On the way to continuous cover forest at middle elevations – the question of forest structure and specific site characteristics

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ABSTRACT: The transformation process of even-aged forest stands to irregular forest stands on waterlogged sites after 20 years effort was analysed. Data from two 1-ha PRP was analysed with special focus on structural (Shannon Evenness Index, Simpson Index and Gini Index) and species (Shannon Evenness Index and Simpson Index) diversity. Different development on study plots confirmed that the highest structural diversity is not often compatible with the concept of species diversity. On PRP 1 high diameter differentiation has led to lower values of species diversity, while on PRP 2 rather moderate diameter differentiation supported higher species diversity in lower DBH classes. The Gini Index was confirmed to be the best indicator for monitoring the diameter differentiation in the course of stand transformation.

Keywords: Dauerwald; stand transformation; diversity; production; waterlogged site

Since the beginning of the 19th century, different methods of natural regeneration and single-tree oriented systems of management have been developed in Western Europe, mainly in southern Germany and in Switzerland (Schmidt 2009). The continuous cover forest, as "Dauerwald" introduced into forestry practice by Alfred Möller in the 1920s, is a concept of forest management which tries to avoid sudden jumps between forest generations and in one of its forms – the selection forest – represents a silvicultural system where the age of individual trees is no more decisive for their harvest, as it is usual in the age-class forestry and its traditionally described forms. New discussions on this topic in forest literature have shown that the near-natural silviculture has to be formulated in a much broader sense than only renewal on a tree-by-tree basis but also as the renewal and growth of trees in discrete generations using progressive group felling – "Femelschlag"; all this with the same goal in mind, i.e. the creation of structured mixed forest (Schütz 1999b). Möller's original definition of the "Dauerwald" is nothing else than the ecosystem oriented, sustainable forest management (Hofmann 1998) and so hardly different from near-natural silviculture as described in the liberal Swiss concept of this term (Schütz 1999b), where both the selection forest and "Femelschlag" are heading to the same goal: near-naturally composed forest stands, structurally rich and differentiated, sustainable and functional with high and valuable timber production. Another important attribute of both production systems must be mentioned here: the effort to achieve maximal benefits with minimal costs. Thus, the ecosystem and its constituents, the trees with their individual growth characteristics, represent a production system combining ecology and economics. Nowadays the concept needs to be extended and to include the importance of favouring the diversity of forest biotopes and the po-

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tential for using natural processes for economic reasons (Schütz 1999a, 2009; Knoke et al. 2001). The resulting scenario also emerges as the optimal choice, particularly for cautious and thus risk-avoiding forest owners who do not have the opportunity to diversify risks by means of large-scale forest properties (Hanewinkel 2002; Roessiger et al. 2011).

This liberal definition is also much better reflecting the existing forest practice, where the site and climatic characteristics are often limiting for creating a functional selection forest. The application of the concept does however still demand a high level of silvicultural competence. The forest manager must determine, based on the knowledge of the forest site and structure of the forest stand, which method of treatment will be best suited to the actual situation (Schütz 2002, 2009), taking into consideration the overall management goal and of course the past forest stand development.

In the research area, recurrent snow damage and wind breaks in even-aged stands of pine and spruce with subsequent weed infestation and waterlogging were the main impulse for the transformation of forest management from age-class forestry to Dauerwald (Remeš, Kozel 2006) characterised by continual renewal, use of natural regeneration and liberal felling policy. Since the abandonment of clear-cut and start of the forest transformation in 1993 on large tracks of forest stands height and diameter differentiation has increased, in some parts the complex forest structure has developed till now.

This paper analyses the transformation process of cultural even-aged spruce and pine forest stands to irregular forest stands after 20 years effort on sites naturally dominated by oak and silver fir. The general aim is to evaluate a possibility of achieving permanent uneven-aged stands with complex forest structure; an optimal management goal in relation to the forest site is discussed.

MATERIAL AND METHODS

The area of interest is managed by Forests of the Czech Republic, State Enterprise. This territory 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 within the vegetation period. The site type on both plots according to the Czech typological system of forest management planning was classified as 4P – *Querceto-abietum*, elevation is 480 m a.s.l., with flat relief.

Data was collected from two 1-ha (100 × 100 m) permanent research plots (PRP 1 Triangle: 49°58'19"N, 14°43'13"E; PRP 2 Swamp: 49°58'19"N, 14°43'28"E). Within each PRP all woody stems ≥ 8 cm DBH were repeatedly measured after six-year periods in 2000, 2006 and 2012. For each stem, diameter (double measurement in NS and EW), total height and crown height (Vertex hypsometer, to the nearest 0.1 m) were measured. Stand density, volume and stand basal area were calculated by standard mensurational methods using volume equations (Petráš, Pajtík 1991).

As spatially inexplicit indices quantifying diameter diversity, the Shannon Evenness Index (*SEI*) (Shannon, Weaver 1949; Pielou 1969), the Simpson Index (*D*)(Simpson 1949) and the Gini Index (Gini 1921) were computed. The Gini Index was calculated from original individual tree data. In our study, a reciprocal form of the Simpson index (1-index value) was adopted in order to increase the index with increasing diversity. We calculated the basal area (G) proportions.

$$SEI = \frac{-\sum_{i=1}^{s} p_i \times \ln p_i}{\ln (S)} \quad (1)$$

$$D = 1 - \sum_{i=1}^{s} p_i^2 \quad (2)$$

where:

S – number of diameter classes,

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

Shannon Evenness Index takes values between 0 for only one diameter class and 1 when all diameter classes are equally abundant. Simpson Index can assume values between 0 and 1 and is interpreted as the probability that any two trees taken at random belong to different diameter classes. The Gini Index was obtained from the area under the Lorenz curve, which in turn was derived by plotting the cumulative basal area proportions of trees per hectare against the cumulative proportions of the number of stems per hectare, after sorting the sample trees according to ascending diameter (Sterba 2008).

The Gini coefficient quantifies the deviation from perfect equality, and has a minimum value of zero, when all trees are of equal size, and a theoretical maximum of one in an infinite population in which all trees except one have a value of zero (Lexerød, Eid 2006).

As a measure of spatially inexplicit species diversity the Shannon Evenness Index (Shannon, Weaver 1949) and the Simpson Index (Simpson 1949) were used. Here the number of diameter classes was replaced by the number of tree species, the basal area of diameter class was replaced by the number of individuals for each species. Species diversity indices were computed both for the whole plot and for the particular diameter classes.

RESULTS

Liocourt model curve (Liocourt 1898) was used to model an ideal selection forest structure for PRP 1 and PRP 2 (Fig. 1a,b). Based on this model curve,

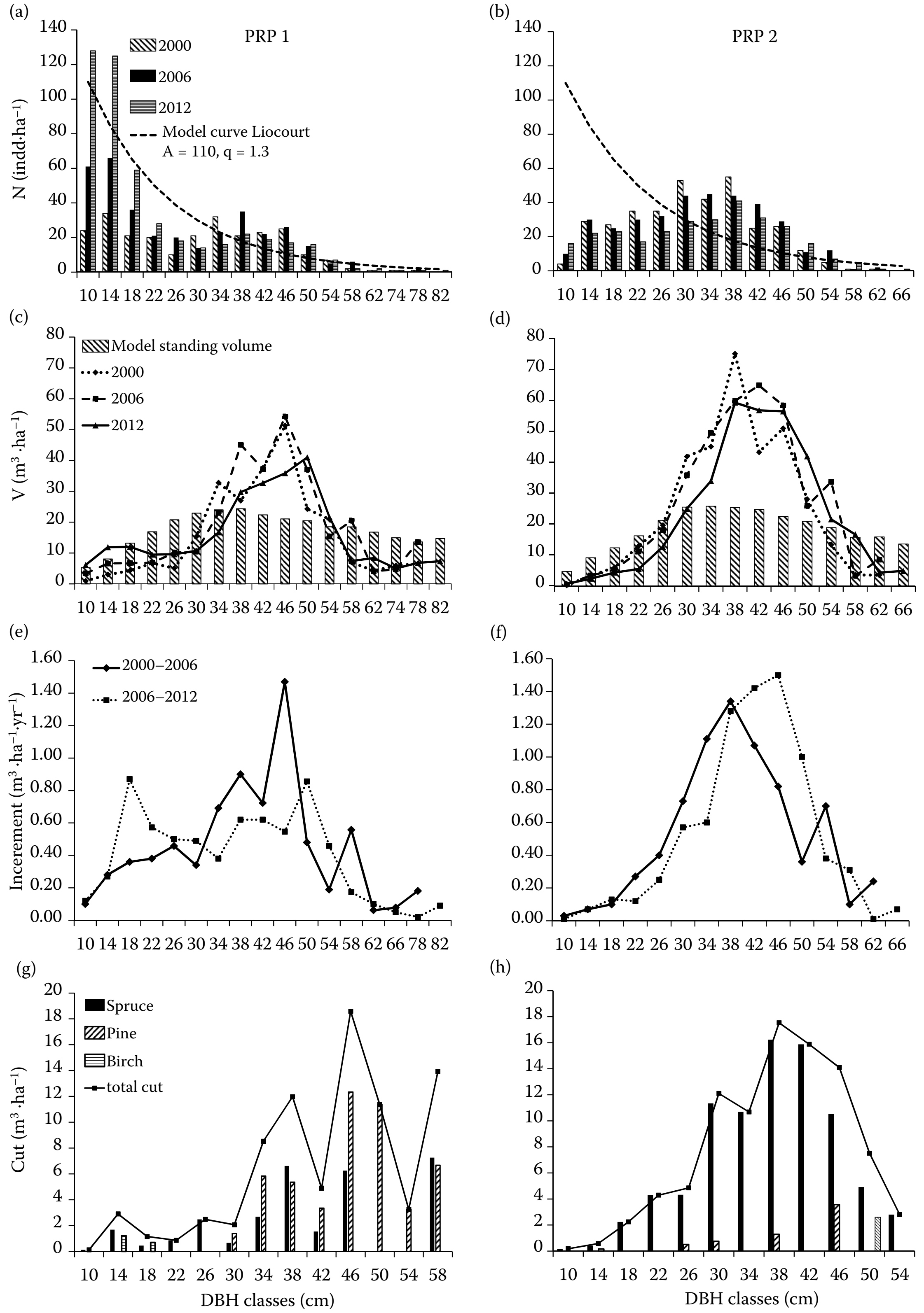

Fig.1. Diameter curve (a, b); standing volume (c, d), current annual volume increment (e, f) and total cut from 2000 to 2012 (g, h) on PRP 1 and PRP 2

Table 1. Development of standing volume, stand basal area, tree numbers, felling, ingrowth, current annual volume increment and increment in 2000, 2006 and 2012 on PRP 1

	Year	Spruce	Pine	Larch	Birch	Total
Standing volume ($m^3 \cdot ha^{-1}$)	2000	108.52	140.76	2.61	0.91	252.87
	2006	143.05	148.80	3.27	3.95	299.07
	2012	149.69	113.62	4.85	4.36	272.52
Stand basal area ($m^2 \cdot ha^{-1}$)	2000	9.93	11.58	0.23	0.15	21.89
	2006	13.04	12.09	0.29	0.54	25.97
	2012	14.38	8.68	0.42	0.67	24.15
Tree numbers ($indd \cdot ha^{-1}$)	2000	160	81	2	10	253
	2006	239	78	6	31	354
	2012	388	54	11	23	476
Felling ($m^3 \cdot ha^{-1}$)	2000–2006	1.06	1.92	0.00	0.30	3.28
	2006–2012	29.53	47.67	0.00	1.62	78.82
Ingrowth ($m^3 \cdot ha^{-1}$)	2000–2006	4.77	0.00	0.24	1.02	6.03
	2006–2012	11.06	0.00	0.44	0.34	11.84
Current annual volume increment ($m^3 \cdot ha^{-1}$)	2000–2006	5.13	1.69	0.07	0.37	7.26
	2006–2012	4.19	2.08	0.19	0.28	6.74
Increment (%)	2000–2006	3.58	1.12	2.09	9.36	2.42
	2006–2012	2.80	1.83	3.93	6.46	2.47

a model standing volume was calculated and compared with standing volume of forest stands in 2000, 2006 and 2012 (Fig. 1c,d). Current annual volume increment and the sum of harvested wood volumes for particular tree species and DBH classes are shown in Fig. 1e–h.

Basic stand development characteristics are listed in Table 1 for PRP 1 and in Table 2 for PRP 2. Current annual volume increment is very similar on both plots with values around 7 $m^3 \cdot ha^{-1}$ for both periods. On PRP 1, the lower standing volume (in 2012 – 272.52 $m^3 \cdot ha^{-1}$ vs. 346.45 $m^3 \cdot ha^{-1}$ on PRP 2) corresponds with higher ingrowth rates (11.84 $m^3 \cdot ha^{-1}$ vs. 0.82 $m^3 \cdot ha^{-1}$) and also higher tree numbers (476 $indd \cdot ha^{-1}$ vs. 288 $indd \cdot ha^{-1}$) at the end of the second observation period. On both plots the main tree species are Norway spruce and Scots pine. While on PRP 1 the majority of new indi-

Table 2. Development of standing volume, stand basal area, tree numbers, felling, ingrowth, current annual volume increment and increment percent in 2000, 2006 and 2012 on PRP 2

	Year	Spruce	Pine	Larch	Fir	Oak	Total
Standing volume ($m^3 \cdot ha^{-1}$)	2000	282.16	47.28	15.81	1.34	0.10	346.71
	2006	310.18	49.16	15.80	2.02	0.99	378.15
	2012	273.40	52.17	16.38	2.99	1.51	346.45
Stand basal area ($m^2 \cdot ha^{-1}$)	2000	24.04	4.36	1.31	0.14	0.02	29.87
	2006	26.02	4.53	1.19	0.20	0.16	32.10
	2012	21.49	4.33	1.21	0.35	0.24	27.62
Tree numbers ($indd \cdot ha^{-1}$)	2000	306	31	7	4	2	350
	2006	301	30	6	6	11	354
	2012	226	26	6	17	13	288
Felling ($m^3 \cdot ha^{-1}$)	2000–2006	9.61	1.69	2.59	0.00	0.00	13.89
	2006–2012	74.24	4.45	0.00	0.00	0.16	78.85
Ingrowth ($m^3 \cdot ha^{-1}$)	2000–2006	0.31	0.00	0.00	0.19	0.79	1.29
	2006–2012	0.24	0.00	0.00	0.42	0.16	0.82
Current annual volume increment ($m^3 \cdot ha^{-1}$)	2000–2006	6.22	0.59	0.43	0.08	0.02	7.34
	2006–2012	6.21	1.26	0.10	0.08	0.07	7.72
Increment (%)	2000–2006	2.01	1.21	2.69	4.02	1.60	1.94
	2006–2012	2.27	2.40	0.61	2.68	4.64	2.23

Table 3. Shannon Evenness, Simpson and Gini indices as measures of diameter diversity on PRP 1 and 2 in 2001, 2006 and 2012

Index	Year	PRP 1	PRP 2
Shannon Evenness	2000	0.764	0.742
	2006	0.819	0.784
	2012	0.751	0.757
Simpson	2000	0.847	0.819
	2006	0.872	0.850
	2012	0.839	0.839
Gini	2000	0.442	0.345
	2006	0.522	0.358
	2012	0.588	0.378

viduals are spruces, on PRP 2 mostly oak and silver fir contributed to the secondary stand. On both plots the felling intensity was rather low during the first period; on the contrary, during the second observation period the removed wood volumes amounted to 79 $m^3 \cdot ha^{-1}$ on both plots.

Diameter diversity and/or diversity of basal areas on PRP 1 and PRP 2 are presented in Table 3. Shannon Evenness Index and Simpson Index identically indicate the highest diameter diversity on both PRP in the middle of the observation period in 2006, and in 2012 again lower values of structural diversity, which are slightly below and slightly above the initial values from 2000 on PRP 1 and PRP 2, respectively. The Gini index indicates on both plots continuous diameter differentiation with the highest values at the end of the observation period in 2012.

On PRP 1 Shannon Evenness Index as a measure of species diversity increased from 0.592 to 0.638 during the first observation period and then it dropped again to 0.467 in 2012. Similar development was also found out in Simpson Index with the initial value of 0.496 in 2000, 0.490 in 2006 and 0.320 in 2012. On PRP 2 Shannon Evenness Index continually increased from the initial value of 0.305 to 0.369 in 2006 and 0.424 in 2012. Simpson Index basically confirmed the same growth of tree species diversity from the initial value of 0.227 to 0.268 in 2006 and 0.389 in 2012. Fig. 2 documents both diversity indices calculated for particular DBH classes on PRP 1 and PRP 2. Shannon Evenness Index curves are discontinuous in case that only one species was present in the particular DBH class.

DISCUSSION

Often antagonistic demands on forestry in general and on close-to-nature silviculture in particular have been described in numerous articles (e.g. Schütz

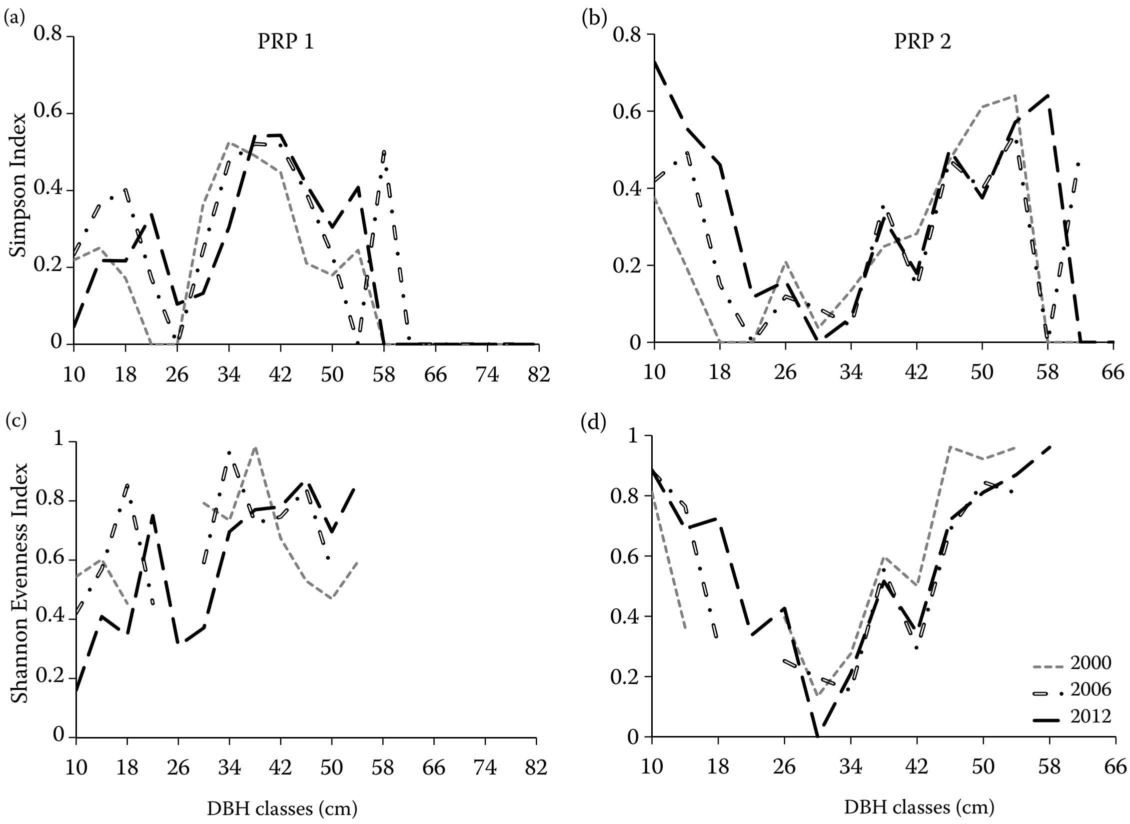

Fig. 2. Simpson Index (a, b) and Shannon Evenness Index (c, d) diversity indices calculated for particular DBH classes on PRP 1 and 2 in 2000, 2006 and 2012

1999a,b). The development of forest structure on PRP 1 and PRP 2 confirmed to a certain extent that the highest structural diversity is not often compatible with the concept of species diversity. On PRP 1 individual selection favoured the dominance of spruce in the regeneration layer and led to an overall decrease of tree species diversity in lower DBH classes (Fig. 2a,c). On the contrary, on PRP 2, where historically larger regeneration patches with artificial regeneration of silver fir and oak were created, the species diversity reached the same values in lower dbh classes as in the upper layer with a still higher proportion of pine and larch (Fig. 2b,d). Considering the horizontal structure of both stands, the main difference is that on PRP 1 new cohorts are interspersed among older cohorts, while on PRP 2 new cohorts are forming family groups or clusters of artificial regeneration. Both strategies for converting even-aged stands to uneven-aged ones may lead to a fully implemented selection system (Nyland 2003), yet with different structural development of these stands. Surprisingly, both strategies after 20 years of implementation has led to the same wood removals with the same or even higher standing wood volumes in 2012 compared to 2000. The question of species diversity remains crucial.

The three evaluated structural coefficients were selected in order to include indices representing different properties. While the Gini Index is mainly influenced by the range, the Simpson Index is defined as a dominance measure and the Shannon Evenness Index is a measure of evenness. An additional advantage of these three selected indices is that the index value does not change when the density of each diameter class is raised in the same proportion. This makes it possible to compare diameter diversity in different stands or in one stand over time, independently of the stand density (Lexerød, Eid 2006). Indices ranging between 0 and 1 are also easy to interpret and allow a quick comparison between each other.

In this study we also omitted frequently used distance dependent indices, since they considerably increase sampling costs and are therefore less suitable for practical forest management. Surprisingly, Shannon Evenness Index and Simpson Index showed almost identical values for both PRPs, while the Gini coefficient clearly indicated differences among plots and particular periods in accordance with the diameter curve (Fig. 1a,b) and its shift from 2000 to 2012. This observation is in accordance with Lexerød and Eid (2006), who showed the highest discriminant ability and best logical ranking for the Gini index. Also Valbuena et al. (2012) pointed out a certain inconsistency of diversity indices when comparing forest structural types and recommended measures of equitability of tree sizes.

Based on data from the Norwegian National Forest Inventory, Lexerød and Eid (2004) found that the Gini coefficient varied from 0.16 to 0.68 in coniferous forests, with a mean value of 0.45. The theoretical value of 1 indicates total inequality with all individuals except that with the value of zero. This is an impossible situation in forest stands, since all stems have a basal area larger than zero.

Lexerød and Eid (2006) analysed an empirical data set with diameter distributions typical of even-aged and uneven-aged forest stands, as well as approximations of other distributions with the Gini coefficient varying from 0.21 to 0.51, with a mean value of 0.38. In simulated diameter distributions the Gini coefficient varied from 0.16 to 0.57, with a mean value of 0.40 (the range of 0.16 to 0.30 indicating normal distribution; the range of 0.44–0.57 indicating J-shaped distribution).

Compared to these values the diameter differentiation expressed as the Gini coefficient on PRP 1 in 2012 is extremely high and is close to the upper limit of this indicator. On the other hand, distinctly lower values of Gini index on PRP 2 indicate quite a uniform diameter distribution. According to Duduman (2011) DBH distribution on PRP 1 can be characterised as uneven-sized with a shift from irregular to balanced, and on PRP 2 as two-sized.

It is broadly accepted that selection forest as an appropriate management method can be applied without major difficulties in the 5th and 6th forest altitudinal zone, where naturally shade-tolerant tree species silver fir, Norway spruce and European beech dominate the forest stands (e.g. Saniga, Szanyi 1998). Based on the presented results we assume that in given conditions in the 4th forest altitudinal zone on waterlogged sites forest stands can develop to a very complex forest structure. At once it should be stated that individual selection will lead to the retreat of oak and other light demanding tree species such as pine, larch and birch. Besides the underplanting of silver fir, forest managers should also rethink the possibilities of creating larger gaps with subsequent artificial regeneration of oak in the sense of "liberal" close-to-nature silviculture, which involves selection forest as well as locally applied small clearcut (Schütz 1999b). Optimal size and orientation of such regeneration groups may be formulated based on further research efforts. It was confirmed that in the given conditions the

Gini Index is the best tool able to monitor a shift from even- to uneven-sized forest stands as result of continuing transformation efforts.

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