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Analysis of operational approach during forest transformation in Klokočná Range, Central Bohemia

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ABSTRACT: In this study immediate results concerning the effectiveness of the applied silvicultural measures in the course of forest transformation were analysed. Diameter distribution, homogeneity index, Gini index, Lorenz ordering and Shannon evenness index were used as indicators of structural changes on 15 study plots (0.25 ha in size) before and immediately after the harvest intervention (harvest intensity from 10% to 31%) aimed at increasing structural heterogeneity on selected study sites. Structural analyses showed that immediate changes in structural indices after the harvest operation are relatively small, while changes in DBH distribution are more evident and they are also a more appropriate tool for a forest manager. The homogeneity index is more suitable for a comparison of present structural characteristics among the study plots. Generally, a longer time is necessary for the evaluation of the effectiveness of particular silvicultural treatments, when structural changes induced by natural regeneration and ingrowth become apparent.

Keywords: stand transformation; harvest; diameter distribution; De Camino homogeneity; Lorenz ordering; Gini index; Shannon evenness index

Clear and consistent definition of close-to-nature silviculture that would be applicable to all forest sites and social, historical and cultural situations is still problematic. Nevertheless, in recent discussions two main principles characteristic of this term have occurred. Firstly, it is the use of natural processes for economic reasons; secondly, it is the effort aimed at higher heterogeneity of forests with positive effect on production and risk prevention, but also non-production functions such as nature conservation (e.g. promotion of attributes otherwise typical of old-growth forest, protection of habitats and endangered species), amenity and recreation (Knoke et al. 2001; Hanewinkel 2002; Franklin et al. 2007; Bauhus et al. 2009; Knoke 2009; Vuidot et al. 2011; Diaci et al. 2011; Roessiger et al. 2011; Huth, Wagner 2013). Whereas the first principle remains the domain of silviculture (forest manager should be the only person who is capable to decide on the best suited operation for attaining a certain management goal), in the second case at least three perceptions of silviculturalist, nature conservationist and forest visitor can interfere. In this paper we will try to discuss the questions of silvicultural technique rather than possible conflicts of interests that often have both scientific and philosophic reasons.

Development in forestry has shown that close-to-nature silviculture has to be formulated in a much broader way than only like the renewal of forest stands on the smallest possible scale and under the shelter of parent stand, but also the renewal and growth of cohorts of trees on larger areas and not always necessarily under the canopy of seed bearers (Schütz 1999; 2014). The rejection of large cover release in stands dominated by fir, beech and spruce is coherent with ecological demands of these tree species, but is less acceptable for example in stands of light-demanding tree species like oaks and pines. A liberal definition of close-to-nature silviculture was firstly introduced by Leibundgut (1949), who rejected schematically used

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silvicultural regimes and proposed the free choice of cutting with the use of varying interventions guided by an appropriate control system (Schütz 2014).

In the study area frequent abiotic disturbances like snow load and windbreaks caused repeated damage in even-aged stands of spruce and pine and accelerated the process of forest transformation from even-aged stands to forest stands characterised by a liberal felling treatment. In order to ensure the success of the transformation process, present and past measures must be appropriately analysed. For the evaluation of ecological, economic and other multi-functional aspects good knowledge of tree size distribution is important (Valbuena et al. 2012). The focus of this article is on the plot-level diversity of diameter classes based on dispersion estimates of tree size before and immediately after selective harvest in particular forest stands. De Camino's homogeneity index (1976) was developed as the application of Lorenz ordering in forestry, though this tool was less frequently used than the Gini index (Gini 1921). Bachofen and Zingg (2001, 2005) showed for example the effectiveness of forest management operations in relation to structure improvement in mountain spruce forests and compared these results with adjacent stands with no treatment. Bachofen (1999) computed this index when comparing two different selection forests in terms of their equilibrium and development. Saniga et al. (2014) used the homogeneity index to describe the vertical structure of beech-dominated natural forest in the Oblík National Nature Reserve. Vencurik et al. (2012) used this measure of forest homogeneity for classification of forest stand structures in the Mláčik National Nature Reserve. As a measure of spatially inexplicit diameter diversity also the Shannon evenness index (Shannon, Weaver 1949; Pielou 1969) was used. All three indices are described in detail in Materials and Methods.

The general aim of this paper is to compare selected spatially inexplicit structural indices and their sensitivity to applied silvicultural measures regarding the stand structure. Further we aim to analyse an operational approach during the forest transformation and to answer the question whether the selected harvest intensity and spatial arrangement decrease or increase the homogeneity of forest stands under study.

MATERIAL AND METHODS

The research area is managed by Forests of the Czech Republic, State Enterprise. This area is a part of the Konopiště Forest Enterprise, Říčany Forest District. The average temperature of the area is 7.5°C, the vegetation period lasts about 150 days, total annual precipitation amounts to 600 mm, with less than 400 mm in the vegetation period, average elevation of the study area is 480 a.s.l. with characteristic flat relief (Remeš, Kozel 2006).

According to the forest management plan the stands are divided into two types of forest development (FDT): A – acidic forest sites (according to the Czech forest ecosystem classification predominantly 3K – *Querceto-Fagetum acidophilum*); B – waterlogged forest sites (predominantly 4P – *Querceto-Abietum variohumidum acidophilum*) (Viewegh et al. 2003). In each forest development type the stands are divided according to their spatial and age structure into four segments: 1 – young even-aged stands with full canopy without undergrowth, minimal area ≥ 0.25 ha (not included in the study); 2 – stands with advance regeneration, the middle layer accounts for less than 10% of the stand volume, minimal area ≥ 0.5 ha; 3 – stands with more than two layers, the middle layer accounts for more than 20% of the stand volume, the upper layer did not reach full maturity, minimal area ≥ 0.5 ha; 4 – stands with similar structure like in segment 3, the upper layer has reached full maturity, minimal area ≥ 0.5 ha.

Data was collected from fifteen 0.25 ha study plots (SP), mostly 50 × 50 m in size, immediately before and after the harvest operation in 2013. The planned harvest in a particular forest site was the major criterion for the selection and establishment of these test sites. Their basic characteristics are indicated in Table 1. Within each study plot all woody stems ≥ 10 cm DBH were measured. For each stem, the diameter in mm at 1.3 m above the ground (DBH) was measured crosswise with a calliper, the measurement point being marked, the total height and the crown height (Vertex hypsometer, Haglöf Sweden AB, Långsele, Sweden, to the nearest 0.1 m) were measured.

From these data heights were calculated by means of the height curve, using the formula according to Näslund (1936). Stand density, volume and stand basal area were calculated by standard mensurational methods using volume equations (Petráš, Pajtík 1991). The Liocourt model curve (Liocourt 1898) was used to model an ideal selection forest. Differences in top heights (calculated as heights of 20% of the thickest trees) between the species and forest development type were separately tested by one-way analysis of variance (ANOVA). Data were log transformed to acquire normal distribution (tested by Shapiro-Wilk test).

De Camino's homogeneity index (1976) was computed as an indicator of stand homogeneity. Equation (1) for this index of homogeneity (H) is as follows:

$$H = \frac{\sum_{i=1}^{u-1} \text{SN\%}}{\sum_{i=1}^{u-1} (\text{SN\%} - \text{SV\%})} \quad (1)$$

where:

SN% – sum of stem percentages up to DBH class i,

SV% – sum of volume percentages up to DBH class i.

The Lorenz curve is then a very useful tool for graphical comparison of stand structures showing the relation between the variables SN% and SV%. For a completely homogeneous stand, the Lorenz curve forms a diagonal between the points (0, 0) and (100, 100). The less homogeneous the stand, the more the Lorenz curve deviates from this diagonal (Kramer 1988; Bachofen, Zingg 2001).

The Gini index was calculated from individual tree data (Gini 1921). The Gini coefficient was calculated using equation (2) according to Glasser (1962).

$$G = \frac{1}{\overline{X}_n (n-1)} \sum (2i - n - 1) X_i \quad (2)$$

where:

X_i – sizes sorted from smallest to largest tree, $X_i \leq X_2 \leq \ldots X_n$.

As spatially inexplicit index quantifying diameter diversity, the Shannon evenness index (S) (Shannon, Weaver 1949; Pielou 1969) was computed. We calculated for basal area (G) proportions as equation (3):

$$S = (-\sum_{i=1}^{M} p_i \times \ln p_i) / \ln(15) \quad (3)$$

where:

M – number of diameter classes;

p_i – proportion of basal area in diameter class i ($m^2 \cdot ha^{-1}$).

S takes values between 0 for only one diameter class and 1 when all diameter classes are equally abundant, while 15 tree species were set as default for maximal entropy.

Data were analysed using the Statistica 12 software. Basic stand parameters, harvested volume and tree species diversity were correlated. Significance of statistics was noted as follows: $P \leq 0.01$, $P \leq 0.05$, $P > 0.05$.

RESULTS

As shown in Table 1, stand characteristics are highly variable with pronounced differences in standing volumes and also tree species composition irrespective of forest development types and their segments. Growing stock on study plots ranged from 244.04 (SP 9) to 542.36 $m^3 \cdot ha^{-1}$ (SP 15), tree numbers ranged from 284 (SP 12) to 516 $trees \cdot ha^{-1}$ (SP 14). Representation of spruce was the highest on SP 1 with 91.20% and the lowest on SP 8 with 9.59%. Nevertheless, a contrast in production capacity between forest development types is apparent from Fig. 1a, where height curves for spruce and pine on FDT A are superior to height curves for FDP B.

Table 1. Study plot characteristics including forest development type and volume proportions for particular tree species

Study plot	Forest development type	Forest stand	Age	Total volume ($m^3 \cdot ha^{-1}$)	Spruce volume (%)	Pine volume (%)	Volume of other spp. (%)	Tree number ($indd \cdot ha^{-1}$)
1	B2	216Fa12b	120	440.08	91.20	5.83	2.97	384
2	B2	216Fa12a/1a	120	489.28	86.94	8.00	5.05	332
3	A2	629A9/4/52	90	323.76	65.89	32.32	1.79	428
4	A2	631C13b/1p	130	523.32	60.48	30.92	8.60	348
5	A2	626C10a/2a	100	397.40	78.46	6.75	14.79	388
6	A3	626C10a/2a	100	286.84	21.34	70.09	8.58	484
7	B4	626B10/5a/2a	100	304.92	36.21	57.98	5.81	400
8	B3	216Fa8	80	286.56	9.59	75.77	14.64	352
9	B4	626B10/5a/2a	100	244.04	58.70	24.42	16.88	456
10	B4	628C11/2	110	327.28	69.78	27.01	3.21	376
11	B3	216Fa12a/1a	120	491.68	59.01	40.59	0.41	312
12	B3	216Fa12a/1a	120	400.36	73.57	18.59	7.83	284
13	A3	626C10a/2a	100	483.84	66.09	25.94	7.97	332
14	B2	216Fa12b	120	323.88	85.91	10.40	3.69	516
15	A3	626C10a/2a	100	542.36	78.87	13.47	7.66	344

Forest development type: A – acidic forest sites (*Querceto-Fagetum acidophilum*); B – waterlogged forest sites (*Querceto-Abietum variohumidum acidophilum*), 2–4 – segment of forest development type, for more details see Materials and Methods; Age – age of the overstorey according to forest management type; Total volume – growing stock per 1 ha calculated from dendrometric data collected on study plots

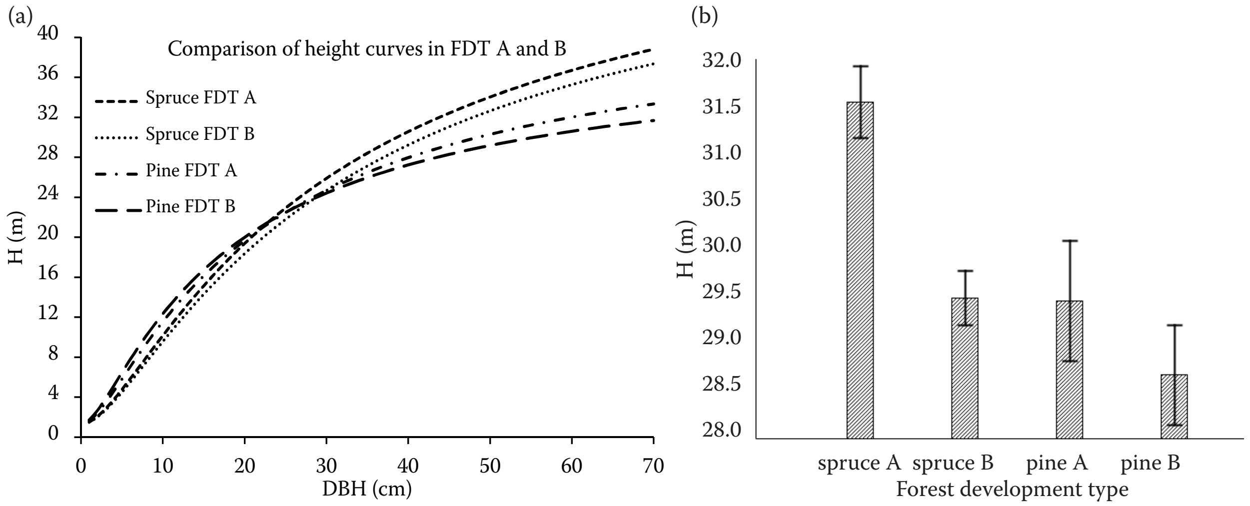

Fig. 1. Height curves for pine and spruce for forest development type (FDT) A – acidic and B – waterlogged forest sites in the study area (a); top heights for particular forest development types and tree species. Error bars denote standard error of the mean (b)

There is a statistically significant difference in top heights of spruce between forest development types ($F_{(1, 138)} = 23.2$, $P < 0.01$), whereas in the case of pine no difference was confirmed ($F_{(1, 42)} = 0.6$, $P = 0.46$) (Fig. 1b).

Removed wood volumes ranged from 32.32 $m^3 \cdot ha^{-1}$ on SP 14 (harvest intensity 10%) to 152.96 $m^3 \cdot ha^{-1}$ on SP 11 (harvest intensity 31%) with the highest average volume of individual harvested tree (2.39 m^3) on this study plot (Table 2). The lowest average volume of harvested tree was 1.04 m^3 on SP 9 and the average value for all plots was 1.50 m^3.

On study plots 3, 8, 9, 12 and 13 the increase or decrease of homogeneity index before and after the harvest operation is not consistent with the change in the value of Shannon evenness index (with the exception of study plot 13 this is also valid for the Gini index). Inconsistency between Shannon evenness and

Table 2. Harvest volumes, homogeneity index (*H*), Shannon evenness index (*S*) and Gini index (*G*) before and after the harvest operation in a particular stand

Forest development type	Study plot	Harvest			H_b	H_a	S_b	S_a	G_b	G_a	Relative change of H and S
		($indd \cdot ha^{-1}$)	($m^3 \cdot ha^{-1}$)	intensity (%)							
B2	1	48	50.56	11.49	6.21	5.87	0.729	0.738	0.236	0.241	↘↗↗
B2	2	32	48.48	9.91	4.51	4.46	0.771	0.777	0.270	0.273	↘↗↗
B2	14	28	32.32	9.98	3.52	3.50	0.794	0.801	0.501	0.531	↘↗↗
A2	3	44	38.32	11.84	3.47	3.49	0.783	0.787	0.335	0.338	↗↗↗
A2	4	40	74.76	14.29	3.40	3.39	0.696	0.703	0.238	0.246	↘↗↗
A2	5	40	65.4	16.46	2.89	2.83	0.844	0.863	0.414	0.430	↘↗↗
B3	8	52	80.80	28.20	2.93	3.07	0.772	0.775	0.381	0.395	↗↗↗
B3	11	64	152.96	31.11	2.58	2.33	0.763	0.783	0.366	0.384	↘↗↗
B3	12	40	59.32	14.82	2.88	2.78	0.719	0.700	0.332	0.332	↘↘↘
A3	6	32	41.76	14.56	2.18	2.26	0.837	0.833	0.487	0.492	↗↘↗
A3	13	56	129.68	26.80	3.25	3.21	0.811	0.720	0.367	0.368	↘↘↗
A3	15	40	46.40	8.56	4.57	4.64	0.744	0.735	0.258	0.247	↗↘↘
B4	7	32	46.36	15.20	2.00	2.00	0.769	0.782	0.448	0.466	→↗↗
B4	9	44	45.72	18.73	2.18	2.23	0.801	0.807	0.514	0.521	↗↗↗
B4	10	40	65.64	20.05	1.99	2.03	0.762	0.755	0.432	0.456	↗↘↗

H_b – De Camino's homogeneity index before harvest; H_a – De Camino's homogeneity index after harvest; S_b – Shannon evenness index before harvest; S_a – Shannon evenness index after harvest; G_b – Gini index of inequality before harvest; G_a – Gini index of inequality after harvest; relative change of *H*, *S* and *G*: ↘ decreasing index value, ↗ increasing index value, → no change in index value

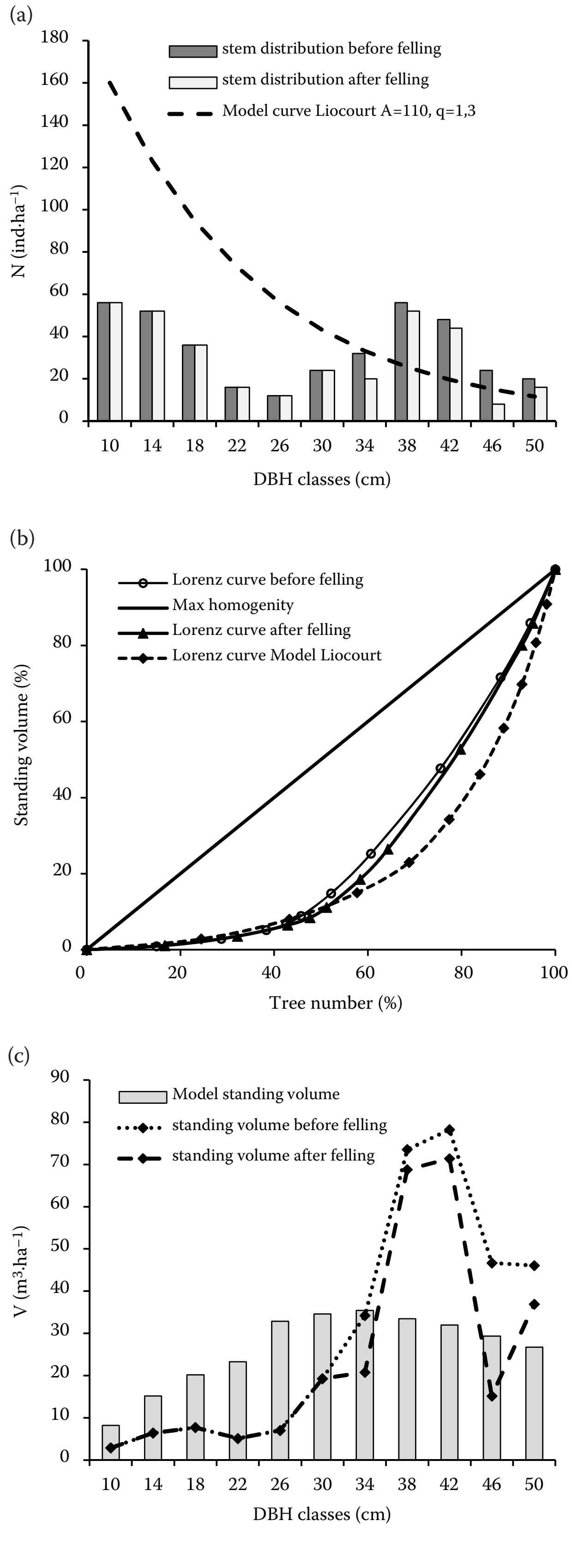

Fig. 2. Stem distribution before felling and after felling with Liocourt model curve (A = 110, q = 1.3); (a) Lorenz ordering with interdependence of the parameters SN (%) and SV (%), (b) distribution of harvested wood volumes among DBH classes, (c) on study plot 10

Gini indices was found only on plots 6, 10, and 13. Generally, the shift in the value of structural indices is very small and correlates neither with number of harvested individuals nor removed wood volumes, or harvest intensity. Only on SP 15 (study plot with the lowest harvest intensity) according to all three structural indices the heterogeneity of forest stand was lower after the harvest operation, whereas on all other plots according to at least one structural index the felling operation immediately contributed to the higher structural diversity of forest stand (Table 2).

As expected, the lowest values of the homogeneity index (*H*) were reached in segment B4 on test sites 7, 9 and 10. Fig. 2 shows a typical situation for this segment on study plot 10, where the applied treatment increased the value of homogeneity index from $H = 1.99$ to 2.03 (the value of homogeneity index calculated for ideal selection structure is $H = 2.42$). Stem distribution before felling, after felling and Liocourt model curve are shown in Fig. 2a, Lorenz ordering is shown in Fig. 2b. In accordance with the model curve (A = 110, q = 1.3) harvested trees were in DBH classes from 34 to 50 cm (Fig. 2c).

Generally, higher values of the homogeneity index (*H*) were reached in segments 2 and 3, nevertheless not always with lower values in segment 2, where the more simplified forest structure was expected. In total, the homogeneity index (*H*) amounted to the highest value on SP 1. DBH structure before and after felling for this SP and the Lorenz ordering are shown in Fig. 3.

The homogeneity index is positively correlated with total basal area ($m^3 \cdot ha^{-1}$), total volume ($m^3 \cdot ha^{-1}$) and volume of Norway spruce ($m^3 \cdot ha^{-1}$) and negatively correlated with the volume of Scotch pine ($m^3 \cdot ha^{-1}$). The Shannon evenness index is negatively correlated with the total basal area ($m^3 \cdot ha^{-1}$) and positively correlated with tree numbers (trees·ha^{-1}). The Gini index is negatively correlated with total basal area ($m^3 \cdot ha^{-1}$), total volume ($m^3 \cdot ha^{-1}$), volume of Norway spruce ($m^3 \cdot ha^{-1}$), and positively correlated with tree numbers (trees·ha^{-1}). Numbers of trees per ha were negatively correlated with both total basal area and total volume, generally on plots with higher tree numbers before felling, the harvest operation removed smaller amounts of wood. With the higher share of pine total basal area as well as total volume decreased on study plots (Table 3).

DISCUSSION

To characterise the stand structure of a particular forest stand, a single variable is insufficient. On all study plots presented here the main goal of for-

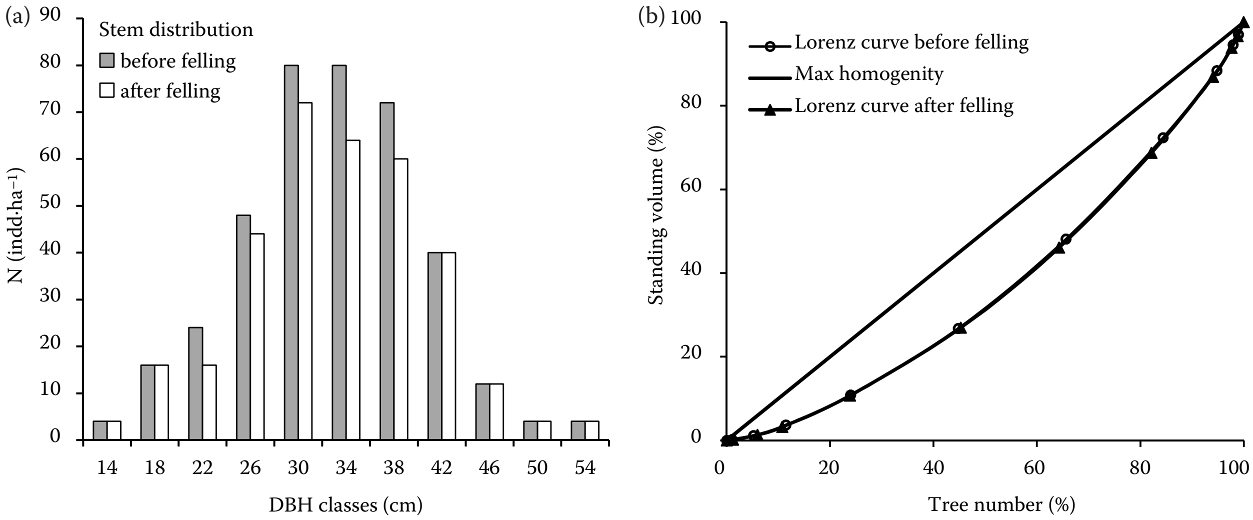

Fig. 3. Stem distribution before felling and after felling; (a) Lorenz ordering with interdependence of the parameters SN (%) and SV (%), (b) on study plot 1

est intervention was to promote forest structures resembling that of a selection forest. Structural analyses show that immediate changes in structural indices after the harvest operation are relatively small, while changes in DBH distribution are more evident and they are also a more appropriate tool for a forest manager. Moreover, according to Bachofen and Zingg (2001) changes in the coefficient of homogeneity and Lorenz curve due to the treatment are not clearly visible. The reason for this may be that the removal of trees implies changes in tree numbers and growing stock in the same direction. Thus we suggest that this structural index is quite a suitable indicator of equilibrium in a long-term survey of selection forest and for the immediate effect of harvest operations rather than the Gini index and diameter distribution among diameter classes should be used.

On the other hand, it has been confirmed that both the Gini index and the homogeneity index are more sensible indicators than the Shannon evenness index. Generally, heterogeneous stands should have a lower coefficient of homogeneity, homogeneous stands a higher one. Camino (1976) gave several examples of forest types and their expected value of homogeneity index: for even-aged spruce stands thinned from above $2.2 \leq H \leq 3.9$; for even-aged beech stands thinned from above $3.4 \leq H \leq 4.2$; for even-aged beech and spruce stands thinned from below $H > 5.0$ and for selection forest $1.3 \leq H \leq 2.8$. In segment 2 our results supported the opinion that the homogeneity of selection forest or stands in a transition period is higher on poorer sites (on acidic sites the average value of $H_b = 3.25$, waterlogged sites $H_b = 4.75$) than on rich ones. Nevertheless, this is not true of segment 3, where acidic sites reached the average value of homogeneity index before harvest $H_b = 3.33$ (even the higher value than in segment 2), while on waterlogged sites only $H_b = 2.80$. This result may be influenced by a very high degree of homogeneity on SP 15 with high growing stock and

Table 3. Correlation matrix describing the stand structure before harvest operation

	Basal area ($m^2·ha^{-1}$)	Volume ($m^3·ha^{-1}$)	Spruce volume ($m^3·ha^{-1}$)	Pine volume ($m^3·ha^{-1}$)	Tree number ($trees·ha^{-1}$)	Harvest ($m^3·ha^{-1}$)	H_b	S_b	G_b
Basal area	1.000								
Volume	0.986**	1.000							
Spruce volume	0.817**	0.836*	1.000						
Pine volume	–0.100	–0.132	–0.637*	1.000					
Tree number	–0.611*	–0.661**	–0.425	–0.125	1.000				
Harvest	0.417	0.430	0.094	0.447	–0.577*	1.000			
H_b	0.554*	0.552*	0.713**	–0.512*	–0.171	–0.174	1.000		
S_b	–0.525*	–0.457	–0.368	–0.019	0.535*	–0.025	–0.380	1.000	
G_b	–0.791**	–0.796**	–0.685**	0.130	0.665**	–0.134	–0.739**	0.688**	1.000

H_b – De Camino's homogeneity index before harvest; S_b – Shannon evenness index before harvest; G_b – Gini index of inequality before harvest; *statistically significant at the level $P < 0.05$, **$P < 0.01$

DBH structure untypical of this FDT (left skewed approaching the shape of the Gaussian curve). On segment 4 the average value of the homogeneity index on waterlogged sites (B4) dropped to the lowest average value $H_b = 2.06$. Despite this Camino (1976) considered this coefficient as capable to monitor the site quality of selection forest, since on poorer sites normally higher homogeneity of selection forests is expected. According to Lexerød and Eid (2006) in simulated diameter distributions the Gini coefficient range from 0.16 to 0.30 indicated normal distribution and the range from 0.44 to 0.57 indicated J-shaped distribution, which was mainly the case of segment B4 in our study. Despite this, it has been shown that segments of forest development types do not always coincide with the observed structural heterogeneity of a particular study site. This is mainly due to rather a coarse spatial forest arrangement, where each FDT covers an area of 0.5 ha at least, while SP covered the area of 0.25 ha only. This explains why for example on SP 5 in segment A2 relatively low value of structural heterogeneity ($H_b = 2.89$), high value of Shannon evenness index ($S_b = 0.844$) and Gini index ($G_b = 0.414$) were reached, while on SP 15 in segment A3 structural heterogeneity amounted to much higher value ($H_b = 4.57$), Shannon evenness index ($S_b = 0.744$) and Gini index ($G_b = 0.258$) dropped to relatively lower values.

In accordance with Bachofen and Zingg (2001) it has been shown that it is possible to increase the heterogeneity by strong interventions. Nevertheless, the forest manager should also consider the question of risk prevention: whereas with moderate interventions the desired effect on stand structure is not assured, intensive harvest may also increase the threat to the stand stability. Whether the forest stand after moderate treatments develops in a desired direction will not be seen immediately, but only within a longer time span. In present observations, with increasing growing stock and basal area it seems logical to observe the lower stand structural diversity, while a higher portion of pine allows the co-existence of shade tolerant spruces in middle and lower layers (Table 3). Thus, at least at the initial stage of forest transformation this tree species could help to create more diversified forest structures, although its share as shade intolerant tree species will successively decrease.

The real effectiveness of a silvicultural treatment cannot be based on one single variable, nor can it be effectively assessed without the reaction of supressed individuals below the measured thresholds or the new seedlings emergence. Since adequate regeneration and ingrowth are prerequisites for the creation and long-term maintenance of a selection forest, on all study plots additional measurements of natural regeneration and advanced individuals up to DBH < 10 cm before and after the treatment with long-term observations are necessary.

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