JOURNAL OF FOREST SCIENCE, *63*, 2017 (10): 476–484

doi: 10.17221/48/2017-JFS

Evaluation of transformation from even-aged to selection forest by means of Gini index

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Abstract

Kadavý J., Kneifl M., Fedorová B., Bartůněk J. (2017): Evaluation of transformation from even-aged to selection forest by means of Gini index. J. For. Sci., 63: 476–484.

We used the Gini index for evaluation of the 40-year transformation to selection forests in the Training Forest Enterprise Masaryk Forest Křtiny (Czech Republic). The Gini index values for particular forest stands were compared with the reference values derived from the diameter distribution model curve (type E) by Meyer. From a total of sixteen stands which were evaluated in 2013 (the last periodic inventory), only two stands reached the desired diameter structure. Four other stands reached the desired diameter structure at least once during the transformation period. We recommend the application of Gini index for determination of a success rate of even-aged stand transformation to selection forest.

Keywords: stand transformation; selection system; structural indices; forest management

Forest structure can be described by means of structural indices. Pommerening (2002) divided structural indices into spatial, non-spatial (neighbourhood), spatial autocorrelation based or relying on species mixture or size class diversity calculations of both horizontal and vertical strata. Pommerening (2002) also examined typical representatives of the classification groups such as Shannon index, Clark and Evans aggregation index, contagion index, Pielou coefficient of segregation, mingling index, diameter differentiation index, pair correlation and mark correlation functions.

In our paper, we focus primarily on non-spatial indices of diameter structure diversity and equitability. Here, the approach based on estimates of tree size variation seems to be the most suitable. Valbuena et al. (2012) classified Gini index (Gini 1912, 1921) into this group. To compute the Gini index, the Lorenz curve is used as a concept related to size ordering for equitability description (Studeny et al. 2011). The Gini index represents the area between the 45° line and the Lorenz curve given as a percentage of the area below the 45° line (triangle area), which is 0.5 (Dixon et al. 1987; Neumann, Starlinger 2001; Lexerød, Eid 2006).

The Gini index was originally designed to determine inequality in income distributions in economics, but it has also been used to measure size hierarchies in plant populations (Weiner, Solbrig 1984). Since that time, the Gini index has also been applied to evaluate how natural forest growth dynamics affected equality among tree sizes (Knox et al. 1989; Lei et al. 2009; Balanda 2012), to assess the transformation process of even-aged forest stands to irregular forest stands (O'Hara 2001; Sterba, Ledermann 2006), to reveal patterns of growth dominance in forests (Binkley et al. 2006) and to evaluate tree species and size diversity patterns in uneven-aged forests (Lundqvist 2004; O'Hara et al. 2007; Hui, Pommerening 2014). The Gini index has gained recent attention as an evaluator of forest management practice (Nyland 2003;

Supported by Mendel University in Brno, Project No. 20/2014.

Lexerød, Eid 2006; Duduman 2011; Klopcic, Boncina 2011).

In forestry, various techniques and methods were historically utilized to evaluate the process of transformation to selection forest (de Liocourt 1898; Meyer 1943, 1952; Doležal 1948; Schütz 1975, 2002). Most of the methods were primarily based on the comparison of actual (real) and model (sample) diameter distributions. A model curve is usually mathematically derived as a descending geometric series e.g. according to de Liocourt (1898).

The aim of this paper is to assess the suitability of the Gini index for evaluation of transformation from even-aged to selection forest.

MATERIAL AND METHODS

Two groups of forest stands designed to transform to a selection forest were selected on January 1, 1973 at the Training Forest Enterprise (TFE) Masaryk Forest Křtiny (Truhlář 1975). A distance between both groups is approximately 2.5 km. The one, Klepačov, is located near the village of Klepačov and the other, Pokojná Hora, between the villages of Olomučany and Rudice (Fig. 1). Characteristics of the stands are listed in Table 1.

Pokojná Hora lies on limestone and on loess loams. The predominant soil types are typical Luvisols and oligotrophic to mesotrophic Cambisols (Němeček et al. 2001). *Fagetum eutrophicum* is a dominant forest type in the study area (European Environment Agency 2007). Forest stands are mostly homogeneous according to Forest Management Plan 2013–2022. Altitudes range between 440 and 510 m a.s.l. This area includes six forest stands (in total 64.91 ha in 2013).

Klepačov is mainly found on amphibole granodiorites with overlays of loess loam. The predominant soil types are similar to Pokojná Hora. Forest stands are heterogeneous, differentiated in diameter and height. Altitudes range between 300 and 400 m a.s.l. At the beginning of transformation, this area included 6 forest stands. In 1993, another three stands (113 A, 114 A and 116 B) were included and in 2003, one more stand (116 E) was added to the group. At present, the total area of Klepačov is 79.93 ha.

In 2013, the total analysed area was 144.84 ha. The average tree species composition based on a forest area was as follows: *Picea abies* (Linnaeus) H. Karsten – 39.9%, *Abies alba* Miller – 21.2%, *Fagus sylvatica* Linnaeus – 16.1%, *Larix decidua* Miller – 10.9%, *Pinus sylvestris* Linnaeus – 10.1%, *Pseudotsuga menziesii* (de Mirbel) Franco – 1.4%, *Quercus* sp. – 0.3% and *Carpinus betulus* Linnaeus – 0.1%. Mean annual precipitation is 618 mm and mean annual temperature is 6.8°C.

Specification of the silvicultural measures for the upper (diameter classes > 34 cm), middle (18–34 cm) and lower storey (< 18 cm) for the transformation to the selective forest was given by Forest Management Plans 1973, 1983, 1993, 2003 and 2013.

In diameter classes > 34 cm silvicultural measures implemented in both areas during the entire transformation period can be described as follows: principles of vitality, structure and target diameter harvest selection were applied. The main focus was the target diameter harvest.

Group selection was applied only in the early stages of transformation in single-storeyed even-aged stands. The aim was to achieve the heterogeneous vertical structure of stands. High quality trees with high DBH increment rates and perfectly shaped crowns were left regardless of diameter.

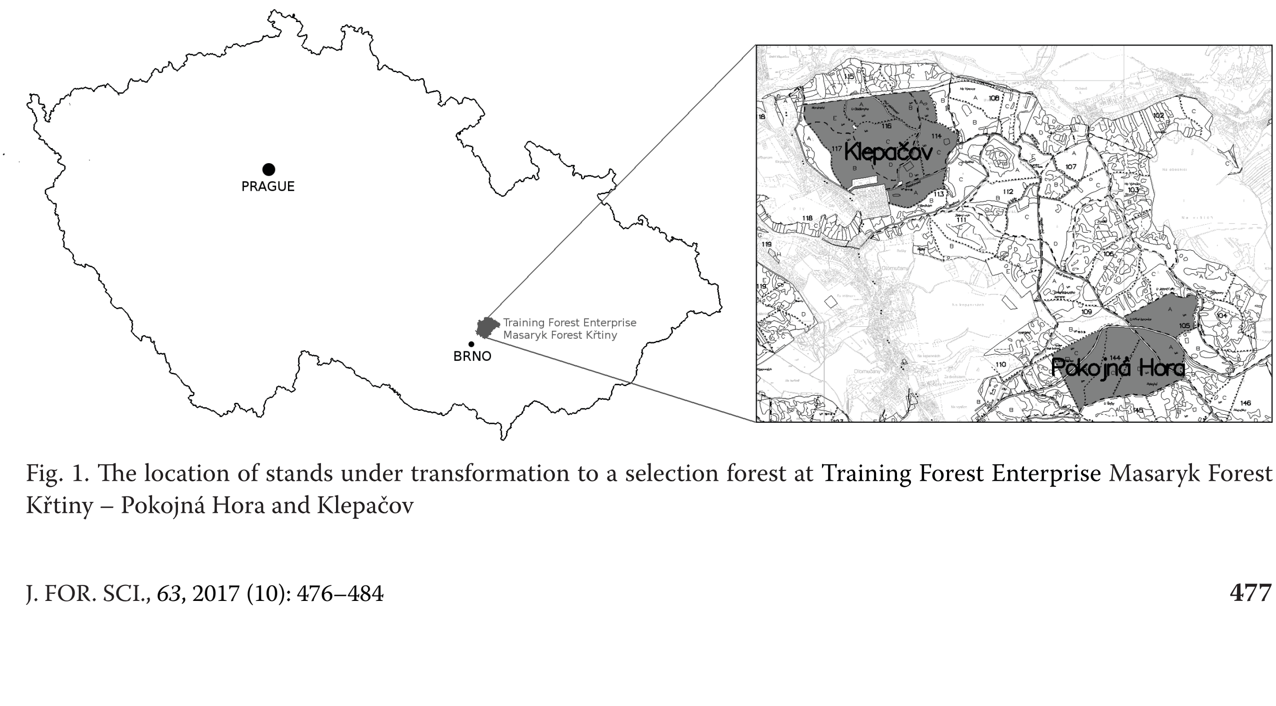

Fig. 1. The location of stands under transformation to a selection forest at Training Forest Enterprise Masaryk Forest Křtiny – Pokojná Hora and Klepačov

Table 1. Basic characteristics of stands under transformation to a selection forest (January 1, 2013)

Study site	Forest stand	Area (ha)	Composition of tree species (in % of standing volume)						Number of trees per hectare	Basal area ($m^2 \cdot ha^{-1}$)	Volume ($m^3 \cdot ha^{-1}$)
			Norway spruce	silver fir	European beech	European larch	other conifers	other broadleaves			
Pokojná Hora	105 A	13.98	57	20	3	12	8	–	420	31.2	376
	109 C	6.24	34	5	42	13	5	1	394	28.2	347
	144 B	8.90	30	2	50	15	2	1	285	32.6	430
	144 C	14.52	45	-	14	32	9	–	422	34.0	405
	144 D	13.70	30	20	12	26	11	1	585	31.0	329
	146 A	7.57	72	8	3	12	5	–	529	30.9	336
Klepačov	113 A	7.85	37	19	8	7	28	1	433	26.6	278
	114 A	3.40	58	11	17	1	11	2	897	18.2	140
	114 C	10.56	57	31	11	1	–	–	516	22.7	239
	114 D	3.48	41	43	3	2	11	–	683	25.9	251
	116 A	6.84	17	47	18	1	17	–	396	23.0	245
	116 B	6.80	46	17	23	6	7	1	591	21.6	211
	116 C	10.17	30	39	17	–	14	–	357	18.6	197
	116 D	7.72	28	43	21	1	7	–	595	26.7	270
	116 E	8.01	27	31	5	15	21	1	334	17.1	183
	117 B	15.1	33	22	19	2	24	–			

In diameter classes between 18 and 34 cm a positive selection with focus on vitality and structure was applied. The aim was to change the single-layer canopy into a vertically heterogeneous stand. Individuals with high potential diameter increment are released by positive selection. More mature trees are released by a stronger intervention, removing the closest stronger and lesser-quality individuals. Trees of the largest diameters, trees of lower quality and trees with insufficient diameter increment are harvested by a group cutting.

In diameter classes < 18 cm, removals of damaged trees were applied. In conifers, positive selection was performed with the focus on valuable trees with high potential diameter increment. On the other hand, among broadleaved trees negative selection was implemented and stand canopy closure was kept denser due to a desired improvement in tree quality.

Data analysis. In 1973, 1983, 1993, 2003 and 2013, both Klepačov and Pokojná Hora were fully callipered (DBH > 8 cm over bark). The trees were permanently marked in the field and DBH was always measured at the same place for each tree. Tree diameters were ordered into 4-cm diameter classes. According to the shape of the distribution of diameter frequencies, types of structures according to Baker et al. (1996) were assigned to forest stands. The types of structures ware based on the inventory in 2013: 4 – two-sized, 5 – uneven-sized irregular and 7 – uneven-sized balanced.

To calculate Gini indices (G_i), numbers of trees in diameter classes and their basal areas were used. For each stand G_i was computed as the ratio of: (*i*) the area identified by the Lorenz curve (Lorenz 1905) and the diagonal, and (*ii*) the whole area below the diagonal (Fig. 2). Eq. 1 was used to calculate G_i (Duduman 2011):

$$G_i = 1 - \sum_{i=1}^{k} \left[\left(ba_{i-1} + ba_i \right) \left(n_i - n_{i-1} \right) \right] \quad (1)$$

where:

k – number of diameter classes,

ba_i (ba_{i-1}) – cumulative fraction of the basal area (%) of trees with diameter smaller than or equal to the i^{th} (i – 1) diameter class (for i = 1, ba_i = 0),

n_i (n_{i-1}) – cumulative fraction of the number of trees (%) with diameter smaller than or equal to the i^{th} (i – 1) diameter class (for i = 1, n_i = 0).

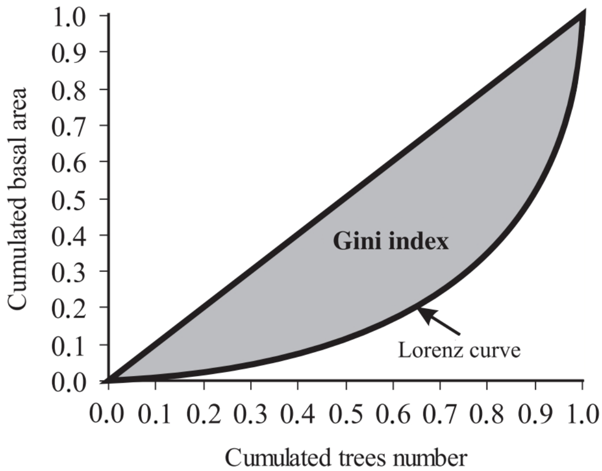

Fig. 2. Lorenz curve plotted against the basal area (Duduman 2011)

G_i always ranges between 0 and 1. The G_i value is lower if the population is more homogeneous, and vice versa (Gini 1912, 1921). Using Lorenz ordering for comparing biomass differences between individuals in a plant community was first suggested by Weiner and Solbrig (1984), who also pointed out the usefulness of estimating diameter variation by means of the Gini coefficient in this context (Valbuena et al. 2012).

The coefficient of variation of diameters for grouped values (S_x%) was also computed in order to test a correlation with G_i, as Eq. 2:

$$S_x\% = \frac{s_x}{\bar{x}} \times 100 \qquad (2)$$

where:
s_x – standard deviation of diameters for grouped values,
$\bar{x}$ – arithmetic mean of diameters for grouped values.

The target G_i value was derived uniformly for all stands from the target diameter structure curve by Meyer (1952), curve of type E (Korf 1955), as Eq. 3:

$$N = 365.5534e^{-0.07266x} \qquad (3)$$

where:
N – number of trees in the diameter class with the mean diameter x.

Based on this diameter distribution model, the target G_i value was 0.5350.

Curve of type E (Korf 1955) starts from the 16 cm registration limit and it has been fitted by the least squares method to include trees in diameter classes 10 and 14 cm. This type of curve, as the model curve, has been used since the beginning of transformation (Forest Management Plan 2003 and 2013). The evaluation of transformation of even-aged stands to selection stands was carried out by comparing the computed G_i values for particular stands with the target G_i value. If the stand reached or exceeded the target value of G_i, it was considered having a target diameter structure.

G_i share in the target value was computed as the ratio of G_i and target G_i.

G_i values were computed by the package ineq (Version 0.2-13, 2014) in the R software (Version 3.2.3, 2015).

RESULTS

G_i and S_x% are correlated (Figs 3a, b). Linear model of the dependence of S_x% on G_i values (Fig. 3a): $S_x\% = 91.5446 \times G_i + 5.7878$. The model explains 96% of variability in the coefficient of variation and is significant (P = 0.000).

Linear model of the dependence of S_x% on G_i values according to the types of structures from the inventory in 2013 for the TFE Masaryk Forest Křtiny (Fig. 3b): $S_x\% = 89.9201 \times G_i + 7.17809$. The model explains 95% of variability in the coefficient of variation and is significant (P = 0.000). Obviously, it is possible to define the types of tree structures based on the G_i.

In Pokojná Hora, the G_i values of particular stands ranged from 0.4014 to 0.5017 in 2013. During the 40-year period, the lowest G_i (0.3422) was evaluated for forest stand 144 B in 1983. On the other hand, the highest value of G_i (0.5017) occurred in stand 105 A in 2013. None of the 6 stands included in Pokojná Hora reached the target value of G_i during the entire transformation period (Table 2). Throughout the transformation in Pokojná Hora, the closest target value of G_i was reached in stand 105 A.

In Klepačov, the G_i values for analysed stands ranged from 0.3751 to 0.5599 in 2013. Over the entire period of transformation, the lowest G_i

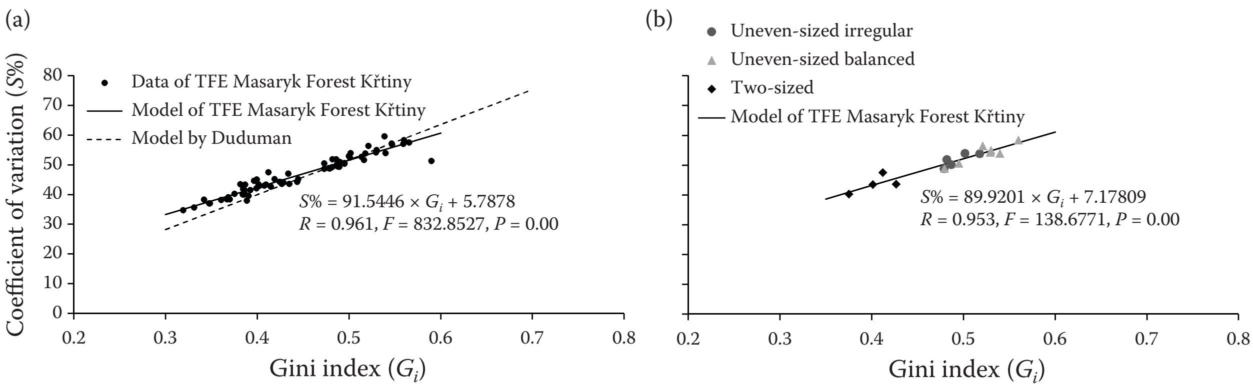

Fig. 3. Correlation between the Gini index and the coefficient of variation of diameters: a model from the stands at Training Forest Enterprise (TFE) Masaryk Forest Křtiny from the period 1973–2013 versus the model of Duduman (2011) (a), the distribution of stand structure around the model – data from 2013 (b)

Table 2. Gini index values and their shares in the target value with expression of the trend of development by years at the study site Pokojná Hora

Stand No.	Characteristic	Year of measurement					Target value
		1973	1983	1993	2003	2013	
105 A	Gini index (G_i)	0.4286	0.3671	0.3686	0.4189	0.5017	0.5350
	G_i share of target value	0.8012	0.6862	0.6889	0.7830	0.9377	–
	trend (year$_{+10}$ versus year$_{–10}$)	–	↘	↗	↗	↗	–
109 C	Gini index (G_i)	0.3864	0.3841	0.4078	0.3845	0.4822	0.5350
	G_i share of target value	0.7223	0.7179	0.7623	0.7188	0.9012	–
	trend (year$_{+10}$ versus year$_{–10}$)	–	↘	↗	↘	↗	–
144 B	Gini index (G_i)	0.4021	0.3422	0.3870	0.3817	0.4123	0.5350
	G_i share of target value	0.7516	0.6395	0.7233	0.7135	0.7706	–
	trend (year$_{+10}$ versus year$_{–10}$)	–	↘	↗	↘	↗	–
144 C	Gini index (G_i)	0.3904	0.3888	0.3923	0.3860	0.4014	0.5350
	G_i share of target value	0.7298	0.7268	0.7332	0.7216	0.7502	–
	trend (year$_{+10}$ versus year$_{–10}$)	–	↘	↗	↘	↗	–
144 D	Gini index (G_i)	0.4447	0.4349	0.4874	0.4729	0.4952	0.5350
	G_i share of target value	0.8312	0.8129	0.9111	0.8840	0.9256	–
	trend (year$_{+10}$ versus year$_{–10}$)	–	↘	↗	↘	↗	–
146 A	Gini index (G_i)	0.3701	0.3859	0.4263	0.4244	0.4870	0.5350
	G_i share of target value	0.6917	0.7212	0.7968	0.7933	0.9102	–
	trend (year$_{+10}$ versus year$_{–10}$)	–	↗	↗	↘	↗	–

G_i share of target value = G_i in the year of measurement/the target value of the G_i, trend (year$_{+10}$ versus year$_{–10}$) = trend G_i, if G_i in the year of measurement > G_i value 10 years ago, then ↗, if G_i in the year of measurement < G_i value 10 years ago, then ↘

(0.3191) was obtained in stand 114 C in 1973. The highest value of G_i (0.5897) occurred in stand 116 D in 1993. In that year, the input values of stand 116 D for calculating the G_i ("cumulative relative number" and "cumulative relative basal area") exceeded the target values in all diameter classes. In contrast, in 2003, the input variables for the G_i were lower than the target values for the 8–36 cm diameter range and for the diameters higher than 38 cm. In 1993, the area between the Lorenz curve and the diagonal was larger compared to the target area, in contrast, in 2003 the resulting G_i was higher in 1993 and in 2003 it was lower in comparison with the target value. In 2013, only two (114 C and D) of all included stands (Table 3) reached the target value of G_i (1.0465 and 1.0093, respectively). Comparison of the target and computed Lorenz curves and the dynamics of G_i over the entire transformation period in stand 114 C are presented in Fig. 4.

If the G_i value reaches or exceeds the target value, then the stand reached the final state, which is diameter structure of selection forest.

The results further confirmed that stand 114 C reached the final state of transformation in 2003 and stand 114 D reached the final state 30 years earlier (in 1983). It means that the forest stand 114 D reached the target value of G_i 30 years earlier. After 1983, silvicultural measures were carried out in the intentions of the following Forest Management Plans.

During the entire transformation period in Klepačov, the target values of G_i were reached in some stands: 114 A (1.0069, in 2003), 116 B (1.0214, in 1993), 116 D (1.1023, in 1993) and 117 B (1.0453, in 1983). In summary, six of the ten analysed stands have already reached the target values of G_i during the transformation period.

DISCUSSION

The results of our study can be compared with the following research papers.

Sterba and Ledermann (2006) compared two growth model based simulations of development of two different forest estates – Weitra and Sonnenwald in Austria (strategy of age-class forestry with natural regeneration versus individual tree harvesting – selection system). The predicted average Gini index values for basal area ranged from 0.3 to 0.5 in both types of management for 100 years of simulation. Throughout most of the simulation period, the

Table 3. Gini index values and their shares in the target value with expression of the trend of development by years at the study site Klepačov

Stand No.	Characteristic	Year of measurement					Target value
		1973	1983	1993	2003	2013	
113 A	Gini index (G_i)	–	–	0.3478	0.3485	0.3751	0.5350
	G_i share of target value	–	–	0.6500	0.6514	0.7012	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	–	–	↗	↗	–
114 A	Gini index (G_i)	–	–	0.3967	**0.5387**	0.4266	0.5350
	G_i share of target value	–	–	0.7414	1.0069	0.7975	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	–	–	↗	↘	–
114 C	Gini index (G_i)	0.3191	0.3996	0.4780	**0.5471**	**0.5599**	0.5350
	G_i share of target value	0.5965	0.7469	0.8934	1.0226	1.0465	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	↗	↗	↗	↗	–
114 D	Gini index (G_i)	0.4147	**0.5656**	0.4950	0.5138	**0.5400**	0.5350
	G_i share of target value	0.7751	1.0573	0.9252	0.9603	1.0093	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	↗	↘	↗	↗	–
116 A	Gini index (G_i)	0.3607	0.3993	0.4094	0.5001	0.5179	0.5350
	G_i share of target value	0.6741	0.7463	0.7653	0.9347	0.9681	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	↗	↗	↗	↗	–
116 B	Gini index (G_i)	–	–	**0.5464**	0.4861	0.4790	0.5350
	G_i share of target value	–	–	1.0214	0.9086	0.8953	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	–	–	↘	↘	–
116 C	Gini index (G_i)	0.3313	0.4435	0.4339	0.5009	0.5303	0.5350
	G_i share of target value	0.6193	0.8289	0.8110	0.9362	0.9912	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	↗	↘	↗	↗	–
116 D	Gini index (G_i)	0.4147	0.4896	**0.5897**	0.4903	0.5213	0.5350
	G_i share of target value	0.7751	0.9152	1.1023	0.9164	0.9744	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	↗	↗	↘	↗	–
116 E	Gini index (G_i)	–	–	–	0.4732	0.5294	0.5350
	G_i share of target value	–	–	–	0.8845	0.9895	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	–	–	–	↗	–
117 B	Gini index (G_i)	0.5301	**0.5592**	0.5165	0.4817	0.4795	0.5350
	G_i share of target value	0.9908	1.0453	0.9654	0.9004	0.8963	–
	trend (year$_{+10}$ versus year$_{-10}$)	–	↗	↘	↘	↘	–

Stands which reached target values of the Gini index in bold, G_i share of target value = G_i in the year of measurement/the target value of the G_i, trend (year$_{+10}$ versus year$_{-10}$) = trend G_i, if G_i in the year of measurement > G_i value 10 years ago, then ↗, if G_i in the year of measurement < G_i value 10 years ago, then ↘

value was above 0.4. In our experiment, the range of Gini index values was very similar to that reported by Sterba and Ledermann (2006).

O'Hara et al. (2007) compared trends of the Gini indices in multi-aged and even-aged stands in long-term permanent research plots in Switzerland (surveyed since 1905). G_i in even-aged stands ranged between 0.2 and 0.6, whereas in multi-aged stands between 0.4 and 0.7. This variability was due to the historical development in some even-aged stands. The Gini indices of these stands were initially declining, but from a certain point onwards they started to grow. As reported by O'Hara et al. (2007), the increase in several even-aged plots corresponded to the development of a second cohort of trees. The Gini index in multi-aged stands tended to increase, while in the even-aged stands, it decreased over time. Higher values of the Gini indices were found in multi-aged stands due to the higher size class diversity.

Hui and Pommerening (2014) evaluated size diversity patterns in multi-species, uneven-aged forests of Northern China. The Gini index values of two compared study areas ranged from 0.58 to 0.64.

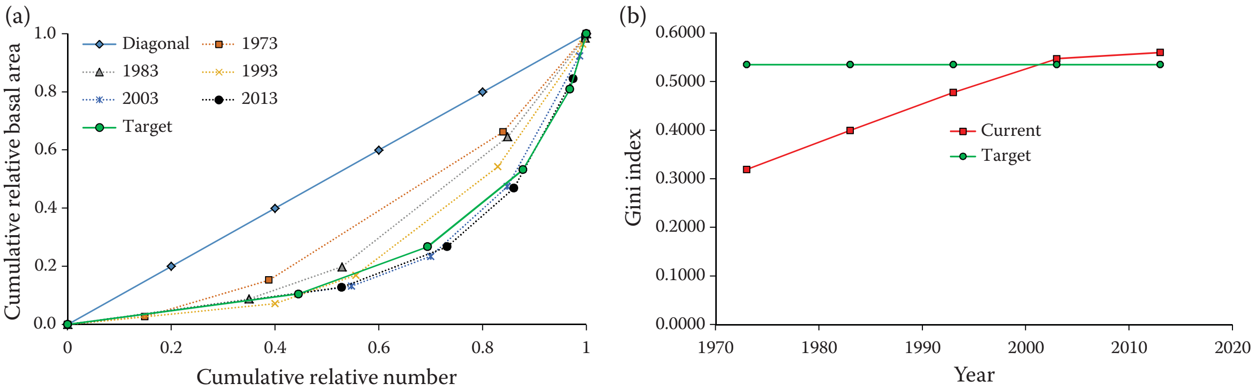

Fig. 4. Comparison of target and computed Lorenz curves (a), Gini index values (b) in individual years of measurements in stand 114 C in Klepačov (the final state was reached in 2003)

Klopcic and Boncina (2011) reported the G_i range from (0.28) 0.35 to 0.52 when studying the stand dynamics of silver fir and European beech forests in three areas in Slovenia. A large range of these values (and/or lower G_i values) was caused by a gradual decrease of the silver fir share.

Based on data from the Norwegian National Forest Inventory, Lexerød and Eid (2004) found that the Gini index values varied from 0.16 to 0.68 in coniferous forests, with a mean value of 0.45. Lexerød and Eid (2006) analysed empirical diameter structure data of even-aged and uneven-aged stands of Norway spruce and Scots pine. Here, the Gini index values varied from 0.21 to 0.51, with a mean value of 0.38. Gini index values ranged from 0.16 to 0.57 for simulated diameter structure, with a mean value of 0.40 (the range from 0.16 to 0.30 corresponded to normal distribution; the range from 0.44 to 0.57 corresponded to J-shaped distribution). They found out that the Gini index can be superior to other measures and have a potential for a wide variety of forest management applications.

The more diverse the diameter structure, the higher the Gini index value (Hui, Pommerening 2014).

As revealed by our research, the Gini index and the coefficient of variation of diameters are correlated (Figs 3a, b). While the coefficient of variation of diameters characterizes only the diameter structure of the stand, the Gini index is a more complex structural indicator to size ordering for equitability description (Studeny et al. 2011). The relationship between the Gini index and the coefficient of variation of diameters was confirmed by Duduman (2011). Both our and that of Duduman (2011) models of this correlation are very similar (Fig. 3a). Duduman (2011) provided the 20–40% range of coefficients of variation of diameters ($S\%$) for even-aged stands and 50–80% for uneven-aged stands. A similar conclusion was drawn in our experiment.

Duduman (2011) also used the Gini index for evaluation of the structure of Romanian uneven-aged stands. The Gini indices in Romanian stands varied from 0.23 to 0.66. Duduman expressed the size of the Gini index for various stand structures and derived the following conclusions: even-sized (even-aged) structure: $G_i \leq 0.35$; two-sized (two-aged): $0.35 < G_i \leq 0.43$; uneven-sized (uneven-aged) irregular: $0.43 < G_i \leq 0.51$ and uneven-sized (uneven-aged) balanced: $G_i > 0.51$.

We compared our Gini index values with those of Duduman (2011) for various stand structures and we concluded that none of the stands reached even-sized structure, 5 stands reached two-sized structure, 6 stands reached uneven-sized irregular structure and 5 stands reached uneven-sized balanced structure.

It is obvious that a clear boundary distinguishing different types of stand structures is only a framework, as is well shown in Fig. 3b. The threshold 0.51 reported by Duduman (2011) does not exactly separate stands of the structure "uneven-sized irregular" and "uneven-sized balanced". In our opinion, Gini index-based stand structure determination should be used with regard to the local and stand conditions. This issue may be a subject for further research in the future.

Although G_i is considered one of the best diversity indices in the assessment of diameter diversity (Lexerød, Eid 2006), it is necessary to take into account that various stand structures with different Lorenz curves can produce the same G_i value (Weiner, Solbrig 1984). That is why the interpretation of the Gini index values should be carried out simultaneously with the interpretation of Lorenz curves, as is suggested e.g. by Klopcic and Boncina (2011). The length of time between particular inventories of diameter diversity is also important. It is better to choose a longer interval to obtain reliable Gini index values.

CONCLUSIONS

Based on aforementioned results of the G_i based evaluation of 40-year transformation to a selection forest at the TFE Masaryk Forest Křtiny, we found that the Gini index values are significantly correlated with the coefficients of variation of diameters.

It is to assume that the Gini index can be applied to evaluate the diameter structure in stands under conversion from clear-cutting to selective harvest management systems and it can also be successfully used as a means of assessment of the long-term development of diameter structure and its convergence to an ideal state.

Acknowledgment

The authors would like to thank all those who carried out the inventories in stands under transformation to the selection forest in TFE Masaryk Forest Křtiny in recent decades. Special thanks belong to Mr. J. Truhlář for his guidance and supervision of inventories.

References

Baker J.B., Cain M.D., Guldin J.M., Murphy P.A., Shelton M.G. (1996): Uneven-aged Silviculture for the Loblolly and Shortleaf Pine Forest Cover Types. General Technical Report SO-118. Asheville, USDA Forest Service, Southern Research Station: 65.

Balanda M. (2012): Spatio-temporal structure of natural forest: A structural index approach. Beskydy, 5: 163–172.

Binkley D., Kashian D.M., Boyden S., Kaye M.W., Bradford J.B., Arthur M.A., Fornwalt P.J., Ryan M.G. (2006): Patterns of growth dominance in forests of the Rocky Mountains, USA. Forest Ecology and Management, 236: 193–201.

de Liocourt F. (1898): De l'aménagement des sapinières. Bulletin trimestriel – Société forestière de Franche-Comté et Belfort, 4: 396–409.

Dixon P.M., Weiner J., Mitchell-Olds T., Woodley R. (1987): Bootstrapping the Gini coefficient of inequality. Ecology, 68: 1548–1551.

Doležal B. (1948): Základní pojmy v učení o kontrolních metodách. Brno, VŠZ: 200.

Duduman G. (2011): A forest management planning tool to create highly diverse uneven-aged stands. Forestry, 84: 301–314.

European Environment Agency (2007): European Forest Types: Categories and Types for Sustainable Forest Management Reporting and Policy. EEA Technical Report No. 9/2006. Copenhagen, European Environment Agency: 111.

Gini C. (1912): Variabilità e mutabilità. Studi Economico-Giuridici della R. Universita di Cagliari, 3: 3–159.

Gini C. (1921): Measurement of inequality of incomes. The Economic Journal, 31: 124–126.

Hui G., Pommerening A. (2014): Analysing tree species and size diversity patterns in multi-species uneven-aged forests of Northern China. Forest Ecology and Management, 316: 125–138.

Klopcic M., Boncina A. (2011): Stand dynamics of silver fir (*Abies alba* Mill.)-European beech (*Fagus sylvatica* L.) forests during the past century: A decline of silver fir? Forestry, 84: 259–271.

Knox R.G., Peet R.K., Christensen N.L. (1989): Population dynamics in loblolly pine stands: changes in skewness and size inequality. Ecology, 70: 1153–1167.

Korf V. (1955): Taxace lesů. 2. část. Hospodářská úprava lesů. Prague, Státní zemědělské nakladatelství: 363.

Lei X., Wang W., Peng C. (2009): Relationships between stand growth and structural diversity in spruce-dominated forests in New Brunswick, Canada. Canadian Journal of Forest Research, 39: 1835–1847.

Lexerød N., Eid T. (2004): Potensielt areal for selektive hogster i barskog – en kvantifisering basert på Landsskogtakseringens prøveflate. Rapport fra Skogforskningen 7/04. Ås, Norwegian Forest and Landscape Institute: 35.

Lexerød N.L., Eid T. (2006): An evaluation of different diameter diversity indices based on criteria related to forest management planning. Forest Ecology and Management, 222: 17–28.

Lorenz M.O. (1905): Methods of measuring the concentration of wealth. Publications of the American Statistical Association, 9: 209–219.

Lundqvist L. (2004): Stand development in uneven-aged subalpine *Picea abies* stands after partial harvest estimated from repeated surveys. Forestry, 77: 119–129.

Meyer H.A. (1943): Management without rotation. Journal of Forestry, 41: 126–132.

Meyer H.A. (1952): Structure, growth, and drain in balanced, uneven-aged forests. Journal of Forestry, 52: 85–92.

Němeček J., Macků J., Vokoun J., Vavříček D., Novák P. (2001): Taxonomický klasifikační systém půd České republiky. Prague, ČZU: 79.

Neumann M., Starlinger F. (2001): The significance of different indices for stand structure and diversity in forests. Forest Ecology and Management, 145: 91–106.

Nyland R.D. (2003): Even- to uneven-aged: The challenges of conversion. Forest Ecology and Management, 172: 291–300.

O'Hara K.L. (2001): The silviculture of transformation – a commentary. Forest Ecology and Management, 151: 81–86.

O'Hara K.L., Hasenauer H., Kindermann G. (2007): Sustainability in multi-aged stands: An analysis of long-term plenter systems. Forestry, 80: 163–181.

Pommerening A. (2002): Approaches to quantifying forest structures. Forestry, 75: 305–324.

Schütz J.P. (1975): Dynamique et conditions d'équilibre de peuplements jardinés sur les stations de la hêtraie à sapin. Schweizerische Zeitschrift für Forstwesen, 126: 637–670.

Schütz J.P. (2002): Silvicultural tools to develop irregular and diverse forest structures. Forestry, 75: 329–337.

Sterba H., Ledermann T. (2006): Inventory and modelling for forests in transition from even-aged to uneven-aged management. Forest Ecology and Management, 224: 278–285.

Studeny A.C., Buckland S.T., Illian J.B., Johnston A., Magurran A.E. (2011): Goodness-of-fit measures of evenness: A new tool for exploring changes in community structure. Ecosphere, 2: 1–19.

Truhlář J. (1975): Soubor porostů v převodu na les výběrný. Hospodářská úprava kontrolními metodami. Brno, Školní lesní podnik VŠZ Křtiny: 24.

Valbuena R., Packalén P., Martín-Fernández S., Maltamo M. (2012): Diversity and equitability ordering profiles applied to study forest structure. Forest Ecology and Management, 276: 185–195.

Weiner J., Solbrig O.T. (1984): The meaning and measurement of size hierarchies in plant populations. Oecologia, 61: 334–336.

Received for publication March 24, 2017
Accepted after corrections October 3, 2017