengiz Yücedağ[1], Sezgin Ayan[2]*, Perla Farhat[3], Halil Barış Özel[4]

(1) Burdur Mehmet Akif Ersoy University, Faculty of Engineering Architecture, Department of Landscape Architecture, TR-15030 Istiklal Campus, Burdur, Turkey; **(2)** Kastamonu University, Faculty of Forestry, Silviculture Department, Kuzeykent Campus, TR-37100 Kuzeykent Campus, Kastamonu, Turkey; **(3)** Université Saint-Joseph, Faculté des Sciences, Laboratoire Biodiversité et Génomique Fonctionnelle, Campus Sciences et Technologies, Mar Roukos, Mkalles, BP: 1514 Riad el Solh, Beirut 1107 2050, Lebanon; **(4)** Bartın University, Faculty of Forestry, Silviculture Department, TR-74100 Bartın, Turkey

*** Correspondence:** e-mail: sezginayan@gmail.com

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ABSTRACT

Degraded forests are among of the most important environmental and commercial problems around the world. Turkey has 22.74 million hectares of forest area, out of which 9.656 million ha (42%) are unproductive. To transform these unproductive forests into productive ones, forest restoration including rehabilitation is one of the best actions. In this sense, juniper species play an important role for degraded lands because they are drought-tolerant and withstand aridity and poor soils better than most timber species grown in Turkey. Therefore, this review presents the ecological considerations for the restoration of degraded forest lands in Turkey under the conditions of climate change. Within this framework, it focuses on the production of planting stock of juniper species, the significance of site-species matching, and post-planting site maintenance for successful rehabilitation.

Keywords: degraded land; juniper; planting stock, rehabilitation; Turkey

INTRODUCTION

Degraded forests have lost much of their productivity, biodiversity and most of the ecological goods and services that they once provided (Lamb and Gilmour 2003). Forest degradation has on-site and off-site ecological and environmental effects, including the deterioration of agro-ecological conditions, increased flooding, lower water quality and the siltation of dams. Unfortunately, human activities are one of the major causes of forest degradation (Mantang et al. 2003). Therefore, the rehabilitation of these lands needs more than just a biological perspective and sustainable management (Thang 1987, Mantang et al. 2003). Rehabilitation is the action of redirecting the existing ecosystem composition or structure towards a more desired state (Burton and Macdonald 2011). In the process of rehabilitation, the conservation of plant diversity and ecosystems both in situ and ex situ, and rehabilitation of degraded lands is ecologically significant (Soejono et al. 2013).

Turkey is located in three biogeographical regions: Anatolian, Mediterranean and the Black Sea region. Owing to its location, it consists of various ecosystems, including forests, mountains, steppe, wetlands, coastal and marine ecosystems (IUCN 2012). Therefore, it is an important hotspot of biodiversity and endemism. However, overgrazing, over-cutting, fires, clearance for agriculture, wars and general misuse of the land have contributed to the drastic decrease in forest area. According to the report of Turkish Ministry of Forest and Water Affairs in 2019, Turkey has 22.74 million ha of forest land of which 42% (9.656 million ha) are degraded (OGM 2019a). In Turkey, *Juniperus* L. is considered as one of the most important genus of Turkish conifer forests. Despite the fact that species of this genus cover a large area of ca. 958.423 ha, most of that area is actually unproductive and degraded (TOD 2019).

Juniperus, locally known as "Ardıç", represents the most diverse genus inside Cupressaceae family and the second most diverse within conifers with approximately 75 species and 40 intraspecific taxa (Farjon 2010, Romo et al. 2013, Adams 2014). Junipers grow in a large spectrum of habitats from the sea level to the highest mountains (Adams 2014). In Turkey, they are considered as the most resistant tree species to extreme growing conditions and are the last to move away from the area in which is subjected to deforestation (OGM 2006). Indeed, its ability to adapt to harsh environmental conditions makes juniper a resistant and robust tree in the face of winter frost, water stress, rocky slopes and shallow soils (Gauquelin et al. 1988, Rawat and Everson 2012, Mathaux et al. 2016, Evren and Kaya 2020). Recently, it was proved that species from this genus are capable to regulate stomatal transpiration for a better water management during drought season (Abdallah et al. 2020), and that their tolerance to summer drought increases with the age (Rozas et al. 2009). All those remarkable characteristics make *Juniperus* an essential potential genus for reforestation and ecological rehabilitation particularly in areas with harsh environment where they are probably the only species able to grow and develop (Yücedağ et al. 2010, Çetin 2014). This includes the Mediterranean basin, where the impact of the recent climatic change is severe and characterized by an increase in the temperature and a decrease in precipitation (Houghton et al. 1996). Based on their resistance characteristics, junipers were chosen as the keystone species for many reforestation and rehabilitation activities such as in Balochistan province of Pakistan (Sarangzai et al. 2012), in Lebanon (MoE 2009), Greece (Vrahnakis et al. 2017), and India (Rawat and Everson 2012).

Juniperus is a species-rich genus represented in Turkey with 8 taxa belonging to the *Caryocedrus*, *Juniperus,* and *Sabina* sections (Eliçin 1977, Adams 2014): *J. communis* L., *J. excelsa* M. Bieb., *J. foetidissima* Willd., *J. oxycedrus* L., *J. phoenicea* L.*, J. deltoides* R.P. Adams (Adams and Mataraci 2011), *J. sabina* L., and *J. drupacea* Lab. (Anşin and Özkan 1993, Davis 2001). Juniper forests in Turkey are dominated by *J. excelsa* (ca. 82%), followed by *J. foetidissima* (ca. 15%) and *J. phoenicea* (ca. 3%) (OGM 2006; Figure 1). However, these forests are subjected to a severe degradation accompanied with the general decline of forests, which makes rehabilitation efforts a crucial priority.

This paper presents a review of the ecological features to use junipers for the rehabilitation of degraded forest lands. Even though several forest tree species are relevant in rehabilitation activities, this article focuses on species belonging to *Juniperus*, which is one of the dominant genera in Turkey both ecologically and economically. Specifically, it focuses on the production of planting stock of juniper species, the significance of site-species matching, and post-planting site maintenance for successful rehabilitation.

JUNIPER LAND DEGRADATION

Human interference played a major role in juniper lands' degradations. Juniper species are highly appreciated in many industrial and medical productions (Adams 2014). For decades, juniper species have been used to produce medicines due to their anti-microbial and antifungal properties (Asili et al. 2010, Orhan et al. 2012, Hojjati et al. 2019, Vasilijevic et al. 2019, Zivic et al. 2019). As well, some species were found to be potentially important for cancer treatments (Sadeghi-Aliabadi et al. 2009, Kapdan et al. 2019). Moreover, juniper trees were intensively cut for the use of their strong wood for furniture and boat production (Adams 2014). Juniper wood was preferred more than other species' wood for the production of outdoor furniture due to its effective, beautiful and distinctive scent (Şirin and Topay 2019).

There are several ecological reasons for juniper forest degradation and fragmentation. Juniper species are wind-pollinated, produce small pollen grains at low quantity and pollen grains have a slow setting velocity (Douaihy et al. 2012), which affects the pollination process. Plus, juniper trees have a low density of reproductive adults, they have a low sound seed ratio (Yücedağ et al. 2010) and suffer from several germination obstacles (Gültekin 2007, Yücedağ et al.

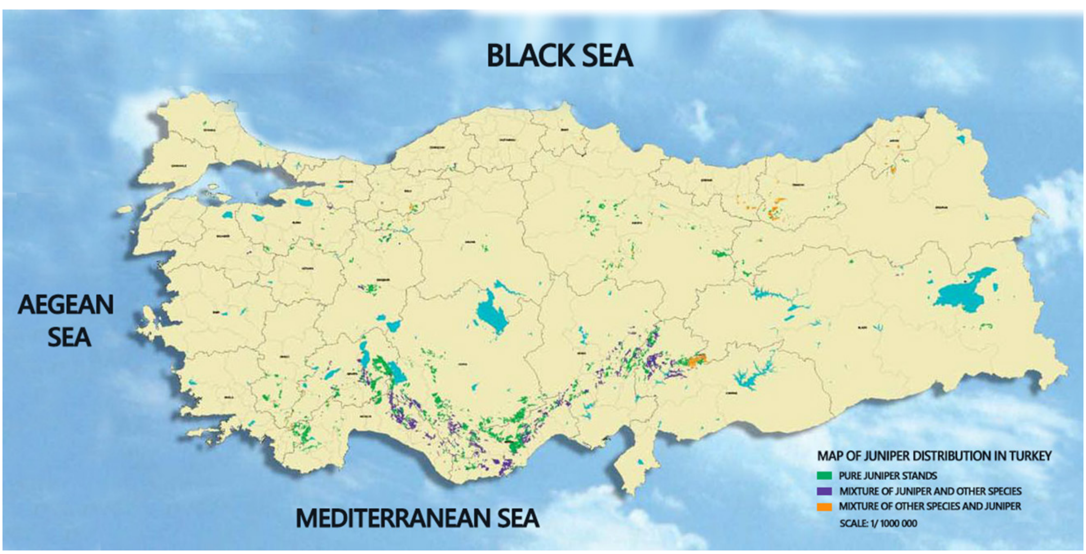

Figure 1. *Juniperus* geographical distribution in Turkey (extracted from TrAgLor 2018).

2010), which reduce the resilience of juniper forest, leading to their fragmentation.

Additionally, climate change has presented dramatic consequences to plant species and their ecosystems (Allen et al. 2010). The increase of temperatures and the reduction of precipitation, especially in arid and semi-arid environments, induced by climate change showed an increase in drought stress on juniper trees at all altitudes (Seim et al. 2016). Despite that *Juniperus* is drought-resistant, the fast climate change would induce a dramatic decline in their population sizes as noted in Oman populations for *J. seravschanica* (MacLaren 2016).

To summarize, the main factors of degradation and fragmentation of juniper forests in Turkey are the historical and recent human activities, the extreme environmental conditions in the distribution area of juniper species, the difficulty of natural regeneration and the impact of rapid climate change of the recent years.

CHALLENGES TO LARGE-SCALE PRODUCTION OF JUNIPER PLANTING STOCK

Seed Supply

The reproductive ecology of juniper provided considerable challenges for the forest nurseries, which may explain, in part, the low rehabilitation and afforestation practices in the past. Seed production in junipers is unpredictable because junipers have a low sound seed ratio (Yücedağ et al. 2010). The number of sound seeds per cone can be determined by the cutting method before collecting cones (Yücedağ et al. 2010). Total juniper seed production per year from all Turkish juniper populations from 2012 to 2019 is available in Figure 2, showing a big variation throughout the years (minimum = 1107 kg, maximum = 5929 kg). This variation in seed production depends on the population location where seeds are collected (Gültekin and Gültekin 2007).

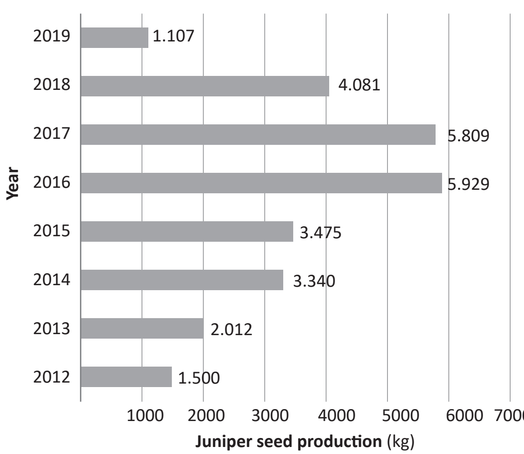

Figure 2. Juniper seed production by year in Turkey (OGM 2019b).

Ideally, in heavy seed years, the mean of sound seed ratio was found to be around 30-52% (Gültekin 2007). However, this percentage could be affected by the method used in the estimation, which was in this case, the "area detection x tree selection" method. Also, this estimation could be affected by the condition of the sampled female cones. Therefore, coarse, healthy (not infected by insects), large and bright female cones should be collected (if available) (Gültekin 2007, Yücedağ et al. 2010).

Propagation by Seed

Juniper seeds have various germination obstacles. Different methods and their combinations are used for removing these obstacles (Gültekin and Gültekin 2003, Gültekin 2007, Yücedağ et al. 2010, Gezer and Yücedağ 2013). The propagation success depends on the species and the method used. In Turkish nurseries, *J. foetidissima* and other native juniper species' seeds are sown after stratification from March to May or directly sown from August to September in natural conditions. If the obtained seeds are immediately sown or stratified, then no pretreatment is applied. The earlier the juniper seeds were sown, the more success in germination rate was obtained. Generally, seeds are sown in late spring for *J. foetidissima* and in summer or early fall for other juniper species (Gültekin 2007).

In the case of seeds pretreatment, after obtaining juniper seeds from cones, they are floated in various concentrations of NaCl solutions depending on the species (e.g. 25 000 ppm for *J. excelsa*). This step aims to detect sound seeds (unfloated seeds) and therefore remove other floated empty seeds. Before sowing, seeds are kept in water containing 20% wood ash for 15 days to remove resin and oils from seeds. After this process, seeds are desiccated under shady conditions for a couple of days (Gültekin et al. 2003, Gültekin 2007, Yücedağ 2008, Yücedağ et al. 2010).

In harsh semi-arid restoration lands in Turkey, the production of containerized seedlings for juniper plantings should be a priority according to the results of the recent scientific research (Örtel et al. 2020, Yücedağ et al. 2021). In the production of containerized juniper seedlings, the ideal growing medium is a mixture of 50-60% forest soil, 5-10% fine sand and 30-40% humus (Gültekin 2007). Gülcü et al. (2010) also reported that *J. excelsa* seedlings with the best quality in terms of the seedling height and root collar diameter were grown in 11 cm x 30 cm pots, using a growing medium mixture that contains 70% forest soil, 15% humus, and 15% pumice or creek sand. Besides, Gülcü and Gültekin (2005a) stated that seed provenance was very important in the production of *J. excelsa* seedlings. Two methods are used for sowing seeds in containers. First, six seeds are directly sown in each container. Second, the germinated seeds after stratification are sown. In terms of nursery practice, the use of the second method is shown to be both cost-effective and easy, especially for *J. foetidissima.* On the other hand, transplanting to the container should be done in winter or early spring, but no later than this period (Gültekin 2007).

In the production of bare root seedlings, seeds are usually sown in late spring, summer and fall, depending on the juniper species. The optimal sowing depth is 5 mm for *J. excelsa* (Gülcü and Gültekin 2005b), 6 mm for *J. oxycedrus* and

J. phoenicea, and 10 to 15 mm for *J. foetidissima*. Seed sowing and mulching were applied to seedbeds. Also, covering seed sowing parcels with plastic shader was found useful in frosty days of late fall and winter. It has been noticed that around 30 to 50 g seeds of *J. excelsa, J. oxycedrus* and *J. phoenicea* and ca. 80 to 160 g seeds of *J. foetidissima* are required to obtain 200 to 350 seedlings per m^2 (Gültekin 2007).

In the growing season, junipers grow roots before shoots. Thus, weeding should be applied 3 to 4 times in three weeks' intervals until June. It is usually done by hand or by machines during the period of the first three months. Hoeing is done twice in May and June in the seedbeds without mulching. The roots are pruned by traction-drawn blades, cutting them at 25 cm below ground level, at the beginning of September. It is not possible to use 2+0 years-old bare root seedlings for restoration activities due to the excess of stem/root ratio. For this reason, two root pruning at 25 cm below ground level in March and July of the second year are proper for this kind of seedlings. In the production of bare-root seedlings, green manure application must be applied to the sowing parcels (Gültekin 2007).

During and after the germination process, measures should be taken for seeds and seedling protection from several stressors. Birds are considered an important problem for juniper seeds. For this reason, the best method is to put "telis" or synthetic material directly onto seedbeds. As well for seedlings, birds along with other animal species such as rabbits, rodents, cockchafers and soil worms can cause a dramatic loss in the increment of young juniper seedlings in a short time. Besides, fungal diseases present a moderate to low problem as they are rarely seen in juniper seedling propagation (Gültekin 2007). Additionally, apart from biotic stressors, juniper seedlings are very sensitive to the abiotic conditions and especially to late frost. It has been previously reported that junipers are affected by low temperatures during germination (Gültekin 2007). For this reason, planting under a canopy or a nurse plant could be advantageous by flattening the environmental stresses on the young seedlings. This was proved by Khoshnevis et al. (2019), who showed that canopy and its geographic orientation had significant positive effects on *J. excelsa* seed germination and seedling survival rates.

Natural juniper seed sources from gene conservation forests are available in Turkey and are registered in the National Register System. These seed stand and gene conservation forests are listed in Table 1. According to this list, four seed stands and 16 gene conservation forests in Turkey were selected and registered (OGM 2020).

The total (815.5 ha) seed stand area consists of *J. excelsa* (3 pcs - 457 ha) and one *J. phoenicea* (1 pcs - 353.5 ha). In addition, the total (2992.1 ha) gene conservation forest area consists of *J. drupacea* (one pcs - 15.1 ha), *J. excelsa* (11 pcs - 2451.3 ha), *J. foetidissima* (three pcs - 369.4 ha) and *J. oxycedrus* (one pcs - 156.3 ha) (OGM 2020).

Table 1. Seed sources according to different juniper species in Turkey (Edited as of 3 January 2020).

National Registered Number	Source*	Species	Regional Directorate	Forest Enterprise Directorate	District Chief	Compartment Number	Area (ha)
375	SS	*J. excelsa*	ANKARA	BEYPAZARI	KARACA	373, 490	149.6
378	SS	*J. excelsa*	ANKARA	ESKIPAZAR	EMIROGLU	2, 3	207.9
377	SS	*J. phoenicea*	MUGLA	MILAS	GURCAMLAR	253, 254, 255, 256	358.5
392	SS	*J. excelsa*	ISPARTA	EGIRDIR	EGIRDIR	29, 50	99.5
12	GCF	*J. excelsa*	MERSIN	TARSUS	BULADAN	52, 53, 54	163
13	GCF	*J. oxycedrus*	MERSIN	MERSIN	KIZILBAG	140, 141, 143	156.3
17	GCF	*J. excelsa*	MERSIN	MUT	SERTAVUL	145, 146	223.4
19	GCF	*J. foetidissima*	DENIZLI	ACIPAYAM	ALCI	49, 64	75.5
22	GCF	*J. excelsa*	DENIZLI	ACIPAYAM	ALCI	79, 80	132.2
32	GCF	*J. excelsa*	MUGLA	SEYDIKEMER	SEKI	147, 176	133.4
39	GCF	*J. excelsa*	DENIZLI	ESKERE	YELKENCIDAG	52, 53	117.6
40	GCF	*J. excelsa*	KONYA	KONYA	HADIM	143, 144, 145, 146	530.7
93	GCF	*J.excelsa*	ANTALYA	SERIK	OREN	1, 2, 3, 6	232.3
112	GCF	*J. foetwidissima*	ISPARTA	BUCAK	KESTEL	126	97.5
120	GCF	*J. foetidissima*	ISPARTA	GOLHISAR	DIRMIL	139, 140, 141	196.4
124	GCF	*J. excelsa*	KONYA	BEYSEHIR	BEYŞEHİR	1005, 1006, 1007, 1008	269.5
190	GCF	*J. excelsa*	ESKIŞEHIR	ESKIŞEHIR	SEYİTGAZİ	132,168	252
195	GCF	*J. excelsa*	ESKIŞEHIR	MIHALICCIK	BEŞPINAR	229, 230, 233, 234	235.7
308	GCF	*J. excelsa*	ANKARA	BEYPAZARI	BEYPAZARI	701, 705	161.5
273	GCF	*J. drupacea*	K.MARAŞ	ANDIRIN	ÇATAK	157	15.1

SS: Seed stand; GCF: Gene Conservation Forest

According to the statements by the Minister of Agriculture and Forestry of Turkey (OGM 2019b), a total of 25 million juniper seedlings were produced between 2011 and 2018. However, Farahat (2020) investigated *J. phoenicea* populations in North Sinai Mountains in Egypt and reported that the seedling supply of juniper species was extremely restricted. According to the statements mentioned above, it has been concluded that juniper seedling propagation is a challenging practice that depends on many factors such as year, population, country and species.

Vegetative Propagation

Although there are important constraints on the seed supply of junipers, the use of vegetative propagation should not be an indispensable option. Vegetative propagation is highly useful for species where seed germination was limited or in case of the failure of optimal germination protocols. In particular, vegetative propagation is an alternative for juniper species presenting low seed germination rates and for those who produce empty seeds at high frequency. Vegetative growing capacities of junipers are very high during the first several years (Gültekin 2007). In Turkey, vegetative propagation of junipers has remained experimental (Keskin 1989, Ayan et al. 2004). For instance, Tektaş et al. (2017) reported that the most proper hormone concentration was identified to be 5000 ppm naphthalene acetic acid (NAA) and the most proper planting time was identified to be April for reliable rooting of *J. excelsa*. However, these factors could not be generalized on the genus scale and they depend largely on the species of interest (Haile et al. 2011, Ramos-Palacios et al. 2012). Among many case studies where this technique was used for restoration purposes, we mention the propagation of native species (*Buddleja cordata* HBK, *Dodonaea viscosa* Jacq and *Senecio praecox* D.C) in Mexico potentially utilized for reforestation (Ramos-Palacios et. al. 2012), the propagation of the native silver fir and *Taxus* L. for the conservation of the Apennine beech forests (Amiata 2007) and the propagation of several tropical trees (Zahawi and Holl 2014). However, vegetative propagation is a difficult and time-consuming practice (Haile et al. 2011) which is coupled with a major disadvantage regarding the offspring genetic diversity (Thomas et al. 2014). This technique will produce clones having the same genetic material as the parental plants. Therefore, the genetic diversity of the propagated trees will be reduced, which might have a severe negative effect on the population and its ability to adapt to biotic and abiotic stresses, especially in degraded land (Thomas et al. 2014). Based on these disadvantages, we highly recommend avoiding vegetative propagation for rehabilitation practices. However, if it is the only possible propagation technique, it should be elaborated by taking cuttings from as many individual plants as possible (Marzo et al. 2015).

Mycorrhizae

A lot of attention has been paid to the great effect of mycorrhizal symbioses in restored ecosystems and serious efforts have been done on establishing the efficiency of the plant-mycorrhizae relationship (Chen et al. 2014). Before application on the field, three important criteria must be fulfilled. First, a compatible mycorrhiza to the plant species of interest must be chosen, second, the mycorrhizal fungus must be suitable to the site to be rehabilitated and finally, no difficulties in the inoculum production must be present (Rincon et al. 2001). For some juniper species, *Cenococcum* Moug. & Fr., fungi are successfully used (Chen et al. 2014). However, this issue was not well explored neither in Turkey nor for *Juniperus*. Therefore, further work must be elaborated to discover the specific mycorrhizal fungus for Turkish *Juniperus* species and the one which is suitable for the sites to be restored. Mycorrhizae inoculation should be conducted for the rehabilitation of the degraded lands having extreme climate conditions in Turkey. If bare root seedlings are used for rehabilitation activities, mycorrhizae inoculation should be conducted both for seedlings in the nursery and planting pit in the rehabilitation area. Besides, the inoculation is sufficient only at the nursery stage if seedlings were grown in containers (OGM 2006). These treatments will provide better growth and survival rate in the early stages of planting. However, there is still a clear gap of knowledge on the extent to which inocula are adapted to some host species and site conditions.

Seeds' Genetic Constraints

The genetic quality of juniper's seed has not been yet well studied. Thus, to make some generalizations we are still relying on recent studies of gene flow and genetic diversity of adult juniper populations (Korshikov and Nikolaeva 2007, Yücedağ 2008, Hojjati et al. 2009, Yücedağ et al. 2010, Douaihy et al. 2011, Gülsoy et al. 2012, Korshikov and Nikolaeva 2013, Yücedağ and Gailing 2013a, 2013b, Pinna et al. 2014, Saeed et al. 2017, Yücedağ and Ozel 2017, Mazur et al. 2018). Studies have shown that a reduction in stand density and isolation of individuals may enhance inbreeding. Douaihy et al. (2011) stated that losses of the old juniper individuals and the lack of natural regeneration could result in a negative genetic effect represented by the fragmentation of local population diversity. Therefore, ideally, seed collections should be made from primary forest stands with a good density of reproductive adults. Unfortunately, due to the extent of forest degradation, this may not always be an option.

REHABILITATION STATUS IN TURKEY

Rehabilitation practices officially began in 1998 in Turkey and were conducted on about 3.1 million hectares totally in 2019 (OGM 2019a). These practices have essential benefits for the sustainability of natural resources such as soil and water. In addition, rehabilitation works have a role in sustaining both Turkey's and the world's biodiversity and in providing several ecosystem services such as carbon storage.

Recently, the importance of the usage of native species during rehabilitation has been highlighted in many practices worldwide (Lamb et al. 2005) and in Turkey. This practice provides significant environmental benefits such as the conservation of the species and its genetic diversity, the reduction of the risk of invasiveness, the high survival rate of native species during rehabilitation actions due to their adaptation to the local climate (Bozzano et al. 2014). Using native and local species in Turkey for rehabilitation has recently increased. Indeed, to restore degraded land in Artvin-Turkey, three native species (*J. foetidissima, Punica granatum* L., and *Cotinus coggygria* Scop.) were used and they revealed high survival rates (greater than 70%) over a period of two years (Balaban 2011). In addition, for the restoration activities of Burdur-Turkey, six native and drought-resistant species were suggested: *J. oxycedrus, J. excelsa, Quercus libani* G. Olivier*, Pinus brutia* Tenore*, Cedrus libani* A. Rich., and *P. nigra* J.F. Arnold (Şahin et al. 2014). These findings emphasize the importance of research to enable site-species matching for the restoration of degraded forest, and the great potential for native species to be used for establishing a nurse canopy. Studies exploring the levels of local adaptation in junipers will not only improve our ability for site-species matching, but also the extent to which generalizations can be made across regions.

In Turkey, juniper forests cover an area of 958.423 ha, of which 218.300 ha (22.77%) is productive, and 740.123 ha (77.22%) is unproductive. Some statistics about juniper forests are presented in Table 2 (TOD 2019).

The natural regeneration of juniper trees is very low, which implicates conservation and rehabilitation actions. Open juniper forests (10 to 40% crown density) and the surrounding degraded areas should be considered for rehabilitation activities. Usually, habitats where junipers grow are characterized by extreme environmental factors (e.g., drought, low nutrient and high/low temperatures), which makes rehabilitation activities more challenging. Therefore, a combination and novel forest establishment methods might be considered during rehabilitation. In all cases, the rehabilitation of an area should be planned according to the land characteristics. Also, planting methods are adapted to the land as an example; methods will differ between areas with or without deep soil (OGM 2006).

It should be noted that four-years-old saplings obtained from natural regeneration have the same height as one-year-old saplings grown in nurseries and used in afforestation. Therefore, planting saplings from nurseries in most cases is cost-effective and planted seedlings grow tall more quickly. Especially, planting 1+1 or 2+0 containerized saplings is essential for a rapid increase in height. Thus, completion and maintenance costs are minimized. In some harshly arid areas, deeper tillage, irrigation and fertilization in the first years would be beneficial. Sexual regeneration methods should be used in rocky areas where tillage is not possible. On the other hand, the number of juniper seedlings planted per hectare in the rehabilitation of degraded lands should be twice as much as the rainfall amount of the region (OGM 2006).

Sapling counts should be conducted for at least two years and 70% success should be considered sufficient. In dense rocky areas, this ratio can be reduced to 50-60% (OGM 2006). Research conducted in the rehabilitation area of Senirkent-Isparta district, Turkey, showed that about 60% of juniper saplings survive (Sungur and Bilir 2015). Another study (Yücedağ et al. 2021) exploring the variability in growth, photosynthetic pigments, proline and plant nutrients of seven *J. excelsa* populations grown in Davraz mountain of Isparta, Turkey (Figure 3) revealed that the mean height and diameter of 10-years-old saplings found were 94.47 cm and 4.18 mm, respectively. Also, the same study reported that very few saplings had a damaged crown, but the survival rate of all populations was 100%. Gültekin et al. (2005) stated that the survival rates in the Lakes District of Turkey, where one-year-old bare-root *J. excelsa* and *J. foetidissima* saplings are planted, were 73% and 92%, respectively. Another research assessing the rehabilitation works in Burdur, Turkey, reported that the mean height of 8-years-old *J. excelsa* saplings ranged from 80 to 151 cm and its growing in the same area was better than that of *Cedrus libani* (Çetin 2014). Another study investigating the effects of four different seedling types (1+0 and 2+0 aged bare-root seedlings, 1+0 and 1+1 aged containerized saplings) of *J. excelsa* on survival rate and their growth in Yalvaç-Isparta and Elmalı-Antalya districts of Turkey showed that sapling type significantly affected survival rate, and 1+1 and 1+0 aged containerized saplings were the most successful seedling types (Örtel et al. 2020).

J. excelsa and *J. foetidissima* saplings are highly used for rehabilitation practices in Turkey. However, there is no exact statistical data on how much each juniper species is produced or planted in this region.

Rehabilitation of degraded forest lands is mostly via the planting of juniper seedlings rather than seed sowing. Thus, this management strategy fundamentally depends on the ability to produce sufficient numbers of viable seedlings of juniper species for planting. However, seed sowing is a mandatory method especially in rocky areas (Gültekin 2007). It can be applied in two ways. First, stratified seeds in summer and fall are sown in natural areas. The second method, direct seed sowing without stratification, can be used in the winter season. Patch sowing should be used particularly in rocky areas and at least 6 seeds should be sown in each

Table 2. The area, volume and increment status of juniper forests in Turkey (TOD 2019).

Attribute	Productive forest area	Unproductive forest area	Total
Area (ha)	218,300	740,123	958,423
Volume (m^3)	15,238,806	4,827,863	20,066,669
Volume in unit area ($m^3 \cdot ha^{-1}$)	69.81	6.52	20.94
Annual increment ($m^3 \cdot year^{-1}$)	331,079	93,740	418,623
Annual increment in unit area ($m^3 \cdot ha^{-1} \cdot year^{-1}$)	1.52	0.13	0.44

Figure 3. Ten-year-old plants in Davraz Common Garden, Isparta of Turkey (Yücedağ et al. 2021).

patch. Previous experimental designs showed that with direct seed sowing, the germination of *J. foetidissima* seeds occurred in the second year, while there was no germination in the first year. Germination rates of *J. excelsa, J. oxycedrus* and *J. phoenicea* were found to be about 15-60% in the first year and the germination of the remaining seeds took place in the second and third year. It has been recommended, in order to have a successful germination rate in nature, that at least 4 kg of sound seeds of *J. excelsa,* 5 kg of sound seeds of *J. oxycedrus* and *J. phoenicea,* and 20 kg of sound seeds of *J. foetidissima* per hectare should be sown. In the case of extreme sites, it was recommended to sow two folds of the quantities of seeds mentioned above (Gültekin 2007; Gültekin and Gültekin 2007).

Unfortunately, the sown seeds suffer from rabbits, sheep and goats during germination. Fall and winter should be preferred for seed sowing. If possible, it should be done in the late summer or fall following the first rains. Seed sowing in the spring should be avoided. Young seedlings that survive till the end of the first year in the harsh lands are usually permanent on site (Gültekin 2007).

EVOLUTIONARY CHALLENGE FOR LAND REHABILITATION BY *JUNIPERUS*

Recently, *Juniperus* was found to be an exception within conifers regarding the evolutionary phenomenon, polyploidy (Farhat et al. 2019a, b). Polyploidy or whole genome duplication is when an organism possesses more than two complete sets of chromosomes (Comai 2005). For example, a triploid, tetraploid and hexaploid hold three, four and six sets of chromosomes, respectively. Polyploidy is considered to be a major phenomenon for plant evolution and especially for angiosperms (Chen 2007, Soltis and Soltis 2009, Tayalé and Parisod 2013). Indeed, around 50 to 80% of angiosperm taxa are polyploid and it was estimated that all angiosperms had at least one polyploidization event in their ancestry (Van de Peer et al. 2017, Otto and Whitton 2000). However, polyploidy was found to be very rare within gymnosperms (ca. 5%) and especially within conifers (ca. 1.5%) where polyploid cases were mainly found to be tetraploid except in one species, *Sequoia sempervirens* (D.Don) Endl., the only hexaploid (Khoshoo 1959, Ahuja 2005, Scott et al. 2016). Recently, *Juniperus* showed a relatively high rate of polyploidy with ca. 15% of tetraploid and one hexaploid, *J. foetidissima* (Farhat et al. 2019a), which makes this genus an exception within conifers regarding this phenomenon. Moreover, intraspecific variations in the ploidy levels were detected in some juniper taxa, *J. sabina*, and *J. chinensis* L., where some populations were found as diploid and the others as tetraploid (Siljak-Yakovlev et al. 2010, Farhat et al. 2019a). Therefore, the ploidy level of juniper seedlings selected for rehabilitation may present an additional challenge to rehabilitated population. Indeed, in the long term, the evolution of the species used during the rehabilitation action would be affected by the choice of individuals and their ploidy levels. Also, this choice would affect the future of the restored region and its neighborhood because polyploidy affects the geographical distribution of the species (Weiss-Schneeweiss et al. 2013). Indeed, polyploidy would affect positively or negatively the polyploid taxa distribution by affecting their adaptation to environmental factors (Weiss-Schneeweiss et al. 2013). Also, in some cases, polyploid plants would become invasive due to their high environmental adaptation followed by the genetic variations acquired by polyploidy (Te Beest et al. 2012). Recently, Farhat et al. (2020) found that interspecific hybridization occurred between diploid and tetraploid *Juniperus* taxa present in sympatry in the wild. Therefore, while using more than one juniper species in the rehabilitation action, a historical assessment on juniper taxa that might be present in the same location is highly recommended. We also suggest that the source of the germplasm used for rehabilitation is from the juniper trees of the degraded population before its degradation. This will ensure planting of the same ploidy level as the previously destroyed juniper population. Alternatively, we suggest to take germplasm from the nearest population and to check their ploidy levels.

POST-PLANTING SITE MAINTENANCE

In general, a 70% survival rate for juniper afforestation areas is considered sufficient and successful. Unless these areas have big gaps, replanting of dead saplings should not be made. If necessary, the containerized seedlings based on the characteristics of the field should be replanted at the end of the first year. Usually, there is no weed problem in the first year in most of the fields prepared by machine. Hoeing is done in the period when cracks occur in the soil and it is repeated if necessary according to the climatic conditions. Generally, there is no need to hoe after the second year in juniper afforestation areas. In extremely arid areas, deep tillage, irrigation and fertilization in the first year would be beneficial. In areas where weeds present a problem, they should be removed and their residues should be spread out on the same area (OGM 2006, Gültekin and Gültekin 2007).

The main goal in the maintenance of junipers' rehabilitation areas is to overcome the first vegetation period. Indeed, deaths from drought are very low after this period. If rabbits and other domestic animals are not allowed to enter the juniper rehabilitation areas, the saplings will survive. Nevertheless, to ensure the rehabilitation success, the areas should be observed for at least 2 years and maintenance should not be ignored. The technical staff of the district where the rehabilitation activity was conducted must program their maintenance work in terms of period and activities (Gültekin and Gültekin 2007).

CONCLUSION

The advancement of strategies for rehabilitation of degraded forest lands is globally of leading importance. These rehabilitation works which require great political driving force and considerable economic incentives can improve the biodiversity and economic value of Turkey's lands, providing socio-economic benefits as well as environmental awareness. Establishment of ex-situ conservation units and seed orchards of juniper species are required. Increasing both our knowledge and capacity to produce genetically diverse planting stock from the species' range is crucial for successful forest recovery. All these efforts could result in significant ecological and economic benefits for Turkish forestry.

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CY, SA, PF, and HBÖ conceived, designed, and wrote the paper together.

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Conflicts of Interest

The authors declare no conflict of interest.

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Variability of Morphological Traits of European Beech (*Fagus sylvatica* L.) Seedlings in Serbia

Vladan Popović[1,*], Aleksandar Lučić[1], Ljubinko Rakonjac[1]

(1) Institute of Forestry, Kneza Viseslava 3, RS-11000 Belgrade, Serbia

*** Correspondence:** e-mail: vladanpop79@gmail.com

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ABSTRACT

The results of interpopulation variability of morphometric parameters of European beech (*Fagus sylvatica* L.) seedlings originating from eight populations from the part of natural distribution area in Serbia are presented in this paper. The studied populations of Dubašnica, Jastrebac, Boranja, Fruška Gora, Mali Pek, Goč, Beljanica, and Javor have various ecological and vegetational characteristics. The results of this paper refer to root collar diameter and height of seedlings at the age of 1+0 and 2+0. Analysis of variance showed a statistically significant difference between the populations in terms of the studied morphological traits of seedlings ($p<0.01$; $\alpha=0.05$). Geographical differentiation of the studied populations has not been determined by applying cluster analysis, but the populations are grouped randomly and they indicate the ecotypic nature of beech genetic variation. The results of this research may serve in beech breeding and the available gene pool conservation. Based on the obtained results it can be recommended that in terms of transfer and use of the beech forest reproductive material greater attention should be paid to the ecological conditions of the parent stands and habitats where afforestation has been performed.

Keywords: European beech; seedlings; variability; population

INTRODUCTION

European beech (*Fagus sylvatica* L.) is the most widespread tree species in Europe and also one of the most ecologically and economically important species. Wide ecological amplitude and growth on elevations from 50 m to over 2000 m indicate great adaptability of the species and existence of a significant genetic variability. The research of beech genetic variability started by establishing the first provenance test in Germany in 1877 and afterward in other European countries (Vidaković and Krstinić 1985, Kajba 2003). The knowledge of certain morphological, physiological and commercial traits of various beech provenances is very significant for beech breeding, and the selection and recognition of seed stands (Gračan 2003). The conducted research of genetic structure of various beech populations in the area of south-eastern Europe had shown significant genetic variability with dominant ecotypic nature of differentiation (Paule 1995, Gömöry et al. 1999, Hazler et al. 1997, Gömöry et al. 2007, Šijačić-Nikolić et al. 2007, Ivanković et al. 2011) as well as that the postglacial recolonization started from different refugia (Brus 2010).

The research of genetic diversity especially in some adaptive traits (growth, survival, and phenology) is very important in the context of global climate change. This is particularly significant for populations in the southern parts of the beech distribution area due to a potentially higher risk of warming in this part of Europe (Ivanković et al. 2011). The parent material should possess as high as possible genetic variability because it is crucial for successful manifestation of adaptive traits (Šijačić-Nikolić et al. 2006). The growth and development of beech seedlings are conditioned by photoperiod, heat quantity, and soil and air humidity (Pšidová et al. 2015). Having in mind that these climate factors are not evenly distributed throughout the species distribution area, one can assume that natural selection of different directions and intensities affects the beech population in dependance on climate factors (Màtyàs et al. 2009).

The objective of this research is to acquire preliminary knowledge of the genetic variability of the studied beech populations based on the quantitative seedling traits in the nursery test.

MATERIAL AND METHOD

The eight beech populations from the species distribution area in Serbia were selected for the research. Their general traits are shown in Table 1, and geographical position in Figure 1.

In the autumn of 2013, the seeds were collected from all eight populations. After the analyses of quality and health had been conducted in a laboratory, in the spring of 2014 a nursery test was established in the nursery of the Institute of Forestry. A hotbed with dimensions of 24 m × 1 m has been divided into 24 equal fields measuring 1 m × 1 m. The trial had been set in three replications (all eight populations were represented in one replication). In each field, 100 seeds had been planted. After sowing, the seeds were covered with a substrate layer of 2 cm thickness. The mechanical weeding, hoeing, and watering were performed during the first and second vegetation periods.

At the end of the growing seasons of 2014 and 2015, at the 1+0 and 2+0 age of seedlings, measuring of height and root collar diameter was carried out. The height was measured by a ruler with an accuracy of 0.1 cm, and root collar diameter by a vernier calliper with an accuracy of 0.1 mm.

The measured morphometric traits of seedlings were processed in the statistical software package Statistica 7.0 (StatSoft Inc. 2004). Basic statistical parameters were calculated for each of the measured traits. The significance of the differences between the mean values of the analysed parameters was verified by one-way analysis of variance (One-Way ANOVA), where the analysed factor was a population.

The additional testing using Fisher's LSD test was carried out in order to determine populations form homogeneity groups. Pearson's correlation coefficient was conducted using the R function in the Hmisc package by Harrell et al. (2019) to determine significant correlations between the analyzed traits and the climate variables of the original habitats of the populations. The inputs for the correlation coefficient were the arithmetic means of the populations for the analyzed morphological traits and different climatic variables connected with their original stands. Interpolated climate data for the reference period 1961-2009 generated by the ClimateEU software (Marchi et al. 2020) were used to characterize the long-term climatic conditions of the original stands. A detailed explanation of the assessment of all available climate variables provided by the ClimateEU software can be found in Wang et al. (2012). For the

Figure 1. Geographical location of analysed beech populations.

Table 1. General traits of analysed beech populations.

Population Mark	Population	Exposition	Elevation (m)	Latitude WGS84	Longitude WGS84	Forest association	Annual mean temperature (°C)	Annual precipitation (mm)
I	Dubašnica	northwest	870	44.100629	21.888005	*Fagenion moesiaceae montanum*	7.3	790
II	Jastrebac	northeast	790	43.556586	21.761478	*Fagenion moesiaceae montanum*	7.9	666
III	Boranja	southeast	650	44.389965	19.289810	*Fagenion moesiaceae submontanum*	8.8	875
IV	Fruška Gora	north, northeast	400	45.141938	19.622889	*Qerceto-Fagetyum*	9.5	699
V	Mali Pek	northeast	650	44.458935	21.978872	*Fagenion moesiaceae submontanum*	8.3	764
VI	Goč	north, northeast	900	43.56751	20.854722	*Abieti-Fagetum serpentinicum*	7.6	833
VII	Beljanica	north, northeast	700	44.070153	21.757080	*Fagenion moesiaceae montanum*	8.3	782
VIII	Javor	northwest	1300	43.455000	20.018890	*Fagenion moesiaceae montanum*	5.9	1007

purpose of the populations' grouping based on the analysed morphometric traits of seedlings, a cluster analysis was applied using a single linkage method (single linkage Euclidean distance).

RESULTS AND DISCUSSION

The mean values of the seedlings' root collar diameter by population are presented in Figure 2. At the end of the first growing season, the Boranja population seedlings achieved the highest mean value of root collar diameter (2.86 mm), and seedlings of the Javor population the lowest (2.39 mm). During the second growing season diameter increment trend changed, so at the end of the growing season the Goč population had the highest mean value of the root collar diameter (3.99 mm), while the lowest mean value of this parameter was recorded in the Mali Pek population (3.22 mm). The highest variability of the studied trait in one-year-old seedlings was found in the Beljanica population (20.9%) and in two-year-old seedlings in the Mali Pek population (23.2%). The lowest variability at the level of one-year-old seedlings was found in the Javor population (13.2%), and at the level of two-year-old seedlings the lowest variability of the root collar diameter was found in the Dubašnica population (13.5%).

The differences between populations for the root collar diameter trait were statistically highly significant both in one- and two-year-old seedlings (Table 2).

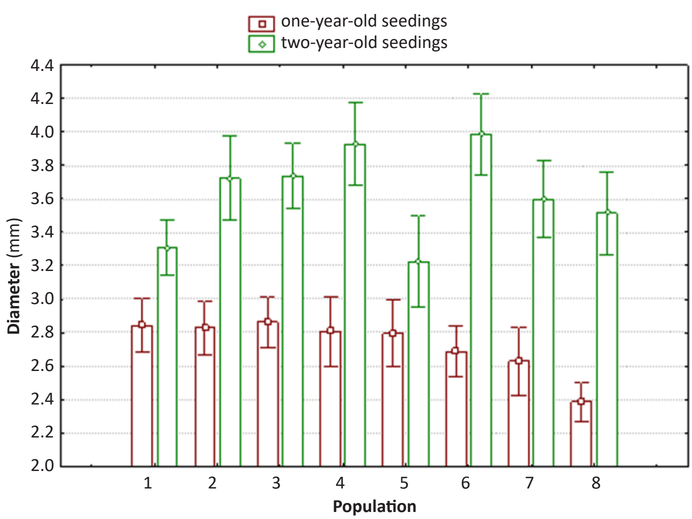

Figure 2. Boxplot of root collar diameter data per provenance.

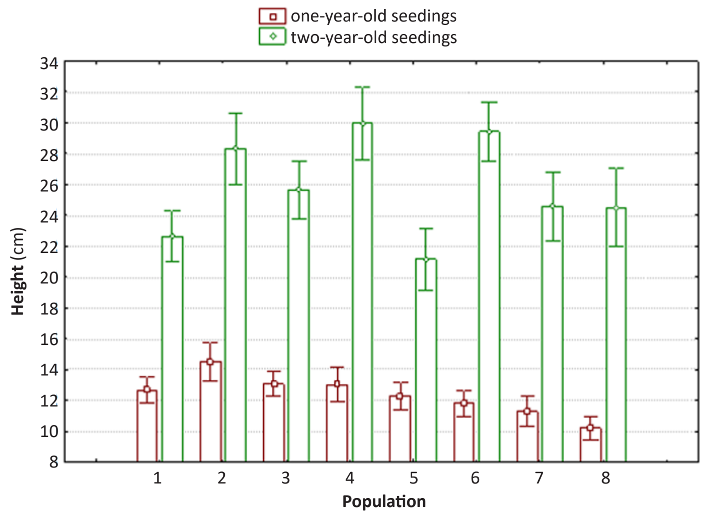

Figure 3. Boxplot of height increment data per provenance.

Mean values of the seedlings' height at the age of 1+0 and 2+0 by populations are presented in Figure 3. The highest mean value of one-year-old seedlings' height was measured in the Jastrebac population (14.5 cm), and the lowest in the Javor population (10.2 cm). At the end of the second growing season the highest mean value of height was measured in the seedlings of the Fruška Gora population (30 cm) and the lowest mean value in the seedlings of the Mali Pek population (21.2 cm). Regarding the height of one-year-old seedlings, the highest variability was found in the Fruška Gora and Beljanica populations (23.2%) and the lowest in the Boranja population (16.4%). The highest variability in height of two-year-old seedlings was determined in the Javor population (28.8%) and the lowest in the Goč population (17.8%).

Table 2. The analysis of variance (ANOVA) for the traits root collar diameter (d) and height (h) of one-year-old and two-year-old seedlings (the same letters associate populations with no statistically significant differences).

Population	Trait			
	One-year-old seedlings		Two-year-old seedlings	
	d (cm)	h (cm)	d (cm)	h (cm)
I	2.84[bc]	12.3[c]	3.31[ab]	22.6[ab]
II	2.83[bc]	14.5[d]	3.72[bc]	28.3[cd]
III	2.86[c]	13.1[c]	3.74[bc]	25.7[bc]
IV	2.81[bc]	13.0[c]	3.93[c]	30.0[d]
V	2.80[bc]	12.3[bc]	3.22[a]	21.2[a]
VI	2.70[bc]	11.8[bc]	3.99[c]	29.4[d]
VII	2.63[b]	11.3[ab]	3.59[bc]	24.6[bc]
VIII	2.39[a]	10.2[a]	3.51[ab]	24.5[bc]
P-value	0.0008	0.0000	0.0000	0.0000

Based on the obtained results of the analysis of variance (ANOVA), it can be concluded that statistically significant differences were found between the studied populations for the analysed morphological traits of seedlings (Table 2). Based on the results of the LSD test, no clear formation of homogeneity groups can be observed. When observing the two-year-old seedlings' traits, the Javor population stands out with the lowest values, while the populations of Dubašnica, Jastrebac and Fruška Gora form a homogeneity group with the highest values. On the other hand, the Mali Pek population stands out with the lowest measured values, while the populations of Fruška Gora and Goč form a homogeneity group that shows the highest values of the measured traits.

In order to determine the pattern in the variations of the studied traits between populations, we conducted the Pearson correlation coefficient between the average values of the populations and the climate and geographical variables of their origin stands (Table 3). Statistically significant correlations were determined in the morphological traits of one-year-old seedlings. The root collar diameter was significantly positively correlated with mean annual temperature (MAT) and negatively correlated with elevation (Elev), mean annual precipitation (MAP), mean summer precipitation (MSP), sum of degree-days <0°C (DD_0), sum of degree-days <18°C (DD_18), and precipitation as snow (PAS). Seedling height was negatively correlated with mean annual precipitation (MAP), mean summer precipitation (MSP), summer heat-to-moisture index (SHM), and climate moisture deficit (CMD).

The estimation of proximity, i.e., a distance of the studied populations based on measured morphometric seedling traits was conducted by applying cluster analysis.

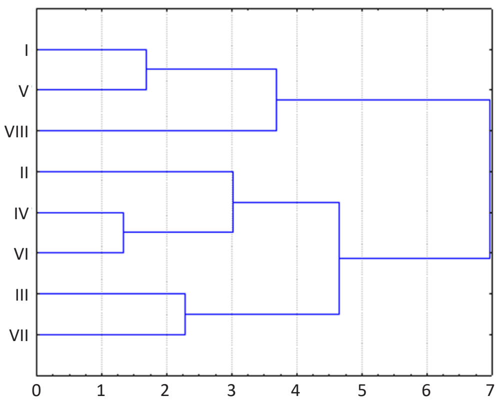

Figure 4. Cluster analysis for measured traits of seedlings.

The populations of Fruška Gora (IV) and Goč (VI), i.e., of Dubašnica (I) and Mali Pek (V) are at the smallest distance (Chart 1). There is no geographic connection or differentiation of the studied populations.

The quantitative traits of beech seedlings have not been extensively studied in Serbia to date. Reasons for the low interest lie primarily in the fact that beech stands are primarily restored naturally. However, in the last few decades, the problem of natural renewal has been more expressed and the necessity of assisted renewal has arisen. This is especially pronounced in the last few years, when natural stands decline over large areas due to changed environmental conditions. In order to ensure the survival of beech in its natural habitats, it is necessary to provide quality reproductive material that will be able to withstand increasing climate change and preserve genetic diversity in the future.

The obtained results indicate the existence of a significant level of variability of beech populations in Serbia, given the studied seedling traits (Figure 2, 3). The height of two-year-old seedlings was the most variable trait, while the one-year-old seedlings' root collar diameter proved to be the least variable. Observing the mean values of one-year-old seedlings' individual traits at the level of populations, the Jastrebac population stands out with the highest values and the Javor population with the lowest. When observing traits of the two-year-old seedlings, the populations of Goč and Fruška Gora stand out with the highest values, while the population of Mali Pek stands out with the lowest values of individual traits.

The results of the analysis of variance showed statistically significant differences caused by the population effect (Table 2). This indicates genetically determined differences of the quantitative traits of seedlings between the analysed populations.

The correlation analysis of average values of seedling traits with climate and geographical variables of populations, indicated the possibility of using seedlings' morphological traits as a tool to investigate the population

Table 3. Statistical significance (p-values) of Pearson's correlation coefficients between analyzed trait population means and climate (geographic) variables of their stands of origin (* - statistically significant correlations, p<0.05).

	One-year-old seedlings		Two-year-old seedlings	
	d	h	d	h
Lat	0.231	0.646	0.968	0.980
Long	0.803	0.859	0.135	0.236
Elev	0.032*	0.129	0.580	0.580
MAT	0.047*	0.145	0.401	0.448
MWMT	0.030*	0.140	0.817	0.719
MCMT	0.016*	0.121	0.936	0.885
TD	0.104	0.222	0.657	0.508
MAP	0.048*	0.025*	0.749	0.485
MSP	0.180	0.041*	0.558	0.262
AHM	0.052	0.059	0.802	0.552
SHM	0.080	0.042*	0.585	0.335
DD_0	0.009*	0.074	0.645	0.607
DD5	0.025*	0.122	0.779	0.676
DD_18	0.016*	0.097	0.732	0.651
DD18	0.085	0.227	0.852	0.711
NFFD	0.033*	0.223	0.981	0.973
bFFP	0.083	0.372	0.815	0.871
eFFP	0.082	0.357	0.682	0.745
FFP	0.081	0.363	0.760	0.819
PAS	0.007*	0.058	0.757	0.682
CMD	0.146	0.034*	0.387	0.165

Lat – latitude; Long – longitude; Elev – elevation; MAT – mean annual temperature; MWMT – mean July temperature; MCMT – mean January temperature; TD – continentality index; MAP – mean annual precipitation; MSP – mean summer precipitation; AHM – annual heat-to moisture index; SHM – summer heat-to-moisture index; DD_0 – sum of degree-days <0°C; DD5 – sum of degree-days >5°C; DD_18 – sum of degree-days <18°C; DD18 – sum of degree-days >18°C; NFFD – number of frost free days; bFFP – beginning of frost free period; eFFP – end of frost free period; PAS – precipitation as snow; CMD – climate moisture deficit.

variability pattern (Table 3). This research indicates an ecotypic population variability pattern, namely, the results of the correlation analysis discovered a pattern of clinal variability between populations associated with elevation and the correlated climatic variables of the original habitats. The established pattern indicates the genetic variability of populations, i.e. the possibility that populations were genetically differentiated through natural selection.

Several authors who conducted researches on some adaptive traits determined a clinal pattern of beech genetic variability (in the direction northwest-southeast) (von Wuehlisch et al. 1995, Nielsen and Jorgensen 2003, Gömöry et al. 2007, Ivanković et al. 2011). In other studies, an ecotypic (random) pattern of interpopulation variability was determined (Comps et al. 1991, Paule 1995, Gömöry et al. 1998, Chmura and Rozkowski 2002, Jazbec et al. 2007, Ivanković et al. 2008, Gavranović et al. 2018, Bogunović et al. 2020). In our research, the results are more in line with the ecotypic variability pattern, although for the conclusion on ecotypic genetic variability it is necessary to conduct additional research that would combine the results of the analysis of progeny tests with the data on ecological parameters of mother stands from which the analysed populations originate. The fact is that the progeny trial has been established in the seedling nursery where the growth conditions are optimal, namely, better than in their parent stands. Màtyàs et al. (2009) showed that genetic differences in height growth among populations were better detected in more stressful site conditions, i.e., they were more difficult to detect in favourable site conditions.

The importance of the proper choice of the reproductive material, along with the proper breeding interventions, is considered to be the main precondition for achieving the maximum benefit of forestry production (Kingswell 1998, Coello et al. 2013). However, the possibility of genetic differentiation of populations dictates the need for caution when choosing reproductive material for assisted reproduction. We believe that the results of our research can recommend the selection of beech seed stands in Serbia with regard to elevation.

CONCLUSIONS

The results confirming the existence of genetic differences among the studied populations were obtained by analysing the growth of beech seedlings during two growing seasons in the nursery test. The differences in height and diameter growth determined among populations indicate the ecotypic nature of beech genetic variability. The Javor population, which, according to the measured parameters, at the end of the first growing season lagged behind, showed significantly higher increment compared to other populations in the second growing season. The Goč and Fruška Gora populations stand out with the highest values of measurement parameters, while in the Dubašnica and Mali Pek populations the lowest values were measured for two-year-old seedlings. Bearing in mind the optimal conditions for seedling growth and development in the seedling nursery, the more distinct differences can be expected after moving seedlings to the field where more stressful environmental conditions occur. The determined variability of morphometric traits can be an indicator for further development of selected populations' seedlings. The conducted researches are important for the improvement of production technology and they recommend the transfer and use of beech forest reproductive material.

Author Contributions

VP and AL conceived and designed the research, VP and AL carried out the field measurements, VP conceptualization, methodology, investigation, performed statistical analyses, data curation, visualization results, LJR secured the research funding, supervised the research and helped to draft the manuscript, VP and AL writing and reviewing the final version of the manuscript, approved the submitted version.

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Conflicts of Interest

The authors declare no conflict of interest.

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Dani Sarsekova[1], Sezgin Ayan[2]*, Talgat Abzhanov[1]

(1) S. Seifullin Kazakh Agro Technical University, Department of Forest Resources and Forestry, Nur-Sultan Zhenis Avenue 62, KZ-010011 Astana, Kazakhstan; **(2)** Kastamonu University, Faculty of Forestry, Silviculture Department, Kuzeykent Campus, TR-37100 Kuzeykent, Kastamonu, Turkey

*** Correspondence:** e-mail: sezginayan@gmail.com

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The authors wish to make the correction of the paper of Sarsekova et al. (2020). In the original paper, there was a mistake in the order of the first and the second name of the author Talghat Abbzhabnov. The correct order is Talghat Abbzhabnov.

The original paper published on 11 May 2020 has been updated and both versions will be available on the paper webpage. The authors emphasize that this change does not affect the results of this research, and they apologize for any inconvenience this change may cause.

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