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STRUCTURE AND STOCKING CONTROL OF UNEVEN-AGED CONIFEROUS STANDS IN BULGARIA

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Abstract

This paper presents results of a study on the stand structure and some stocking control approaches of uneven-aged coniferous stands. The even-aged forest management prevails in silvicultural practices in Bulgarian forestry. Uneven-aged silviculture started in the early 1930s when the Biolley control method has been applied in the forest management plan of 'Chamkoria' forest. There is relatively little knowledge of uneven-aged forest management compared to a large amount of forest research related to even-aged one. The stand structure of uneven-aged stands is described by diameter distribution and normal, exponential and Weibull distributions have been tested for fit. The optimal distribution of trees by diameter classes (14–18 cm, 22–38 cm, above 42 cm) is calculated for stands with exponential and Weibull distribution.

Key words: exponential distribution, Gini index, normal distribution, Norway spruce, Silver fir, Weibull distribution.

Introduction

The uneven-aged forest management in Bulgaria started in 1924 (Rafailov 2003) when in the then definitive forest management plan of the 'Chamkoria' municipal forest the separation of 2 management units was envisaged, for one of which (200 ha) a selection system with a 40-year rotation period was planned to be introduced. In the definitive forest management plan (DFMP) of the same forest from 1936, the uneven-aged management was planned to be carried out on an area of 1325.41 ha, using the control method, and another 218.93 ha had to be selected for selection segments, the amount of use of which to be tailored to 'recreational needs at any given time' (cit. DFMP).

Due to the lack of regional data on the structure of the stands and the optimal growing stock, data from Switzerland were adopted. The following diameter classes were proposed: small – 14–24 cm, medium – 26–40 cm and large – over 40 cm, with a stock ratio of 20:30:50 % respectively.

The application of the control method has been interrupted in 1952, and this required the development of new methods for the management of these forests. Nedyalkov (1963, 1965a,b) grouped the stands at three levels of productivity at equal ratio of tree number and stocks by diameter classes (40:50:10 % and 15:50:35 %).

In clarifying the questions regarding the distribution of the trees by diameter classes, different approaches have been developed over the years.

Among the most widespread distribution models are the negative exponential distribution (Meyer 1953, Leak 1965, Alexander and Edminster 1977, Murphy and Farrar 1981, Cancino and von Gadow 2002, Gül et al. 2005, Westphal et al. 2006), Weibull distribution (Stiff 1979, Martin 1982, Khatouri and Denis 1990, Gove and Fairweather 1992, Zhang and Liu 2006) and the Beta distribution (Zöhrer 1969, 1970; Loetsch et al. 1973; Larsary et al. 2016).

The negative exponential diameter distribution has an advantage due to its comparative simplicity and its widespread practical application in the management of the uneven-aged forests, whereas the Weibull distribution is characterized by its versatility and ability to describe a variety of different biological models.

Various methods for describing the diameter distribution are also known in the literature provided that the basal area is adopted in advance (Leak 1964, Moser 1976, Cancino and von Gadow 2002). The approach of Cancino and von Gadow (2002) is appropriate for determining the annual allowable cut for the uneven-aged forest when a pre-determined balanced exponential distribution is established.

The ideal diameter distribution could be described (Meyer 1953) using the smallest diameter (d_{min}), the target diameter (d_t), the coefficient q, the target basal area (B) and the number of trees with the target diameter (N_1).

According to Kerr (2014), the publication of de Liocourt of 1898 has been misunderstood and incorrectly quoted. The most common error is that in this case the Silver fir stands that are managed under the selection system have a diameter distribution with a constant value of q, and according to Kerr (2014), none of the distributions have a constant value of q. Picard and Gasparotto (2016), revising the original publication of de Liocourt of 1898, conclude that nothing is said about a geometric sequence for reducing the number of trees from small to large diameter classes, and in fact the publication concerns only a polynomial of 4th degree. Thus, the well-known common ratio of the geometric sequence has been described in 1900 by de Liocourt (1900) (according to Picard and Gasparotto 2016) and the average ratio was1.4.

One of the main considerations for the management of multi-aged forest stands is to achieve sustainability in terms of productivity and forest structure. The objective is to maintain a sustainable horizontal and vertical structure in each subsequent rotation period (cutting cycle) while maintaining the constant target stock.

One of the most popular methods for the management of uneven-aged stands is the BDq method (O'Hara 2002, Rafailov 2003, Trasobares and Pukkala 2004). It is believed (Kerr 2014), that it has been first applied in the northern hardwood forests of the eastern side of North America by Meyer and Stevenson (1943) (cit. by Kerr 2014). The B defines a basal area, the D is the target diameter at breast height and q is the common ratio of geometric series of the number of trees by diameter classes.

The change in the value of 'B' allows foresters to increase or decrease the growing stock of the stands. At the same value of q, the increase in B will result in an increase in the number of trees by diameter classes and hence an increase in the stock. The target diameter can also be changed and will accordingly affect the value of the basal area.

The value of the coefficient q does

not have a biological meaning, and it is not sufficient for determining the density of individual forest stands and what type of cuttings to plan. Managing of uneven-aged forests is a complex task, which, except the balanced structure of diameter and different treatment for individual tree species in the stand composition, includes also the issue what diameter classes will be harvested.

Maintaining the diameter distributions by changing the *q* values will result in a different number of trees in small and large diameter classes, and hence in the density and area available for the individual trees. Ideally, only the trees that exceed the ideal distribution should be cut. In practice, the shortage of trees at certain diameter classes will lead to deviations in the use of adjacent classes.

The disadvantage of this method is that it cannot be used for cases when uneven-sized forest stands are concerned which however are not uneven balanced. With the adoption of the negative exponential distribution, trees can be cut without considering the rate of growth and the individual characteristics of the stands.

Stand density index (*SDI*) has been developed by Reineke (1933) as a measure of relative density for even-aged stands. There is a linear relationship between the logarithm of the number of trees (*N*) and the logarithm of quadratic mean diameter for even-aged stands at maximum stand density.

For uneven-aged stands *SDI* has been proposed by Long and Daniel (1990) using individual tree diameters – equation (1) or diameter classes – equation (2) and the number of trees represented by the tree or class.

$$SDI = \sum \left(\frac{D_i}{10}\right)^{1.6}, \qquad (1)$$

where D_i is the breast height diameter in inches of the *i*-th tree in the stand.

$$SDI = \sum (TPA_j \left(\frac{D_j}{10}\right)^{1.6}), \qquad (2)$$

where: D_j is the middle of the *j*-th diameter class (in inches), and TPA_j is the number of trees per acre in the *j*-th diameter class.

When *SDI* is calculated by any of the above formulas, according to Ducey and Larson (2003) it is not identical with the one proposed by Reineke and should be marked with *SDI**. Long and Daniel (1990) consider it is not necessary the distributions that are considered to be balanced to have even distribution of their basal area or *SDI* by diameter classes. This contradicts the assumption that the balanced uneven-aged structure has an equal growing space by diameter classes. An alternative is allowed, with the presence of fewer trees with small diameters, a larger number of thicker trees, and a smaller total number of trees.

An alternative method for stocking control of an uneven-aged stand has been proposed by O'Hara (1988), recommending the use of the leaf area index (LAI), which is a ratio of the total leaf area per unit of a land surface. The author suggests that with such an approach, the forester can be advised about the possible density of the understory at a given diameter distribution of the upper layer.

This is a non-standard approach that goes beyond maintaining certain diameter distributions but focuses on maintaining structures that are directly related to productivity and growth and considers the differential growth rates of the particular cohort as well as the maximum LAI. In loblolly-shortleaf pine stands management in the USA volume control guiding diameter limit method has been used (Baker et al. 1996, Guldin 2002). First the maximum stand productivity must be determined, then the volume growth rate calculated and the cutting cycle length determined. Determining the allowable cut is done by multiplying the annual growth rate by the cutting cycle length.

The ‘unit area control’ method (Hallin 1959) has been developed as a means for controlling heterogeneous forest stands by separating them into small areas, thus transforming an uneven-aged structure throughout a form of group selection.

The optimization of the forest management can be done through a set of models and appropriate software for predicting the dynamics of the stands under different management parameters (Haight et al. 1992, Palahí and Pukkala 2003, Trasobares and Pukkala 2004).

Krastanov (1975) has suggested a method for calculation the value of annual allowable cut that has been subsequently implemented in Bulgaria and is still used today, which is related to the analysis of the value of the growing stock and its comparison first to the optimal growing stock, then to the volume distribution of territory by age classes and last – to the number of trees. Then the number of trees is compared to the optimal structure within the diameter classes. The intervals in the diameter classes are 14–18 cm, 22–38 cm and over 42 cm.

Annual cut (E) is given by equation (3).

$$E = V_a - V_{opt} + Z_v, \qquad (3)$$

where: V_a is actual growing stock, $m^3 \cdot ha^{-1}$; V_{opt} – optimal growing stock, $m^3 \cdot ha^{-1}$; Z_v – current annual increment for the future 10-years, $m^3 \cdot ha^{-1}$.

For the optimal stock structure by diameter classes and productivity groups, the following ratios are assumed for the volume (5:35:60, 8:37:55, 10:40:50 %) and for the number of trees (35:45:20, 40:42:18, 45:40:15 %). Optimal growing stocks are 400, 300, 250 $m^3 \cdot ha^{-1}$, and target diameters – 74, 70, 66 cm.

The goals of this study were to quantify existing structure in uneven-aged mixed and pure conifer stands with a focus on diameter distribution, to assess the capacity of two indices (Gini index and coefficient of variation) and to propose optimal percentage structure of the number of trees in three diameter classes (I: 14–18 cm; II: 22–38 cm; and III: over 42 cm).

Materials and Methods

The data for this study was collected in Rila and Rhodopes Mountains of the Republic of Bulgaria at the territories of experimental forestry enterprise ‘Yundola’ and State forestry enterprise ‘Beglika’ (Fig. 1).

The average temperatures for the Rila Mountains are 4.8–7.4 °C, the average number of days with t > 10 °C is 110–150, the amount of precipitation is 850–960 mm per year. For the region of the western part of the Rhodopes the average temperatures are 4.8–6.4 °C, the average number of days with t > 10 °C is 100–140, the amount of precipitation is 800–950 mm per year.

The forest stands in which the sample plots were located are predominantly mixed fir-spruce-beech-pine and pure spruce stands and are situated in the range 1400–1750 m a.s.l. They are classified as EUNIS (Davies et al. 2004) habitat types: G3.4C Southeastern European *Pinus sylvestris* forests, G3.1E *Abies* and *Picea* woodland, G3.16 Moesian *Abies alba* forests, G4.6 Mixed *Abies–Picea–Fagus* woodland.

All stands are managed. On the territory of Yundola single-tree selection system and selection thinning has been carried out. In the early stages of transformation on the territory of Beglika, a group-selec-

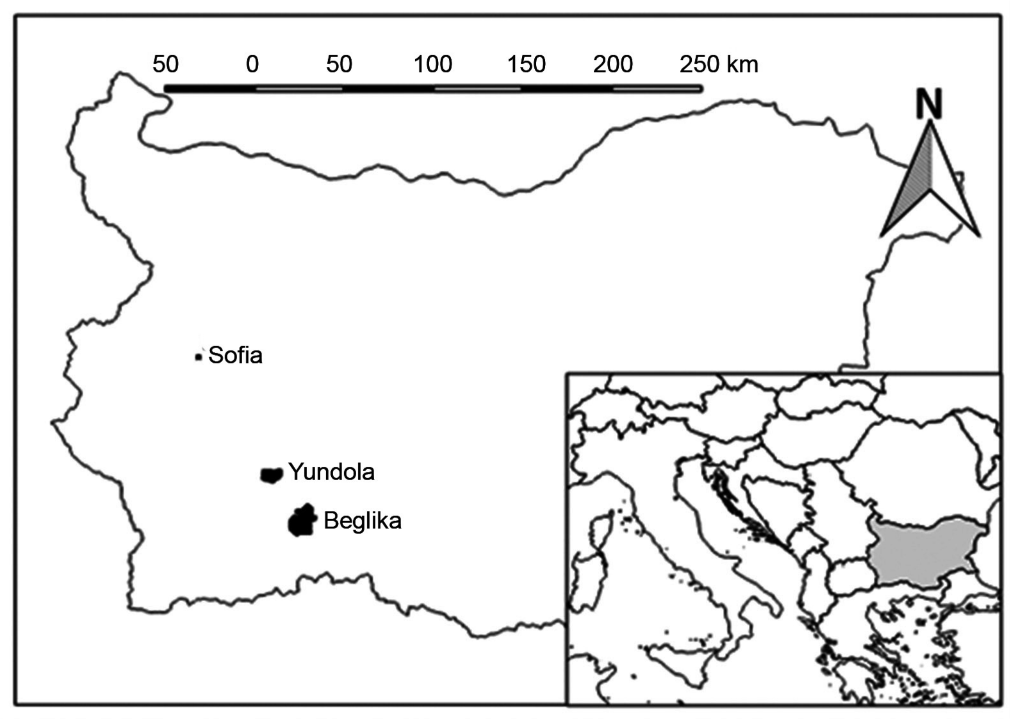

Fig. 1. Study area of experimental forestry enterprise 'Yundola' and state forestry enterprise 'Beglika'.

tion system has been carried out for heterogenization of the vertical stand structure.

Data were collected from 2 permanent and 24 temporary sample plots. The permanent sample plots have been set up in 1949. They are rectangular with an area of 0.2 ha and the aim was an observation of structure and productivity of stands for conversion into two-aged Scots pine-Norway spruce stands. The temporary sample plots were circular with radii of 20 or 25 m, requiring a minimum of 50 trees. All trees with a diameter at breast height over 6 cm were inventoried by diameter classes of 4 cm.

The characteristics of sample plots are given in Table 1.

To estimate the heterogeneity of all stands using the 'gini' function from 'reldist' package (Handcock 2016), the Gini index (the ratio of the area separated by the Lorenz curve and the diagonal and area which is below the diagonal – Fig. 2) was calculated by equation (4).

$$G = \frac{\sum_{1}^{n}(2j-n-1)g_j}{\sum g_j\,(n-1)}, \qquad (4)$$

where: g_j is the basal area of the tree with rank j; j is tree rank according to a diameter at breast height in ascending order 1, ..., n; n is total number of trees.

The index quantifies the deviation of the index from the perfect equality line with a minimum of zero and a theoretical maximum value of 1. With the increase of stands heterogeneity, the Gini index has higher values.

Table 1. Characteristics of sample plots.

Sample plot	Stand composition, %	Upper diameter class, cm	Average diameter, cm	Dominant height, m
Yu1	PA – 65, AA – 31.4, FS – 3.6	98	33.8	38.5
Yu2	PA – 59.6, PS – 20.8, AA – 16.3, FS – 3.3	82	33.9	39.5
Yu3	PA – 61.9, PS – 19.5, AA – 15.6, FS – 3.0	74	35.9	36.3
Yu4	PA – 46.6, PS – 35.7, AA – 17.0, FS – 0.6	86	33.4	37.1
Yu5	PA – 47.3, PS – 36.0, AA – 15.4, FS – 1.4	86	32.4	37.2
Yu6	AA – 53.8, PA – 33.4, PS – 8.4, FS – 4.5	82	31.2	35.4
Yu7	PS – 46.3, PA – 32.4, AA – 20.9, FS – 0.4	86	32.7	35.2
Yu8	PS – 58.3, PA – 25.3, AA – 15.5, FS – 0.4, PT – 0.3	82	32.6	34.1
Yu9	AA – 67.8, PA – 17.6, FS – 12.7, SA – 0.7, PS – 0.6, SC – 0.6	102	35.7	32.8
Yu10	AA – 67.9, FS – 17.3, PA – 14.6, PS – 0.2	94	40.2	32.2
Yu11	AA – 63.2, PA – 21.0, FS - 15.7, PS – 0.1	110	34.7	36.3
Yu12	AA – 72, PA – 17.9, FS – 9.5, SA – 0.6	82	32.3	31.9
Yu13	AA – 76.9, PA – 12.8, FS – 9.9, PS – 0.3	74	33.1	34.3
Yu14	AA – 58.8, PA – 32.3, FS – 8.8, PS – 0.2	90	31.9	33.3
Yu15	AA – 49.0, PA – 31.2, FS – 18.7, PS – 1.2	102	34.8	37.6
Yu16	PS – 72.4, PA – 27.6	46	24.6	30.8
Yu17	PS – 52.5, PA – 47.5	46	25.8	31.6
Yu18	PA – 100	34	14.6	14.5
Yu19	PS – 75.2, PA – 24.8	42	23.7	32.8
Yu20	PS – 52.6, PA – 47.4	46	25.0	34.3
Yu21	PA – 100	34	15.3	15.3
Be1	PA – 82.6, PS – 17.4	86	37.6	35.3
Be2	PA – 82.1, PS – 17.7, AA – 0.2	82	34.8	34.1
Be3	PA – 90.1, PS – 9.9	82	33.8	35.8
Be4	PA – 95.2, PS – 4.8, AA	90	35.9	32.2
Be5	PA – 99.5, PS – 0.3, AA – 0.2	70	32.8	34.0

Note: AA – Silver fir (*Abies alba* Mill.), PA – Norway spruce (*Picea abies* (L.) H. Karst.), PS – Scots pine (*Pinus sylvestris* L.), FS – European beech (*Fagus sylvatica* L.), PT – European aspen (*Populus tremula* L.), SA – Rowan (*Sorbus aucuparia* L.), SC – Goat willow (*Salix caprea* L.).

The normal, the Weibull and the negative exponential distributions are used for fitting the empirical data. The probability density functions (PDFs) of the normal, the Weibull, and the negative exponential distribution were calculated by equations (5), (6), and (7) respectively.

$$f_{(norm)}(x \mid \mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \qquad (5)$$

where: μ and σ are the mean and the standard deviation;

$$f_{(Weibull)}(x \mid \alpha,\beta) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}, \qquad (6)$$

where: α and β are the shape and the scale parameter;

$$f_{(exp)}(x \mid \alpha,\gamma) = \alpha exp(\alpha, x), \qquad (7)$$

where: scale parameter α > 0.

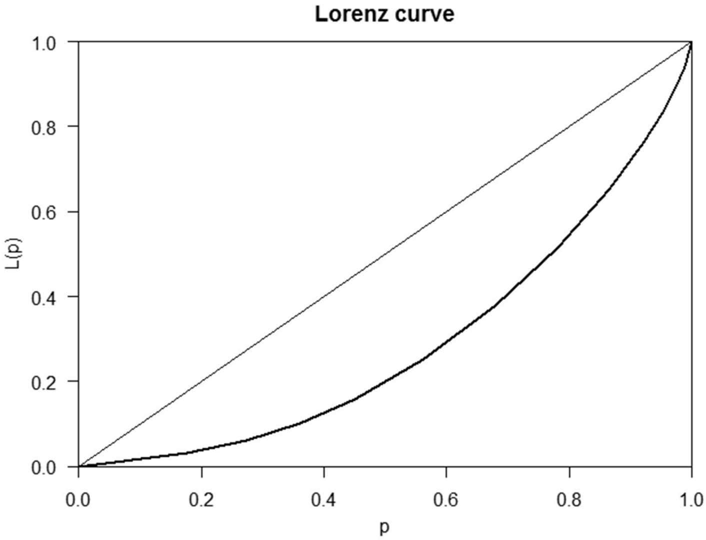

Fig. 2. Lorenz curve for sample plot U7.

by type of distribution, the single-factor ANOVA was used, followed by a post-hoc Tukey multiple range test. To determine the confidence interval of the Gini indices and the variation coefficient, a bootstrap procedure based on the Monte-Carlo method (Canty and Ripley 2017) was applied.

Parameter *q* that characterizes the diminution ratio of the number of trees between successive diameter classes was calculated according to Meyer (1952) and Gul et al. (2005) using equation (9):

$$q = e^{-\alpha w}, \quad (9)$$

where: α is the rate of negative exponential function; *w* – width of the diameter class.

The coefficient of variation (*CV*%) was calculated using equation (8).

$$CV\% = \frac{s}{\overline{x}}100 \,, \quad (8)$$

where: *s* is the standard deviation of diameters for grouped values; $\overline{x}$ – an average of diameters.

The Shapiro-Wilk test was used for determining of sample plots with the normal distribution. The Hartigan Modality Test (Maechler 2016) was applied to identify all sample plots with most likely bimodal or multimodal distributions. The most likely theoretical distribution for sample plots that reject the null hypothesis (H0: data come from a population with normal distribution) was determined using the Anderson-Darling test and the fitdistr function of the MASS package (Venables and Ripley 2002). When there was more than one adequate model, the choice was based on the lower Akaike information criterion (AIC).

To analyze the differences of the Gini coefficients and the variation coefficients

Results

After applying the Shapiro-Willks test whether the samples come from a normal distribution, it was found that 8 of the 26 sample plots could not reject the null hypothesis (Yu16-Yu21, Be2, Be4), which indicates that the distributions are normal. In the remaining 18 stands, most adequate distribution was determined using the Anderson-Darling test goodness-of-fit to a specified continuous univariate probability distribution.

For sample plots, Yu2, Yu4-Yu9, Yu11, Yu12, Yu14, Yu15 the Weibull distribution model was the most adequate and for sample plots Yu1, Yu3, Yu10, Yu13, Be1, Be3, Be5 the most adequate model was the exponential distribution.

According to the Hartigan test, no bi-modal or multimodal distribution is presented in the investigated sample plots.

For the comparing the results to these of other studies, the coefficients of the Gini index and the variation coefficient were calculated for diameters of breast height over 12 cm.

The Gini coefficients varied from 0.243 to 0.609 with an average value of 0.442, with the coefficient of variation min = 22.9 %, max = 65.9 %, average value of 44.22 %.

The one-way ANOVA shows a statistically significant difference between the Gini coefficient, the variation coefficient (C.V.) and the factor 'type of distribution' (Table 2).

Table 2. Anova table for the Gini coefficient and the variation coefficient.

Source	Degrees of freedom	Sum of squares	Mean squares	*F* value	*Pr* (>*F*)
Gini – type of distribution	2	0.1147	0.0574	16.50	<0.001
Gini-residuals	23	0.0800	0.0035		
C.V. – type of distribution	2	1492.79	746.40	15.43	<0.001
C.V. – residuals	23	1112.82	48.36		

The Tukey's range test was performed to identify differences between means of each type of distribution for the Gini coefficient and the variation coefficient. There were no significant differences between mean values for Weibull-exponential distribution, while the means of the normal-exponential and the Weibull-normal distributions were significantly different (Fig. 3).

To evaluate forest stands heterogeneity in terms of the diameter distribution by classes according to the values of the

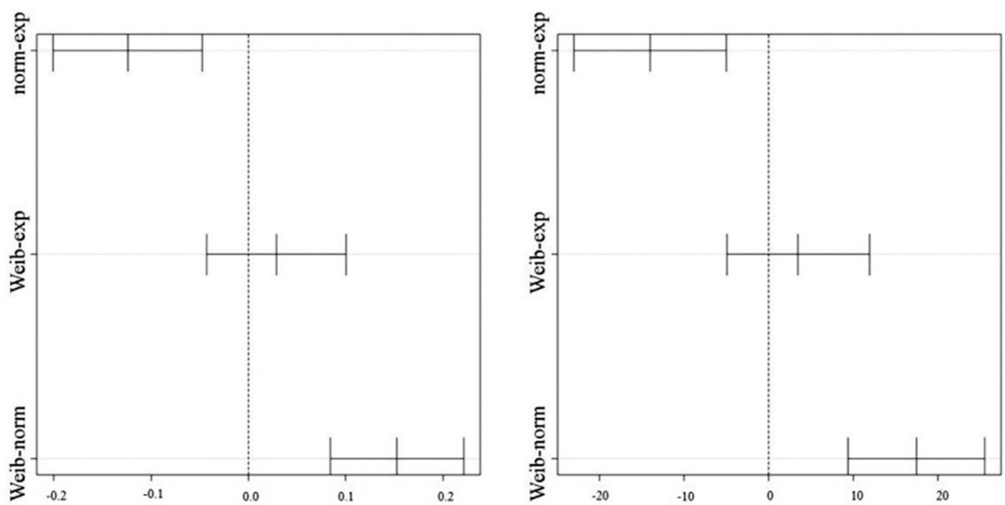

Fig. 3. Plot of the Tukey's HSD estimated differences and confidence intervals for the Gini index (left) and for the variation coefficient (right).

Gini index and the coefficient of variation, their confidence intervals are determined by applying the bootstrap procedure. The results are presented in Table 3.

Table 3. 95% confidence intervals of variation of the Gini index and the variation coefficient.

Type distribution	Gini coefficient			Variation coefficient		
	Kendall's tau	lower	upper	Kendall's tau	lower	upper
Normal	0.344	0.297	0.391	33.05	28.27	37.96
Weibull	0.497	0.463	0.531	50.54	46.18	54.68
Exponential	0.468	0.443	0.4939	47.04	44.27	49.75

The confidence intervals of the exponential-normal distribution and the Weibull-normal did not overlap until the Weibull-exponential distribution did. In other words, according to the Gini coefficient and the variation coefficient, only the exponential from the normal distribution and the Weibull from the normal distribution could be distinguished with statistical confidence.

Linear regression analysis and Pearson correlation coefficient were performed to determine the correlation between the Gini index and the variation coefficient (*VC%*) of diameter numbers by equation (10).

$$VC\% = 115.159 \cdot \text{Gini index} - 6.711 \quad (10)$$

The coefficients of *VC%* (10) were statistically significant, R-squared = 0.9907.

The obtained equation allows predicting the values of the variation coefficient and hence the affiliation of a stand to the respective distribution type only by the value of the Gini coefficient, which could be calculated easily after the inventorying the trees.

The q-coefficient values for the exponential and the Weibull distribution ranged from 1.164 to 2.059 with a mean of 1.444 (p-value < 0.001). The Kruskal-Wallis test showed a statistically significant difference between the values of q-coefficient and the factor 'type' of distribution (Kruskal-Wallis chi-squared = 7.138, p-value = 0.0075). The 95% intervals for the q-coefficient for the exponential and the Weibull distribution were obtained after the bootstrap procedure. The intervals were 1.195–1.290 (Kendall's tau – 1.242) for the exponential and 1.405–1.739 (Kendall's tau – 1.572) for the Weibull distribution, respectively.

There was no statistically significant difference between the percentage of trees for the different diameter classes and the type of distribution. The average values for Class I (14–18 cm) were 34.5 %, for Class II (22–38 cm) – 39.0 % and for Class III (>42 cm) – 26.5 %.

Discussion

From the study of 14 Alpine Norway spruce stands in the Rhodopes, Aleksandrov (2015) has found that 5 of the stands fits the exponential, 4 – the uniform, 3 – the normal distribution and 1 stand is bimodal. Aleksandrov and Molle (2014) reported no statistically significant relationship between the Gini index values and the three groups of distributions, and only the STVI index (Staudhammer and LeMay 2001) demonstrated such a relationship. There was a clear distinction between the exponential and the bimodal distributions on the one hand and the uniform distributions, on the other. There was no significant difference between STVI values and the bimodal distribution, and the exponential distribution.

Although there are numerous indices in the literature to describe the heterogeneity of the stand structure, the Gini index has become the best predictor (Lexerød and Eid 2006).

In a study of the diameter structure for even-aged and uneven-aged stands of Norway spruce and Scots pine, Lexerød and Eid (2006) set a Gini coefficient in the range from 0.21 to 0.51 (mean value – 0.38). They reported that the values from 0.16 to 0.30 corresponded to normal distribution, while the range from 0.44 to 0.57 corresponded to J-shaped distribution.

In a study of management systems (clear cut management system and selection forestry) for Austria, Sterba and Ledermann (2006) found range of the Gini coefficient from 0.3 to 0.5, and for most of the studied period the values were above 0.4. For mixed Norway spruce, Silver fir and European beech stands in Switzerland O'Hara et al. (2007) reported values for even-aged stands between 0.2 and 0.6 (except values above 0.3) and uneven-age stands between 0.4 and 0.7.

For uneven-aged Norway spruce, Silver fir and European beech stands in Romania, Duduman (2011) established the following ranges for the Gini index (G_i): even-sized structure: $G_i \leq 0.35$; two-sized: $0.35 < G_i \leq 0.43$; uneven-sized irregular: $0.43 < G_i \leq 0.51$ and uneven-sized balanced: $G_i > 0.51$. Studying the stand dynamics of Silver fir and European beech stands in Slovenia Klopcic and Boncina (2011) set values of G_i 0.35 to 0.52, while the values for mixed uneven-aged forests of two study areas of *Juglans mandshurica* Maxim., *Fraxinus mandshurica* Rupr. and *Phellodendron amurense* Rupr., *Quercus liaotungensis* Koidz., *Carya cathayensis* Sarg. and *Pinus armandii* Franch. of Northern China ranged from 0.58 to 0.64 (Hui and Pommerening 2014).

Studying the results of a 40-year transformation period to an uneven-sized structure of *Picea abies*, *Abies alba*, *Fagus sylvatica*, *Larix decidua*, *Pinus sylvestris* in the Czech Republic Kadavý et al. (2017) obtained a Gini index variation values from 0.32 to 0.59.

Duduman (2011) and Kadavý et al. (2017) established a linear relationship between the Gini index and the coefficient of variation of the diameters, with the resulting patterns of this regression being relatively close. The linear model derived from our data is very close to the Duduman model (2011) and differs from that of Kadavý et al. (2017).

Applying Gini index interval values from the present study with those reported of Duduman (2011) for all sample plots, 4 of the stands reach the even-sized structure, 6 stands reach the two-sized structure, 12 stands reach the uneven-sized irregular structure and 4 stands reach the uneven-sized balanced structure. The Gini index increases with age for uneven-aged stands, while in the even-aged stands cases it decreases. This, according to O'Hara et al. (2007) is due to the greater variety in the classes of diameter, and the increase in some even-aged stands is related to the development of the second cohort of trees.

Despite the advantages of the Gini Index, it cannot be used as a universal tool for assessing the structural diversity of the stands. It should be noted that stands with a different structure in diameter may have the same Gini indices (Weiner and Solbrig 1984), and the time between two successive inventories should be considered (Kadavý et al. 2017). Also, the Gini index cannot distinguish the differences between a managed forest and an unmanaged one (Rouvinen and Kuuluvainen 2005).

The values of the variation coefficient of diameters here obtained are similar to these in similar stands in Romania (Giurgiu 1969, 1979; Leahu 1994), and for uneven-aged stands – 50–80 %.

The optimal structure of stands is an important feature of the selection forests. This structure, which provides long-term maximum current annual increment, can be considered as optimal. The optimal growing stock of a forest under certain habitat conditions, forest type and management is a variable that depends on the state of the stands of this type of forest. In each stand condition, it has certain values that must be the goal of the management for the future cutting cycle. Due to the small number of stands with an uneven-aged balanced stand structure, according to Duduman (2011) the range of the Gini coefficient, no optimum stock values are given, but only a distribution of the percentage of trees by diameter classes.

The values of the percentage distribution of the number of trees by diameter classes are very similar to these of Krastanov (1975) for the first group of productivity and for the habitat Mixed fir-spruce-beech woodland.

Conclusions

The distribution of studied coniferous stands could be fitted with the normal, the exponential and the Weibull function. The Gini index is a good descriptor of the type of diameter distribution and it is highly correlated with the variation coefficient. The exponential from the normal distributions on one hand and the Weibull from the normal distribution on the other hand could be distinguished using the Gini index and the variation coefficient. The Gini index values obtained from this study are similar to these reported for the Central European forests.

Because of the lack of statistically significant difference between the percentage of trees for the different diameter classes from our data and these from Krastanov (1975) we could use them for stocking control and calculating the annual allowable cut for similar type of stands in other regions of Bulgaria.

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