environmental sciences proceedings

MDPI

Proceedings

Spatial Structure of Uneven-Aged Stands of Fir and Beech on the Borja Mountain (Bosnia and Herzegovina)†

Vojislav Dukić[1]*, Danijela Petrović[1] and Goran Jović[2,]

[1] University of Banja Luka, Faculty of Forestry, Stepe Stepanovića 75a, 78000 Banja Luka, Bosnia and Herzegovina; vojislav.dukic@sf.unibl.org (V.D.); danijela.petrovic@sf.unibl.org (D.P.)
[2] Public Forest Enterprise „Forests of the Republic of Srpska“, Trg Republike Srpske 8/11, 78000 Banja Luka, Bosnia and Herzegovina; jovic1971@hotmail.com
* Correspondence: vojislav.dukic@sf.unibl.org;
† Presented at the title, place, and date.

Abstract: In the territory of Bosnia and Herzegovina, uneven-aged stands of fir and beech are very important from the economic and ecological point of view. A major practical lack of information on the simple structure of stands is that they cannot be used to draw valid conclusions about the spatial distribution of woody species, the position and dimensions of trees and this is one of the bases for sustainable management of mixed and uneven-aged forests. In four mixed uneven-aged fir and beech stands and one pure fir stand on the Borja mountain, the basic elements of tree growth were measured and the data needed to determine the indicators of the spatial stand structure were determined. According to the index of aggregation of Clark and Evans, when all trees are observed, on average there is a tendency towards a uniform spatial distribution of trees in the stand. When only fir trees were selected as reference trees, it is evident that there is a tendency to group fir trees in the stand. The diameter differentiation index shows that the average tree diameter differentiation is on all sample plots. The determined values of the Weber's height competition index by stands are approximately the same, ie it can be stated that there is no significant difference between stands in terms of competition between trees when it comes to vertical structure of stands.

Keywords: fir, beech, spatial stand structure, Borja, Bosnia and Herzegovina

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Proceedings* **2021**, 68, x. https://doi.org/10.3390/xxxxx

Published: date

1. Introduction

According to the forest inventory data in Bosnia and Herzegovina, the total area of forests and forest land is 3 231 000 ha. High forests with natural regeneration occupy more than 50% of the total forest area. The area of high forests with natural regeneration is dominated by deciduous forests with about 50% share, the share of mixed deciduous and coniferous forests is about 30% and the remaining 20% are coniferous forests [1]. In the mountain belt of Bosnia and Herzegovina, fir and beech form a community of beech-fir forests (Abieti fagetum) as one of the most important forest communities in this area.

Over the past decades, a large number of researchers of various profiles have pointed to the numerous ecological and economic advantages of mixed uneven-aged stands over pure even-aged stands. The advantages are primarily manifested in the more efficient use of habitat potential and space for growth, and greater stability and resilience of mixed uneven-aged stands. The orientation of modern forestry towards mixed and uneven-aged stands opens up numerous new unknowns about the growth characteristics of the tree species that make up the mixture and their mutual relations [2]. The most important systemic characteristic of mixed and uneven-aged forests, where growth conditions and growth flows are highly variable, is detailed structural determination [3]. Defining and analyzing structural indices that characterize the horizontal and vertical structure of stands are among the most important tasks in modern forestry research [4 - 9].

2. Materials and Methods

The research area is Mount Borja (Dinaric Massif), located between the rivers Velika and Mala Usora in the northern part of Bosnia and Herzegovina. On the mountain Borja, mixed stands of Silver fir (Abies alba Mill.) and European beech (Fagus sylvatica L.) predominate, and pure stands of Silver fir also appear. The required data were collected by setting up 5 sample plots (2500 m^2). In sample plots 1, 2 and 4, the presence of the association Rusco hypoglossi-Abietetum Brujić 2004 was determined, and in sample plots 3 and 5 Galio rotundifolii-Abietetum M. Wraber 1959. In addition to the survey of the basic elements of tree growth (diameter and height), the necessary data for determining the indicators of the spatial structure of the stand were determined. The investigated stands are managed by a system that is a combination of group selection system and single tree selection system, which results in a very heterogeneous state.

In this study, the spatial structure of stands is presented on the basis of the stand structure index and the Weber height competition index [10]. From the stand structure index, i.e. stand structure indicators, the following were calculated: Clark-Evans aggregation index [11] and diameter differentiation index [12,6].

3. Results and Discussion

Basic data on the elements of the structure of stands by sample plots are given in table 1. On sample plot 3 is a pure fir stand and on the other mixed stands of fir and beech. The number of trees per sample plots is in the range from 98 to 183, i.e. the number of fir trees is in the range from 50 to 151. The diameter of the arithmetic mean tree per section (d_q) for fir is in the range 22.8 cm to 39.3 cm and for beech in interval from 20.5 cm to 37.3 cm. The volume of wood mass (V) per sample area is in the range from 273.7 to 710.1 m^3/ha.

Table 1. Characteristics of sample plots.

Sample plots	n			d_q (cm)		h_L (m)		V (m^3 ha^{-1})		
	fir	**beech**	**total**	**fir**	**beech**	**fir**	**beech**	**fir**	**beech**	**total**
1	151	32	183	29,1	23,4	26,5	25,3	518,3	71,9	590,2
2	67	31	98	38,7	20,5	27,6	23,6	416,0	49,9	465,9
3	151	2	153	28,8	25,4	27,2	24,4	524,5	5,1	529,6
4	50	69	119	39,3	31,7	30,1	31,3	354,1	356,0	710,1
5	130	17	147	22,8	37,3	18,7	20,5	195,6	78,1	273,7

Note: n – number of trees on the sample plot, d_q – quadratic mean diameter, h_L – Lorey's mean height and V – wood volume per hectare

The Clark-Evans aggregation index "R", an indicator of stand structure, represents the ratio of the concrete and expected mean distance between the nearest neighboring trees. Two forms of competition were observed, in the first case all trees were taken as the main (reference) trees and in the second fir trees (Table 2). In the first form of competition (fir and beech - fir and beech) in the two stands there is a tendency towards the uniform of the spatial distribution, and in the other three the distribution of trees tends to a random distribution. In the second form of competition (fir and beech - fir) in the three stands there is a tendency towards the uniform of the spatial distribution, and in the other two the distribution of trees tends to a random distribution. In this first form of competition, when all trees (fir and beech) are taken as the main (reference) trees, with a random distribution on individual experimental surfaces, there is a tendency towards the uniform of the spatial distribution of trees in the stand. In the second case, only fir trees were selected as the main (reference) trees. In this form of competition, lower values of calculated indices are evident. In the first form of competition (fir - fir and beech) in three stands there is a tendency towards grouping of trees, and from the remaining two stands in one there is a tendency towards uniform of spatial distribution, and in the other towards random distribution. In the second form of competition (fir - fir) in the three stands there is a clear tendency to group trees, and in the other two stands the distribution of trees is completely random. On average, in this case when only fir trees were taken as the main (reference) trees, with a random distribution on individual experimental areas, there is a tendency to group fir trees in the stand. Compared to the previous case of competition, there is a higher coefficient of variation of the determined indices per sample area.

According to Lafond et al. [13] individual selection of trees for felling led to a random or uniform distribution of trees, while group selection of trees for felling (formation of groups) enabled greater grouping of trees in space. Vacek [14] analyzed the structure of natural mixed forests (spruce - beech - fir) in the nature reserve Orlické hory Mts. Of the four permanent sample plots, only one has a tendency to group trees. In mixed old forests (spruce-fir-beech) in the Western Carpathians, based on the value of the aggregation index, Parobekova et al. [15] determined a random arrangement of trees in all layers by stages of development: initial (1.03), optimal (1.08) and terminal (1.05).

Table 2. The index of aggregation of Clark and Evans.

Sample	**fir and beech**		**fir**	
plots	**fir and beech**	**fir**	**fir and beech**	**fir**
1	1,253	1,293	1,104	1,044
2	1,121	1,082	0,861	0,746
3	1,057	1,051	1,044	1,044
4	1,063	1,238	0,806	0,599
5	0,980	0,966	0,880	0,842
Mean	1,095	1,126	0,939	0,855
SD	0,102	0,136	0,128	0,193
$CV_{(\%)}$	9	12	14	23

Note: Mean - arithmetic mean; SD - standard deviation; $CV_{(\%)}$ - coefficient of variation

In order to more fully define the stand structure, it is necessary to analyze the differences in the dimensions of trees and their immediate neighbors. For this purpose, the diameter differentiation index (T_d) was determined. All trees (fir and beech) were selected as the main (reference) trees for which the diameter differentiation index was calculated. The form of competition was observed: fir and beech - fir and beech. The average value of the index based on the differentiation of the diameters of the two observed trees (reference tree and the first neighbor) by the sample plots is in the range from 0.381 to 0.479. The mean value of the diameter differentiation index of all five sample plots is 0.442. This practically means that, on average, a randomly selected tree and its immediate neighboring tree are in such a relationship that the diameter of a thinner tree is 56% of the diameter of a thicker tree. We can state that in all cases the average differentiation of tree diameters according to Pommerening [8]. In order to gain the most realistic real idea of the level of diversity of tree diameters, the (T_{d3}) index (difference in diameters between the reference tree and its three closest neighbors) was determined. The size of the (T_{d3}) index at the stand level is in the range from 0.355 to 0.470. The mean value of the diameter differentiation index of all five sample plots is 0.423. These are approximately the same values as the values obtained on the basis of the reference tree and the first neighbor, with the variation of the determined individual values by stands, expressed by the coefficient of variation, being significantly less.

Table 3. The diameter differentiation index.

Sample plots	**n**	**Mean**	**Min**	**Max**	**CV(%)**	**Mean**	**Min**	**Max**	**CV(%)**
		T_{d1}				**T_{d3}**			
1	183	0,478	0,021	0,837	49	0,449	0,098	0,830	31
2	98	0,479	0,011	0,880	52	0,470	0,178	0,790	31
3	153	0,430	0,019	0,848	58	0,405	0,076	0,828	40
4	119	0,381	0,002	0,792	59	0,355	0,063	0,791	43
5	147	0,442	0,003	0,845	47	0,434	0,116	0,751	29
total	700	0,442	0,002	0,880	53	0,423	0,063	0,830	36

Vacek [14], analyzing the structure of natural mixed forests (spruce, beech and fir) in the nature reserve Orlické hory Mts on four permanent sample plots, determined the values of the diameter differentiation index (0.415; 0.428; 0.474 and 0.549) which are slightly higher than obtained in this study. In mixed old forests (spruce-fir-beech) in the Western Carpathians, Parobekova et al. [15] determined the values of the differentiation index by stages of development: initial (0.55), optimal (0.50) and terminal (0.56). The stated values are higher than those obtained in this study, i.e. the differentiation of tree diameters is higher. Analysis of variance and Duncan's test showed that two homogeneous groups can be formed when it comes to (T_{d1}) and three homogeneous groups when it comes to (T_{d3}), i.e. greater differentiation is evident when looking at the reference tree and its three closest neighbors (Table 5).

Analyzes that provide a detailed insight into the vertical structure of stands are important. One of the parameters that allows this is the Weber's height competition index (CI). The index is equal to zero when all competing trees are higher than the observed tree, i.e. it is equal to one when all competing trees are lower than the observed tree. Therefore, higher values of the index mean that the observed tree has greater competitive power, i.e. less competition in its environment. In the first variant (form of competition: fir - fir and beech), the determined average values of the Weber's height competition index per sample plot are in the range from 0.467 to 0.550, i.e. the average for trees from all sample plots is 0.486. In the second variant (form of competition: fir and beech - fir and beech), the determined average values of the Weber height index per sample plot are in the range from 0.474 to 0.508, i.e. the average for trees from all sample plots is 0.487 (Table 4). The determined values of the Weber's height competition index by stands are approximately the same, i.e. it can be stated based on the analysis of variance (Table 5) that, based on this index, there is no statistically significant difference between stands in terms of competition between trees when it comes to vertical stand structure.

Table 4. Weber's height competition index - CI.

Sample plots	**fir - fir and beech**				**fir and beech - fir and beech**			
	n	**Mean**	**SD**	**CV(%)**	**n**	**Mean**	**SD**	**CV(%)**
1	151	0,472	0,356	75	183	0,474	0,353	75
2	67	0,550	0,359	65	98	0,488	0,360	74
3	151	0,487	0,342	70	153	0,486	0,341	70
4	50	0,467	0,340	73	119	0,484	0,349	72
5	130	0,474	0,354	75	147	0,508	0,356	70
total	549	0,486	0,350	72	700	0,487	0,350	72

Table 5. Analysis of variance - The diameter differentiation index and Weber's height competition index.

Index	Sample plots					ANOVA		
	1	**2**	**3**	**4**	**5**	***F***	***p***	**n**
T_{d1}	0.478^{a}	0.479^{a}	$0.430^{a,b}$	0.381^{b}	0.442^{a}	3,611	0,0064	2
T_{d3}	0.449^{a}	0.470^{a}	0.405^{b}	0.355^{c}	$0.434^{a,b}$	10,113	0,0000	3
CI (fir)	0.472^{a}	0.550^{a}	0.487^{a}	0.467^{a}	0.474^{a}	0,6215	0,6474	1
CI (fir and beech)	$0,474^{a}$	$0,488^{a}$	$0,486^{a}$	$0,484^{a}$	$0,508^{a}$	0,1740	0,9520	1

n - number of homogeneous groups by Duncan's test (α = 0.05)

a, b, and c – tags for homogeneous groups

4. Conclusions

In the mountain belt of Bosnia and Herzegovina, fir and beech form a community of beech-fir forests (Abieti fagetum) as one of the most important forest communities in this area. The investigated uneven-aged, mixed stands are managed by a system that is a combination of group selection system and single tree selection system, which results in a very heterogeneous state. Clark-Evans aggregation index, when all trees (fir and beech) were taken as the main (reference) trees, shows that on average there is a tendency towards uniform of spatial distribution of trees in the stand, and when only fir trees are taken as the main (reference) trees, there is a tendency towards grouping of fir trees in the stand and greater variation of index values by sample plots.

The diameter differentiation index, based on one and also the three nearest neighboring trees, shows that the average tree diameter differentiation is on all experimental surfaces. It was also determined that there are statistically significant differences between individual sample plots in terms of tree diameter differentiation.

The determined values of the Weber height competition index by stands are approximately the same, i.e. it can be stated that there is no significant difference between stands in terms of competition between trees when it comes to the vertical structure of stands.

Author Contributions: Conceived and designed the research: G.J., V.D.; carried out the field measurements: G.J.; processed the data and performed the statistical analysis: G.J., D.P.; writing—original draft: V.D.; writing—review and editing: D.P., G.J. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Čabaravdić, A.; Dundjer, A.; Avdagić, A.; Delić, S.; Osmanović, M.; Mraković, A. 2016 Bosnia and Herzegovina. In *National Forest Inventories*; Vidal C, Alberdi I, Hernández Mateo L, Redmond J., Eds.; Springer International Publishing. New York, USA, **2016**; pp. 181 – 196.
2. Vučković, M.; Stajić, B. Zadaci i značaj istraživanja rasta i proizvodnosti šuma za ekologiju i šumarstvo. *Glasnik Šumarskog fakulteta u Banjoj Luci*, **2004**, 1, 15-35.
3. Pretzsch, H. Analysis of modeling of spatial stand structures: Methodological considerations based on mixed beach-larch in Lower Saxony. *Forest Ecology and Management* **1997**, 97, 237-253.
4. Wenk, G.; Antanaitis, V.; Šmelko, Š. Waldertragslehre. Deutscher Landwirtschaftsverlag Berlin, Germany, **1990**; pp. 448
5. Pretzsch H., Konzeption einer modellorientierten Mischbestandforschung, Deutscher Verband Forstlicher Forschungsanstalten, Germany, **1991**, 1-20.
6. Füldner, K. Strukturbeschreibung von Buchen-Edellaubholz-Mischwäldern. Dissertation, Institut für Forsteinrichtung und Ertragskunde der Universität Göttingen, **1995**.
7. Gadow, K.v.; Hyi, G.Y.; Albert, M. Das Winkelmaß – ein Strukturparameter zur Beschreibung der Individualverteilung in Waldbeständen. *Centralblatt für das gesamte Forstwesen* 115. **1998**, 1, 1-10.
8. Pommerening, A. Approaches to quantifying forest structures. *Forestry* **2002**, 75, 305-324, doi:10.1093/forestry/75.3.305.

9. Pommerening, A. Evaluating structural indices by reversing forest structural analysis. *Forest Ecology and Management* **2006**, 224, 266-267, doi:10.1016/j.foreco.2005.12.039.
10. Weber, P.; Bugmann, H.; Fonti, P.; Rigling, A. Using a retrospective dynamic competition index to reconstruct forest succession. *Forest Ecology and Management* **2008**, 254, 96-106, doi:10.1016/j.foreco.2007.07.031.
11. Clark, P.J.; Evans, F.C. Distance to nearest neighbour as a measure of spatial relationships in populations. *Ecology* **1954**, 35, 445–453.
12. Gadow, V. K. Zur Bestandesbeschreibung in der Forsteinrichtung. *Forst und Holz*. **1993**, 48, 602-606.
13. Lafond, V.; Lagarrigues, G.; Cordonnier, T.; Courbaud, B. Uneven-aged management options to promote forest resilience for climate change adaptation: effects of group selection and harvesting intensity. *Annals of Forest Science* **2014**, 71, 173–186, doi:10.1007/s13595-013-0291-y.
14. Vacek, Z. 2017 Structure and dynamics of spruce-beech-fir forests in Nature Reserves of the Orlické hory Mts. in relation to ungulate game. *Central European Forestry Journal* **2017**, 63, 23–34, doi:10.1515/forj-2017-0006.
15. Parobeková, Z.; Pittner, J.; Kucbel, S.; Saniga, M.; Filípek, M.; Sedmáková, D.; Vencurik, J.; Jaloviar, P. Structural Diversity in a Mixed Spruce-Fir-Beech Old-Growth Forest Remnant of the Western Carpathians. *Forests* **2018**, 9(7), 379, doi:10.3390/f9070379.