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TREE SPECIES DIVERSITY IN THE STANDS OF BEECH AND VALUABLE BROADLEAVES IN THE AREA OF THE NP `DJERDAP`

Branko Stajic

University of Belgrade, Faculty of Forestry, Belgrade, SERBIA

branko.stajic@sfb.bg.ac.rs

ABSTRACT

The tree species diversity in mixed stands of beech and valuable broadleaves was researched in the area of the National Park `Djerdap` on fifteen sample plots (total study area of about 5 ha). For this purpose, the following diversity measures were applied: (1) Shannon`s index H', (2) Simpson`s index (Simpson 1949), (3) McIntosh`s diversity index D' (McIntosh 1967), (4) Hill's N1 diversity number, (5) Hill's N2 diversity number and (6) Hill's E5 index. The results showed that the tree species diversity in the study forest stands didn't depend significantly on the type of the index applied to measure diversity.

INTRODUCTION

Among numerous and diversified natural resources and outstanding beauty of the NP `Djerdap`, mixed, even-aged and uneven-aged stands of beech and valuable broadleaves attract special expert and scientific attention. Apart from economic `benefits` (high potential value and quantity of wood and biomass, rapid growth and early attainment of usable dimensions), there are great aesthetic values, high degree of resistance and stability to harmful effects of various abiotic and biotic factors that, according to Drachenfels *et al*. (1984), classify these forests as European forest communities that are the richest in tree species (Stajić 2010, Stajić, Vučković 2012). As such, these stands are of immense importance in studying and quantifying the diversity of tree species and stand structure and represent a constant focus of interest of various scientists.

In the early stages of studying and quantifying diversity, some researchers equated the concepts of *species richness* and *species diversity* or at least considered *species richness* to be one of several measures of diversity (Hulbert 1971). However, a forest stand which has a large number of tree species can be characterized by lower species diversity if the secondary species are unevenly distributed, compared to a stand which has a smaller number of tree species but its individuals are evenly distributed among the species. Therefore, in order to make an accurate assessment of species diversity, it is necessary to apply those diversity indices that account for both *species richness* and *evenness*, or the number of individuals per species. Considering the above, the aim of this

study was to use different measures of diversity to find the level of diversity of tree species in mixed stands of beech and valuable broadleaves in the National Park `Djerdap`.

MATERIAL AND METHODS

The study used the data and results by Stajić (2010) as starting material. The stands are located on the territory of the National Park `Djerdap` (north-eastern Serbia). The size of 15 sample plots ranges from 0.25 to 0.45 ha, and the total research area covers about 5 ha. The average number of trees per ha is as follows: 621 (EUa), 401 (EUb), 309 (EUc) and 570 (EUd). The average basal area per ha is: 37. 4 m^2 (EUa), 34.9 m^2 (EUb), 37.3 m^2 (EUc) and 27.9 m^2 (EUd), while the average volume per ha amounts to: 453 m^3 (EUa), 431 m^3 (EUb), 494 m^3 (EUc) and 298 m^3 (EUd). Visual assessment of tree size structure and stand physical appearance reveals that the stands of EUa and EUd are closest to uneven-aged forests and the stands of EUb and EUc to even-aged. The sites belong to the syntaxonomic units *Corylo colurnae-Fagetum*, sub-associations *aceretosum* (EUa – 4 stands) and *typicum* (EUd - 3 stands) and *Fagetum moesiacae montanum*, sub-association *aceretosum* (EUc - 4 stands).

Quantification of tree species diversity was carried out using (1) Shannon`s diversity index H' (Pielou 1977), (2) Simpson`s diversity index λ (Simpson 1949), (3) McIntosh`s diversity index D' (McIntosh 1967), (4) Hill's N1 diversity number (index), (5) Hill's N2 diversity number (index) and (6) Hill's E5 index (Hill 1973). In order to facilitate the analysis and interpretation of the results as well as the comparison of the aforementioned diversity indices (the higher the index size – the greater the diversity), Simpson`s diversity index was further calculated by the equation given by De Jong (1975), Swind *et al*. (1991) and Neumann and Starlinger (2001) and designated λ^*.

RESULTS AND DISCUSSION

Despite certain difficulties and ambiguities related to the calculation of diversity by means of diversity indices, as described by Hulbert (1971), Alatalo (1981), Ludwig and Reynolds (1988), Gove *et al.* (1994), these indices are often applied in ecology, biology and forestry. There are plenty of diversity indices (Hill 1973, Peet 1974, Ludwig, Reynolds 1988).

The size of H' taken as the proportion of each species relative to the number of individual trees (H'_N) ranges from 0.57 to 1.91 (Table 1). The highest value of H'_N was recorded on SP6 where the presence of 11 tree species was determined. However, the size of the index depends not only on the number of species present, but also on their relative proportion in the total number of trees. Thus, for instance the lowest value of H'_N was determined on SP1, which wasn't the plot with the smallest number of tree species. This indicates that the sample plots with a smaller number of species (SP9, SP11 and SP12) have a far evener distribution of secondary species compared to SP1. The fact that the same size of H'_N may be the result of different combinations of species number and their relative proportion is clearly shown in the case of SP12 and SP15. In fact, almost the same size of H'_N (0.93 to 0.95) was determined on the sample plots with 5 (SP12) and 10 (SP15) tree species present.

The highest value of H' per number of trees calculated for different ecological units was recorded in EUb (averagely 1.73), and the lowest in EUa (averagely 0.80). For the purpose of comparing the level of species diversity determined on the basis of H'_N in this research with the results of Fuldner's (1995) research conducted in the mixed forests of beech and valuable broadleaves in the area of Niedersachsen in the Federal Republic of Germany, the size of H' relative to the number of trees was calculated both using the natural and the common logarithm. The values of H'_N calculated using the common logarithm range from 0.25 (SP1) to 0.83 (SP6), while they amount from 0.20 to 0.35 in Fuldner`s research. The results point to a far more pronounced diversity of tree species in the NP `Djerdap` compared to the stands on the territory of Niedersashsen.

With the indices that are based on the relative proportion of species (p_i), p_i may refer to different elements of stand growth, such as number of trees, basal area, volume, crown size, canopy cover (Swindel *et al.* 1991, Füldner 1995, Stajić, Vučković 2005, Sterba, Zingg 2006...). This method of quantifying diversity is considered somehow more appropriate and comprehensive by numerous authors, as diversity quantification includes the real dimensions of trees and shows their impact on not only the diversity and abundance of the young growth, ground flora, and accompanying wildlife, but also on the stability and performance of forest ecosystems. Therefore, in addition to the relative proportion of tree species in the total number of trees (H'_N), H' was calculated as the proportion of tree species in the total basal area (H'_G) and in the total stand volume (H'_V) - Table 1. At the level of sample plots, the highest values of H'_G and H'_V were found on SP7 (H'_G = 1.74, H'_V = 1.60), and the lowest on SP1 (H'_G = 0.56, H'_V = 0.50). At the level of ecological units, the highest diversity expressed through H'_G and H'_V was found in EUb (H'_G averaged 1.57 and H'_V 1.44) and the lowest in EUa (H'_G averaged 0.71, H'_V 0.63).

Table 1. Number of tree species (S) and diversity indices (H'_N, H'_G, H'_V, λ_N, λ_G, λ_V, λ^*_N, λ^*_G и λ^*, D', N1, N2 and E5) per sample plots and ecological units.

	Sample plots														
	Ecological unit EUa				***Ecological unit EUb***				***Ecological unit EUc***				***Ecological unit EUd***		
	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10	SP11	SP12	SP13	SP14	SP15
S	7	11	7	7	9	11	9	8	5	7	6	5	10	10	10
H'_N	0,57	0,98	0,85	0,78	1,51	1,91	1,84	1,66	0,91	1,22	1,26	0,93	1,33	0,83	0,95
H'_G	0,56	0,90	0,68	0,68	1,36	1,70	1,74	1,46	0,90	0,86	1,21	0,91	1,34	1,06	1,02
H'_V	0,50	0,82	0,63	0,58	1,26	1,59	1,60	1,31	0,80	0,73	1,09	0,79	1,28	1,05	1,00
λ_N	0,76	0,56	0,62	0,66	0,30	0,19	0,19	0,22	0,51	0,39	0,35	0,51	0,42	0,65	0,61
λ_G	0,77	0,61	0,70	0,72	0,35	0,24	0,23	0,32	0,54	0,58	0,40	0,55	0,38	0,50	0,54
λ_V	0,80	0,65	0,70	0,76	0,40	0,28	0,29	0,39	0,61	0,65	0,47	0,61	0,40	0,50	0,55
λ^*_N	0,24	0,44	0,38	0,34	0,70	0,81	0,81	0,78	0,49	0,61	0,65	0,49	0,58	0,35	0,39
λ^*_G	0,23	0,39	0,30	0,28	0,65	0,76	0,77	0,68	0,46	0,42	0,60	0,45	0,62	0,50	0,46
λ^*_V	0,20	0,35	0,30	0,24	0,60	0,72	0,71	0,61	0,39	0,35	0,53	0,39	0,60	0,50	0,45
D'	0,13	0,26	0,23	0,20	0,49	0,63	0,62	0,59	0,32	0,42	0,45	0,32	0,37	0,21	0,24
N1	1,76	2,69	2,35	2,18	4,53	6,73	6,29	5,25	2,48	3,38	3,53	2,55	3,77	2,30	2,57
N2	1,31	1,78	1,60	1,51	3,30	5,40	5,16	4,56	1,96	2,58	2,83	1,97	2,37	1,53	1,65
E	0,29	0,41	0,44	0,40	0,69	0,79	0,84	0,80	0,56	0,63	0,70	0,58	0,58	0,36	0,41
E5	0,41	0,46	0,45	0,43	0,65	0,77	0,79	0,84	0,56	0,67	0,72	0,62	0,50	0,41	0,41

Comparing the sizes of $H'_{N,}$ H'_G and $H'_{V,}$ we can see that the species diversity calculated on the basis of the number of trees is greater than the diversity based on the basal area or volume in all stands and ecological units, except in EUd. In this ecological unit, the size of H'_N is approximately the same (SP13) or even smaller (SP14 and SP15) than the size of H'_G and H'_V. The results can be explained by the fact that the beech, as the most common tree species, has a stronger participation in the total basal area and volume of EUa, EUb and EUc stands than in the total number of trees. The relations between the beech and the secondary species in terms of abundance are more favourable within EUd, since it dominates other secondary species in number, but not in size. In the case of ranking sample plots according to the lowest level of diversity, the differences between $H'_{N,}$ H'_G and H'_V were not determined, because all three variants of H' found the lowest level of diversity on SP1.

Simpson diversity index is the measure of diversity less sensitive to rare species than H'. The results of this research show that the level of diversity determined by λ^* is not substantially different from the level of diversity determined by H'. The greatest diversity calculated by λ^*_N (number of trees) was determined, as in the case of H'_N on SP 6 (0.81) and the smallest on SP 1 (0.24). At the level of ecological units, the highest diversity was found on the sample plots of EUb (on average λ^*_N was 0.78), and the smallest on the sample plots of EUa (on average λ^*_N was 0.35).

Apart from the relative proportion of each tree species in the total number of trees ($\lambda_{N,}$ λ^*_N), both variants of Simpson`s index were further calculated as the proportion of individual species in the total basal area ($\lambda_{G,}$ λ^*_G)) and the total stand volume ($\lambda_{V,}$ λ^*_V – Table 1). Comparing the values of λ^*_N, λ^*_G and λ^*, we can conclude that, similarly to H', the level of tree species diversity calculated by the number of trees is greater than the level of species diversity calculated by the basal area or volume in all stands and ecological units, except in EUd. In this ecological unit, the values of λ^*_N are smaller than the values of λ^*_G and λ^*_V. There is no difference in ranking sample plots and ecological units by the level of diversity when the species diversity is calculated by λ^*_G and λ^*_V from the one based on λ^*_N. In other words, the greatest diversity was recorded on SP6 and within EUb, and the smallest on SP1 and within EUa.

Since McIntosh diversity index D' (McIntosh 1967) takes into account the number of individuals per species and the total number of individuals, the calculation of D' within the framework of this research was carried out only by the number of trees. The size of D' ranges between 0.13 and 0.63 (Table 1). The highest value of D' was recorded on SP6, and the lowest on SP1. Regarding ecological units, the highest average value of D' was recorded within EUb (averagely 0.58), and lowest within EUa (averagely 0.21).

Ludwig and Reynolds (1988) indicate that the quantification of diversity using the so-called Hill's diversity numbers (Hill 1973) provides results which are much easier to interpret. Therefore, we further defined the level of diversity on the basis of N1 and N2 diversity numbers (Table 1). According to Hill (1973), N1 is *the number of abundant species*, *i.e*. the species with a large relative proportion. Compared to H', the measure of N1 gives the number of species that would, if each were equally common, produce the same H' as sample (Ludwig, Reynolds 1988). . The values of N1 range from 1.76 (SP1) to 6.73 (SP6) at the level of sample plots, while they average between 2.25 (EUa) and

5.70 (EUb) at the level of ecological units. The results indicate that the greatest diversity, quantified by this measure, was determined within EUb, which again had the greatest number of abundant, dominant species whose individuals are evenly distributed among species. On the other hand, the small value of N1 in EUa can be explained by the fact that this ecological unit has on average only 2.25 abundant and evenly distributed tree species, whose abundance is much greater compared to other secondary tree species.

N2 index refers to the number of very abundant species (Hill 1973). N2 values range from 1.31 (SP1) to 5.40 (SP6), and averagely 1.55 (EUa) to 3.84 (EUb) for different ecological units - Table 1. The results show that there are no differences in terms of ranking sample plots and ecological units using N1 or N2. It is also obvious that much smaller diversity within EUa compared to EUb, results from the fact that EUa has on average 1.55 abundant tree species, while EUb has 3.55. Therefore, the existing relations between very abundant and remaining secondary species within EUa in terms of their relative proportion contributed to the lowest average distribution of species and thus to the lowest diversity of this ecological unit compared to the others.

E5-evenness (equitability) indices, which are in the available literature generally classified as diversity indices, were also used to characterize the level of diversity in this paper. E5 is a more appropriate than other indices of evenness, since it is less affected by the number of species (Ludwig and Reynolds, 1988). At the level of sample plots, the values of E5 range from 0.41 (SP1, SP14, SP15) to 0.84 (SP8), and 0.44 (EUa) to 0.65 (EUb) for ecological units.

Table 2. Correlation coefficients between different measures of diversity ($\alpha = 0.01$)

	H'_N	H'_G	H'_V	λ_N	λ_G	λ_V	λ^*_N	λ^*_G	λ^*_V	D'	N1	N2	E5
H'_N	1.00												
H'_G	0.94	1.00											
H'_V	0.91	0.99	1.00										
λ_N	-0.97	-0.89	-0.84	1.00									
λ_G	-0.93	-0.99	-0.98	0.91	1.00								
λ_V	-0.90	-0.99	-0.99	0.86	0.99	1.00							
λ^*_N	0.97	0.89	0.84	-1.00	-0.91	-0.86	1.00						
λ^*_G	0.93	0.99	0.98	-0.91	-1.00	-0.99	0.91	1.00					
λ^*_V	0.90	0.99	0.99	-0.86	-0.99	-1.00	0.86	0.99	1.00				
D'	0.98	0.90	0.85	-0.99	-0.91	-0.85	0.99	0.91	0.85	1.00			
N1	0.99	0.93	0.90	-0.94	-0.90	-0.88	0.94	0.90	0.88	0.95	1.00		
N2	0.96	0.90	0.86	-0.93	-0.87	-0.84	0.93	0.87	0.84	0.96	0.99	1.00	
E5	0.86	0.75	0.68	-0.94	-0.78	-0.70	0.94	0.78	0.70	0.95	0.84	0.89	1.00

Correlation analysis was conducted in order to test the interdependence of the diversity indices applied to assess the level of species diversity. The results are presented in Table 2. All the correlations between the applied indices of tree species diversity were

highly significant, at the 0.01 level of significance. A negative correlation, due to the nature of the indices and their mutual relations, was established between the two variants of Simpson`s index ($\lambda_N$, $\lambda_G$, $\lambda_V$, on the one hand and $\lambda^*_N$, $\lambda^*_G$ and $\lambda^*$, on the other), as well as between Shannon`s index (H'_N, H'_G and H'_V) and Simpson index (λ_N, λ_G, λ_V). Furthermore, λ had a negative correlation with D', N1, N2 and E5.

CONCLUSIONS

In general, the measurement and quantification of different elements of diversity in the forestry in our country has often been conducted using in some aspects inadequate and too general methodology and equating diversity with the number of woody plants, herbaceous species, plant communities or soil types. However, the number of species is largely dependent on the sample size. The larger the sample, the greater the number of species, since such samples are more likely to include some rare species. In addition, diversity refers not only to the number of species within a population of a specific area, but also to the way individuals of each species are distributed in the population. In principle, the methodology of diversity assessment depends on the time and money available to carry it out, desired level of the quantification accuracy and may also vary depending on the goal to be achieved. In this study, species diversity in the study stands was determined using diversity indices.

Based on the above, it can be concluded that in terms of ranking sample plots and ecological units by the level of diversity there are no significant differences if diversity is determined using different indices of diversity. Out of the total of 13 diversity indices used, 8 indices (H'_N, λ_N, λ_V, λ^*_N, λ^*, D', N1, N2) found the largest level of diversity on SP6, while all 13 diversity indices used in this study measured the lowest diversity on SP1. At the level of ecological units, all the indices measured the highest species diversity in EUb, and the lowest in EUa. The results show that there is high correlation among different measures (indices) of diversity, which proves that the assessment of the level of diversity and the ranking of the study stands and ecological units did not depend much on the applied methods and measures of diversity.

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