Relation between selected indicators of forest stand diversity and quality of timber production in young stands aged up to 40 years

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ABSTRACT: The present study examines the relationships between the indicators of tree species and structural diversity and the quality of timber production in young even-aged forest stands with the average age below 40 years. The study is based on the forest inventory data from University Forest Enterprise Kostelec nad Černými lesy, Czech Republic, performed from 2009 to 2011. The examined young stands were recorded in 256 sample plots representing 21.2% of the enterprise area. On each sample plot, we quantified 171 partial biodiversity indicators. In total, we analysed 16,416 different variants of the relationship between the diversity indicator and the quality of timber production. The analysis revealed that similarity indicators such as the range of tree heights, Canberra distance, Bray and Curtis index, and index of species evenness and heterogeneity were the most frequent basic indicators occurring in significant correlations. The results indicate a positive relationship between the proportions of assortments in quality classes I to IV and stand diversity expressed by the number of tree species and Canberra distance.

Keywords: species and structural diversity; managed forest; assortment

Forests represent the most important repositories of terrestrial biological diversity (Honnay et al. 1998, 1999). It includes diversity of plants, animals and habitats. Due to the complexity of both biodiversity and forest ecosystems, complete assessments of biodiversity are not practically achievable (Humphrey, Watts 2004) because it is impossible to monitor all taxa or features (Lindenmayer 1999). Therefore, means and measures that reduce the complexity are usually applied for the biodiversity assessment. In terrestrial conditions, vascular plants are considered suitable species indicator groups, because this category is well-described and because several studies have documented correlations between the overall biodiversity and the diversity of vascular plants or tree species (Barthlott et al. 1998; Kati, Papaioannou 2001; Kati et al. 2004; Schmit et al. 2005). For the assessment of forest biodiversity, stand structural diversity is often used as an indicator of the overall biodiversity (Staudhammer, LeMay 2001), as the forest structure covers three major characteristics: species diversity, spatial distribution, and the variation in tree dimensions (Pommerening 2002). The structure of a forest is the result of natural processes and human disturbances. Important natural processes are species-specific tree growth, mortality and recruitment and natural disturbances (e.g. wind, fire, snow damage). Human disturbances include forest management practices, such as thinnings, fellings, and plantings (von Gadow et al. 2012). They affect not only the forest structure but also the assortment structure of stands (Prka 2012). Forest management influences stand density, spatial distribution, and species composition, which affect the tree habitus. Hence, two trees with the same dimensions may be of a very different quality (Liang et al. 2007) depending upon the diversity of forest structure.

The goal of this study was to analyse the relationships between the indicators of tree species and structural diversity and the quality of timber

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production in young even-aged forest stands up to 40 years old along several gradients (site, age, canopy cover).

MATERIAL AND METHODS

For the present study, University Forest Enterprise Kostelec nad Černými lesy, Czech Republic, was chosen as a pilot area (Fig. 1). The area of the enterprise is 6,581 ha. Forests cover 95.4% of the area (calculated as a proportion of the forest area from the total area of the enterprise including meadows, etc.). As can be seen in Fig. 1, the enterprise is fragmented, particularly in its eastern part. It includes five forest altitudinal zones as defined by Zlatník (1976): pine zone (0.8%), oak zone (0.5%), oak-beech zone (18.6%), beech-oak zone (61.5%) and beech zone (18.5%). Mean annual temperature varies from 7.0°C to 7.5°C, mean temperature in the growing season ranges between 13.0°C and 13.8°C. Growing season lasts 153 days on average. Mean annual precipitation fluctuates from 600 mm to 650 mm.

In the study, the data from forest inventory performed in the period from 2009 to 2011 based on a stratified sampling design were used. The area of the enterprise was stratified on the basis of three variables: site (5 categories), age (12 categories) and canopy cover (5 categories). Site category was defined by a combination of species richness and timber price (1 – lower species richness and higher timber price, 2 – moderate tree species richness and moderate timber market price, 3 – higher species richness and high timber price, 4 – high species richness and low timber price, 5 – low species richness and lower timber price). Age categories were defined by an interval of 20 years, e.g. category 01 is from 1 year to 20 years, category 02 from 21 years to 40 years, etc. Canopy cover was defined as a ratio of the sum of tree crown projections reduced for the overlapping area to the total area of the sample plot. Hence, the maximum value of canopy cover is 100%. It was visually estimated in the field in % with the accuracy of 5% separately for the two groups of trees with diameter at breast height below and above 7 cm (hereafter called as young and old trees, respectively). Categories of crown cover are defined by the step of 20 from the scale between 0 and 100. A simple validation analysis of the data obtained from the field inventory in 2009 to 2011 revealed the suitability of the applied design for the stratification of the forest enterprise (Merganič et al. 2012).

In total, 1,188 sample plots in 86 strata were established during the inventory. The sample plots were

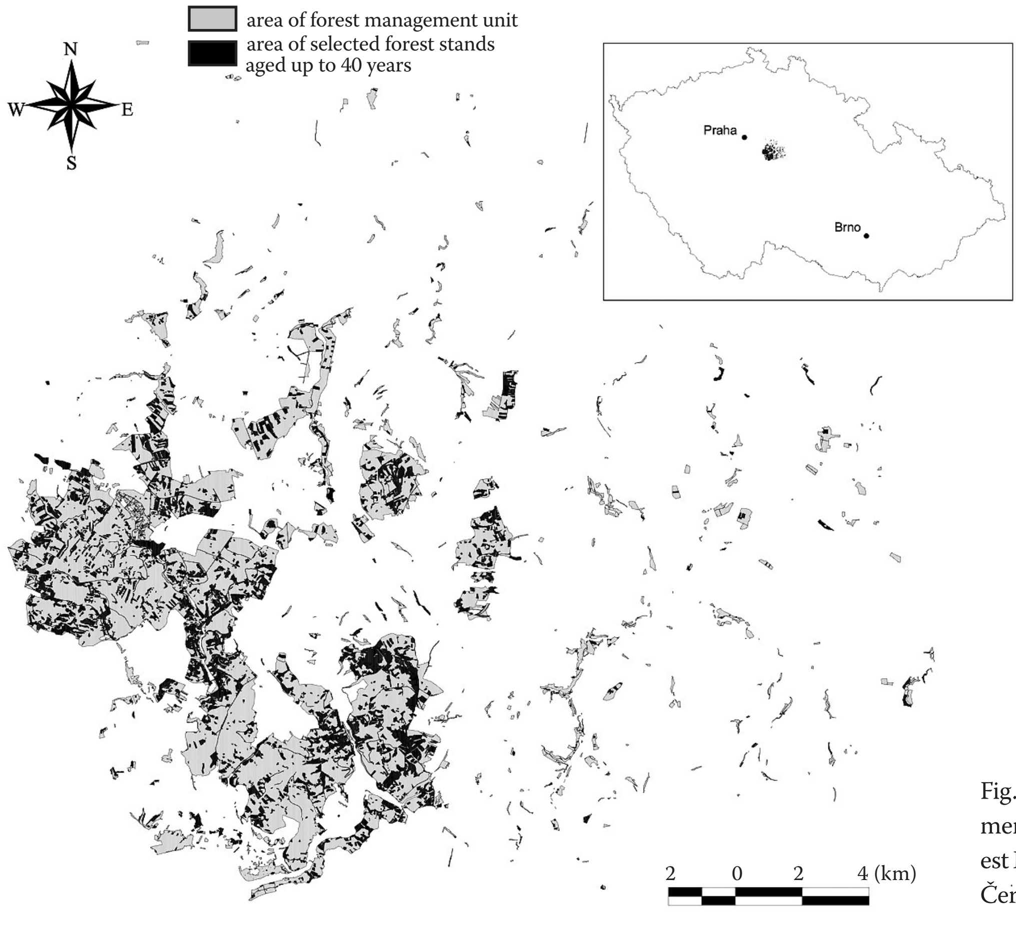

Fig. 1. The forest management unit University Forest Enterprise Kostelec nad Černými lesy

circular with an area of 500 m^2, on which approximately 100 variables were assessed for young and old trees with diameter at breast height below and above 7 cm, respectively. The stands were classified as even-aged stands if the forest had a character of one-layer structure. The following variables were determined for each tree species and each group of trees (young and old): number of trees; minimum, maximum and mean values of tree diameter, height and age; prevailing health conditions of trees and stem quality; level of tree aggregation and mixture.

For the purposes of this work, the data from the young stands aged up to 40 years were used. Sampling inventory covered such stands in 24 strata and 265 sample plots, which represent 21.2% of the enterprise area. The largest strata are strata under numbers 2025 and 2015, which encompass stands in the second site category characterised by moderate tree species richness and moderate timber market price (Merganič et al. 2012) with the crown cover of old trees above 90 (from the scale between 0 and 100). These two strata cover approximately 70% of the area of all stands with the age up to 40 years.

According to the data from forest inventory, 29 tree species were found in the selected sample plots. In the group of young trees with diameter at breast height below 7 cm the following species occurred (the values in the brackets are the percentage proportions of the species calculated from the number of young trees): *Picea abies* (26.43), *Quercus robur* (21.67), *Fraxinus excelsior* (18.41), *Pinus sylvestris* (8.5), *Fagus sylvatica* (6.92), *Acer platanoides* (5.95), *Carpinus betulus* (3.05), *Sorbus aucuparia* (2.71), *Abies alba* (2.26), *Betula pendula* syn. *Betula verrucosa* (2.05), *Larix decidua* (0.56), *Quercus petraea* (0.39), *Alnus glutinosa* (0.26), *Robinia pseudoaccacia* (0.25), *Tilia cordata* (0.23), *Acer pseudoplatanus* (0.12), *Populus tremula* (0.11), *Pseudotsuga menziesii* (0.03), *Prunus avium* (0.03), *Quercus rubra* (0.02), *Abies grandis* (0.02), *Pinus strobus* (0.01). In the group of old trees with diameter at breast height above 7 cm the following tree species occurred (the values in the brackets are the percentage proportions of the species calculated from the stand volume): *Picea abies* (53.43), *Pinus sylvestris* (18.44), *Fagus sylvatica* (8.6), *Larix decidua* (5.17), *Populus alba* and *P. canescens* (3.51), *Quercus petraea* (2.39), *Abies alba* (2.04), *Alnus glutinosa* (1.92), *Quercus robur* (1.5), *Pseudotsuga menziesii* (1.13), *Pinus nigra* (0.62), *Carpinus betulus* (0.24), *Betula pendula* syn. *Betula verrucosa* (0.24), *Fraxinus excelsior* (0.23), *Quercus rubra* (0.23), *Salix alba* (0.1), *Populus tremula* (0.07), *Tilia cordata* (0.04), *Acer platanoides* and *Abies grandis* (0.03), *Sorbus aucuparia*, *Acer pseudoplatanus*, *Prunus avium*, *Pinus strobus*, *Padus avium* syn. *Padus racemosa*, *Juglans regia*, *Malus sylvestris*, *Salix caprea.*

Biodiversity was quantified by means of the following basic indicators that describe species and structural diversity of forest stands. Species diversity was quantified by the following indicators: N0 – Hill (1973); R1 – Margalef (1958); R2 – Menhinick (1964); BP – Berger, Parker (1970); E1 – Pielou (1975, 1977); E3 – Heip (1974); E5 – Hill (1973); D – McIntosh (1967); Si – Simpson (1949); H – Shannon and Weaver (1949); HB – Brillouin (1956), number of shrub species, number of moss and lichen species. Structural diversity was assessed using the following indicators: QS – Sørensen (1948); BC – Bray and Curtis (1957); ED – Euclidian distance; BUB – Baroni-Urbani and Buser (1976); Y – Boyce (2003); DF – index of similarity (Canberra distance; Lance, Williams 1966), proportional similarity PS (Czekanowski 1909), absolute and relative range of tree heights, species aggregation and mixture assessed in the field, volume of fine and coarse woody debris on a plot, number of layers according to Zlatník (1976). Species diversity indicators were calculated for the three pre-defined groups of trees: (1) a group of young trees with diameter at breast height below 7 cm, (2) a group of old trees with diameter at breast height above 7 cm, and (3) for all trees, i.e. young and old trees together. Structural indicators were calculated for the group of all trees only. The indicators were quantified using four stand parameters: total number of trees, sum of tree heights, average tree height and total growth area. Sum of tree heights is a summary parameter such as basal area and stand volume, which can also be calculated for young trees. Growth area is the area of a forest stand that is utilized by an individual tree for its growth. It was calculated on the basis of tree height or tree diameter using the model by Merganič (2007). Partial biodiversity indicators were defined by combining basic indicators with groups of trees, and stand parameters. For example, from basic indicator H [i.e. index of species heterogeneity (Shannon, Weaver 1949)] 12 partial indicators were derived. One of the partial indicators of basic indicator H is H_ML_Nr, i.e. H index of species heterogeneity (Shannon, Weaver 1949) of trees with diameter below 7 cm (ML), while species composition was derived from tree number (Nr). In total, 171 partial biodiversity indicators were quantified on each plot (Table 1).

Tree volume was calculated according to Petráš and Pajtík (1991). Wood assortment was per-

Table 1. Example of quantification of diversity indicators for sample plot No. 202515, which represents the 2nd site category, stand aged 21 to 40 years and category of canopy cover between 81 and 100%. The proportion of assortments in quality classes I to IV in this plot is 0.26, i.e. 26%

A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	4	21	0.56	41	0.56	61	0.96	81	0.94	101	1.51	121	0.01	141	0.83	161	1
2	0.71	22	0.37	42	50.71	62	0.5	82	0.01	102	2	122	131.34	142	0.66	162	0.22
3	0.48	23	0.61	43	0.7	63	0.6	83	0.28	103	1	123	1.39	143	0.96	163	0.06
4	1.32	24	1.43	44	0.69	64	0.41	84	0.34	104	0.99	124	0.75	144	4.02	164	3.74
5	0.51	25	2	45	0.69	65	0.62	85	0.37	105	0.52	125	1	145	2	165	0.27
6	1.28	26	1	46	0.93	66	1.48	86	0.01	106	0.51	126	1	146	3	166	0.03
7	0.69	27	7	47	0.31	67	2	87	137.84	107	0.28	127	1	147	34.24	167	0.01
8	0.92	28	1.21	48	0.31	68	1	88	1.28	108	0.63	128	4	148	0.55	168	0.04
9	0.86	29	0.59	49	0.35	69	0.99	89	0.69	109	1.52	129	2	149	0.99	169	2
10	0.88	30	1.46	50	0.38	70	0.51	90	0.92	110	2	130	3	150	0.68	170	4
11	2.33	31	0.5	51	0.96	71	0.51	91	0.86	111	3	131	1.59	151	0.93	171	6.69
12	2	32	1.42	52	1.04	72	0.28	92	0.88	112	337.74	132	0.79	152	0.01		
13	3	33	0.7	53	1.28	73	0.61	93	2.33	113	0.72	133	0.99	153	0.32		
14	5	34	0.73	54	0.69	74	1.49	94	2	114	0.99	134	0.98	154	0.26		
15	0.93	35	0.52	55	0.92	75	2	95	3	115	0.75	135	0.98	155	0.18		
16	0.59	36	0.76	56	0.86	76	3	96	0.97	116	0.94	136	4	156	0.01		
17	0.96	37	2.34	57	0.88	77	679.69	97	0.51	117	0.01	137	2	157	188.1		
18	0.31	38	2	58	2.33	78	0.7	98	0.6	118	0.25	138	3	158	4		
19	0.91	39	3	59	2	79	0.99	99	0.41	119	0.31	139	1.61	159	57.1		
20	0.47	40	0.44	60	3	80	0.72	100	0.64	120	0.35	140	0.79	160	20.85		

A – indicator number, B – indicator value. Indicators derived from the tree number calculated for a group of trees with diameter below 7 cm: 1 – N0 index of species richness (Hill 1973), 2 – R1 index of species richness (Margalef 1958) , 3 – R2 index of species richness (Menhinick 1964), 4 – HB index of species heterogeneity (Brillouin 1956), 5 – D index of species evenness (McIntosh 1967), 6 – H index of species heterogeneity (Shannon, Weaver 1949), 7 – Si index of species heterogeneity (Simpson 1949), 8 – E1 index of species evenness (Pielou 1975, 1977), 9 – E3 index of species evenness (Heip 1974), 10 – E5 index of species evenness (Hill 1973), 11 – BP index of species evenness (Berger, Parker 1970), 12 – species aggregation (clustered, random, regular), 13 – species mixture (single tree-wise, group-wise, monoculture). Indicators derived from the tree number calculated for a group of trees with diameter above 7 cm: 14 – N0, 15 – R1, 16 – R2, 17 – HB, 18 – D, 19 – H, 20 – Si, 21 – E1, 22 - E3, 23 – E5, 24 – BP, 25 – AG, 26 – SM. Indicators derived from the tree number calculated for a group of all trees: 27 – N0, 28 – R1, 29 – R2, 30 – HB, 31 – D, 32 – H, 33– Si, 34 – E1, 35– E3, 36 - E5, 37– BP, 38 – AG, 39 – SM, similarity between the trees with diameter below 7 cm and the trees with diameter above 7 cm: 40 – QS1 index of similarity (Sorensen 1948), 41 – QS2 index of similarity (Sorensen 1948) calculated from the number of species, 42 – ED1 index of similarity (absolute Euclidean distance), 43 – ED2 index of similarity (relative Euclidean distance), 44 – DF1 index of similarity (Canberra distance; Lance, Williams 1966), 45 – DF2 index of similarity (Canberra distance; Lance, Williams 1966), 46 – BC1 index of similarity (Bray, Curtis 1957), 47 – BC2 index of similarity (Bray, Curtis 1957), 48 – PS index of similarity (proportional similarity; Czekanowski 1909), 49 – BUB index of similarity (Baroni-Urbani, Buser 1976), 50 – Y index of similarity (modified Yule index, Boyce 2003), 51 – ratio between the trees with diameter above 7 cm and the trees below 7 cm, 52 – ratio between the trees with diameter below 7 cm and the trees above 7 cm. Indicators derived from the sum of tree heights of species calculated for a group of trees with diameter below 7 cm: 53 – H, 54 – Si, 55 – E1, 56 – E3, 57 – E5, 58 – BP, 59 - AG, 60 – SM; calculated for a group of trees with diameter above 7 cm: 61 – H, 62 – Si, 63 – E1, 64 – E3, 65 – E5, 66 – BP, 67 – AG, 68 – SM; calculated for a group of all trees: 69 – H, 70 – Si, 71 – E1, 72 – E3, 73 – E5, 74 – BP, 75 – AG, 76 – SM, 77 – ED1, 78 – ED2, 79 – DF1, 80 – DF2, 81 – BC1, 82 – BC2, 83 – PS, 84 – BUB, 85 – Y, 86 – PmS, 87 – PmM. Indicators derived from the tree growth area of species calculated for a group of trees with diameter below 7 cm: 88 – H, 89 – Si, 90 – E1, 91 – E3, 92 – E5, 93 – BP, 94 – AG, 95 – SM; calculated for a group of trees with diameter above 7 cm: 96 – H, 97 – Si, 98 – E1, 99 – E3, 100 – E5, 101 – BP, 102 – AG, 103 – SM; calculated for a group of all trees: 104 – H, 105 – Si, 106 – E1, 107 – E3, 108 – E5, 109 – BP, 110 – AG, 111 – SM, 112 – ED1, 113 – ED2, 114 – DF1, 115 – DF2, 116 – BC1, 117 – BC2, 118 – PS, 119 – BUB, 120 – Y, 121 – PmS, 122 – PmM. Indicators derived from the average tree height of species calculated for a group of trees with diameter below 7 cm: 123 – H, 124 – Si, 125 – E1, 126 – E3, 127 – E5, 128 – BP, 129 – AG, 130 - SM; calculated for a group of trees with diameter above 7 cm: 131 – H, 132 – Si, 133 – E1, 134 – E3, 135 – E5, 136 – BP, 137 – AG, 138 – SM; calculated for a group of all trees:

139 – H, 140 – Si, 141 – E1, 142 – E3, 143 – E5, 144 – BP, 145 – AG, 146 – SM, 147 – ED1, 148 – ED2, 149 – DF1, 150 – DF2, 151 – BC1, 152 – BC2, 153 – PS, 154 – BUB, 155 – Y, 156 – PmS, 157 – PmM. Other indicators: 158 – number of layers (Zlatník 1976), 159 – ratio of the number of tree layers to the maximum number of tree layers, 160 – absolute range of tree heights, 161 – relative range of tree heights, 162 – volume of coarse woody debris, 163 – volume of fine woody debris, 164 – ratio of the volume of coarse woody debris to the volume of fine woody debris, 165 – ratio of the volume of fine woody debris to the volume of coarse woody debris, 166 – ratio of the volume of coarse woody debris to the volume of living trees, 167 – ratio of the volume of fine woody debris to the volume of living trees, 168 – ratio of the volume of fine and coarse woody debris to the volume of living trees, 169 – number of shrub species, 170 – number of moss and lichen species, 171 – total volume of living trees

formed using national assortment tables (Pařez, Michalec 1987) that quantify the proportion of high quality assortments (national quality categories I–IV) and the proportion of fuel wood (quality category V). These two ratios were taken as the indicators of quality of timber production (QTP).

For the whole selected set of young stands and for individual strata, the relationship between the quality of timber production (QTP) and each partial diversity indicator (ID) was examined using two models, one linear (LM) and one non-linear quadratic (QM) model as follows:

$$\mathrm{QTP} = a + b \times \mathrm{ID} \qquad (1)$$

$$\mathrm{QTP} = a + b \times \mathrm{ID} + \mathrm{c} \times \mathrm{ID}^2 \qquad (2)$$

where:
a–c – coeficients.

The correlation coefficient of each relationship was tested by Student's t-test. The tested null hypothesis was that the coefficient is equal to zero, i.e. that there exists no relationship.

In total, 16,416 variants (2 models × 171 partial diversity indicators × 2 indicators of quality of timber production × 24 strata) were examined. The two QTP indicators were the proportion of high-quality categories I–IV, and the proportion of fuel wood V.

Two criteria were used to assess the correlation between diversity indicators and indicators of the quality of timber production: (1) significance of the relationship ($P \leq 0.05$), (2) tightness of the relationship defined by the value of correlation coefficient R_{xy} or I_{xy} equal to or greater than 0.6 and by the minimum number of sample plots in one stratum equal to 5. We performed a summary analysis for each combination of model, QTP and correlation criterion. We counted in how many strata the analysed relationships of the partial indicator met the particular correlation criterion, and for each partial indicator we calculated the sum of correlation coefficients R_{xy} or I_{xy} of the relationships that fulfilled the criterion. Next, for each combination of model, QTP and criterion we selected the 10 best partial indicators with the most significant or tightest correlations to QTP on the basis of the sum of correlation coefficients. The greater the sum, the higher the probability that the diversity indicator occurs in significant and tight relationships to indicators of the quality of timber production.

Afterwards, an analysis regardless of the correlation criterion, model, and QTP was performed, i.e. the overall occurrence of the indicators in the best relationships was examined. In the last step, we summarised the results for the basic indicators from the best relationships of partial indicators to QTP. The major part of the analysis was performed in Mathcad 15.0 software (PTC 2011).

RESULTS

The results of the analysis of significant relationships ($P \leq 0.05$) revealed that among the partial indicators the absolute range of tree heights was the most suitable indicator irrespective of the applied model. A significant relationship between this indicator and the quality of timber production was found in 10 strata out of 17 analysed strata. This indicator was also found best for the linear model (LM) (sum of R_{xy} = 5.23). High values were also revealed for H index of species heterogeneity (Shannon, Weaver 1949) of all trees, for which the species composition was derived from the sum of tree heights; D index of species evenness (McIntosh 1967) of trees with diameter above 7 cm; and HB index of species heterogeneity (Brillouin 1956) of trees with diameter above 7 cm.

The situation was slightly different if we evaluated partial diversity indicators from the aspect of correlation tightness (defined by 5 or more sample plots in one stratum, and correlation coefficient R_{xy} or I_{xy} equal to or higher than 0.6). The best indicator was again the absolute range of tree heights followed by R2 index of species richness (Menhinick 1964) of trees with diameter above 7 cm; E5 index of species evenness (Hill 1973) of all trees, for which the species composition was derived from the tree number; and E1 index of species evenness (Pielou 1975, 1977) of trees with diameter above 7 cm, while the species composition was derived from the average tree height.

The combined analysis of significant ($P \leq 0.05$) and tight correlations (i.e. 5 or more sample plots in one stratum, and correlation coefficient R_{xy} or I_{xy} equal to or higher than 0.6) irrespective of the model and the indicator of the quality of timber production revealed that 29 partial diversity indicators occurred in the 80 best relationships. Among them, the four best diversity indicators were: absolute range of tree heights; DF1 index of similarity (i.e. Canberra distance; Lance, Williams 1966) between the trees with diameter below 7 cm and the trees with diameter above 7 cm calculated from the number of trees per species; and BC2 index of similarity (Bray, Curtis 1957) between the trees with diameter below 7 cm and the trees with diameter above 7 cm calculated from the number of trees per species.

Table 2. Summary overview of the occurrence of basic diversity indicators in the analysed relationships with the quality of timber production

Indicator	Count	Sum
Range of tree heights	8	44.50
DF1 index of similarity (Canberra distance; Lance, Williams 1966)	10	40.17
BC2 index of similarity (Bray, Curtis 1957)	7	30.05
E3 index of species evenness (Heip 1974)	5	27.85
E5 index of species evenness (Hill 1973)	6	25.70
H index of species heterogeneity (Shannon, Weaver 1949)	4	25.19
D index of species evenness (McIntosh 1967)	6	25.05
R2 index of species richness (Menhinick 1964)	5	23.19
Si index of species heterogeneity (Simpson 1949)	3	18.58
E1 index of species evenness (Pielou 1975, 1977)	4	18.54
HB index of species heterogeneity (Brillouin 1956)	3	16.68
BUB index of similarity (Baroni-Urbani, Buser 1976)	4	15.35
PS index of similarity (proportional similarity) (Czekanowski 1909)	4	12.50
BP index of species evenness (Berger, Parker 1970)	4	12.37
Y index of similarity (Modified Yule index) (Boyce 2003)	3	10.65
Ratio between the trees with diameter above 7 cm and the trees below 7 cm	2	7.44
ED2 index of similarity (relative Euclidean distance)	2	4.94

Count – frequency of an indicator in analysed variants of significant and tight correlations between a partial indicator and an indicator of the quality of timber production, Sum – sum of correlation coefficients of R_{xy} or I_{xy} in analysed variants of significant and tight correlations between a partial indicator and the quality of timber production

Finally, we analysed the overview of basic indicators occurring in significant and tight correlations. As can be seen in Table 2, the range of tree heights was found to be the most frequent indicator, for which the sum of correlation coefficients R_{xy} or I_{xy} was equal to 44.50. If we compare this result with the results of the previous analyses of partial indicators, we can see that this index was ranked at the first places, and frequently occurred among the 10 most significant and tightest relationships. DF1 index of similarity (Canberra distance; Lance, Williams 1966) was the second most frequent basic indicator (Table 2), and ranked as the 3rd or 4th in tight and significant correlations. The indicators ranking next were BC2 index of similarity (Bray, Curtis 1957), E3 index of species evenness (Heip 1974) and E5 index of species evenness (Hill 1973).

We applied a simple regression analysis to examine the general relationship between the partial indicators and the quality of timber production using all data regardless of stratification in the stands with the age up to 40 years. The highest correlation was found for the following indicators: absolute range of tree heights (R_{xy} = 0.60); ED1 index of similarity (absolute Euclidean distance) between the trees with diameter below 7 cm and the trees with diameter above 7 cm calculated from the average tree heights of species (R_{xy} = 0.50); ratio between the trees with diameter below 7 cm and the trees above 7 cm calculated from the average height (R_{xy} = 0.32); R1 index of species richness (Margalef 1958) of trees with diameter above 7 cm (R_{xy} = 0.28); R2 index of species richness (Menhinick 1964) of trees with diameter above 7 cm (R_{xy} = 0.28).

We can see in Fig. 2 that the greater the difference between tree heights of the trees with diameter below 7 cm and the trees with diameter above 7 cm, the higher the proportion of high quality assortments.

The analysis also revealed that except for the range of tree heights, the relationships between diversity indicators and the quality of timber production inside

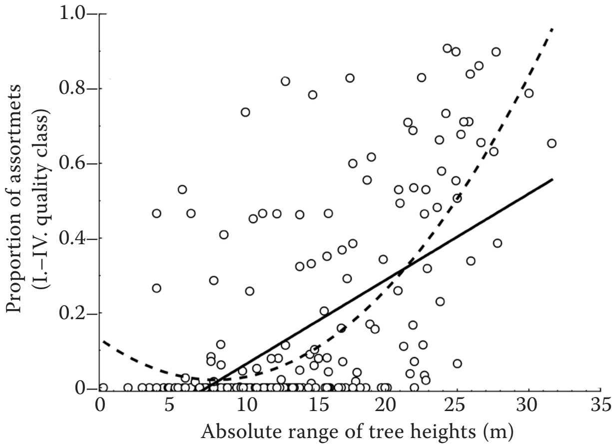

Fig. 2. General relationship between the absolute range of tree heights and the quality of timber production (proportion of assortments in quality classes I–IV)

the specified strata differed from the relationship for all data together. For example, the general relationship between the quality of timber production and DF1 index of similarity (Canberra distance; Lance, Williams 1966) between the trees with diameter below 7 cm and the trees with diameter above 7 cm calculated from the number of trees per species, or BC2 index of similarity (Bray, Curtis 1957) between the trees with diameter below 7 cm and the trees with diameter above 7 cm calculated from the number of trees per species, was loose with the correlation coefficient equal to 0.09 and 0.13, respectively. However, the stratified analysis revealed that DF1 and BC2 indices were the top diversity indicators after the range of tree heights (Table 2). As can be seen in Fig. 3, the values of intercepts and regression coefficients greatly varied between the strata.

The analysis of regression coefficients of linear correlations with other indicators of high interpretation value revealed that the share of high-quality timber assortments rises with increasing heterogeneity of old trees with diameter above 7 cm (Table 3). As indicated in Table 3, heterogeneity increases with the higher number of tree species.

DISCUSSION

The assortment structure of forest stands is formed since the young age. In commercial forests, forest managers support individuals of better quality as such trees are considered to be the basis of high and valuable production at maturity age. Diversity changes are also related to age. According to Spies and Franklin (1988), the relationship between diversity and age can be S-shaped or U-shaped. The development of forest characteristics, e.g. tree size, tree size diversity, wood biomass, and forest floor depth, follows the S-shaped pattern. The U-shaped curve represents the pattern when diversity in young and old stands is higher than in mature stands (Stelfox 1995). The results of our

Table 3. Analysis of the trend of linear models describing the correlation between the indicators of species diversity and the quality of timber production (proportion of assortments in quality classes I–IV)

Indicator			Site category								
			1			2			3		
			H_ST_Hpr	N0_ST_Na	E3_ST_Hpr	H_ST_Hpr	N0_ST_Na	E3_ST_Hpr	H_ST_Hpr	N0_ST_Na	E3_ST_Hpr
Age category (years) 1–20	Canopy cover category	3	–	–	–	+	+	+			
		4	–	–	+	–	–	+			
		5				+*	+	+	–	+	+
21–40		1				+	+	–***			
		2				+	+	+			
		3	+	+	+	–*	–	–***			
		4	+***	+***	–	+	+	+*	+	+	+
		5	+	+	–	+***	+***	+*	+**	+**	+

H_ST_Nr – H index of species heterogeneity (Shannon, Weaver 1949) of trees with diameter above 7 cm, while the species composition was derived from the average tree height, N0_ST_Na – N0 index of species richness (Hill 1973) of trees with diameter above 7 cm, E3_ST_Hpr – E3 index of species evenness (Heip 1974) of trees with diameter above 7 cm, while the species composition was derived from the average tree height. Significance level: *90%, **95%, ***99%

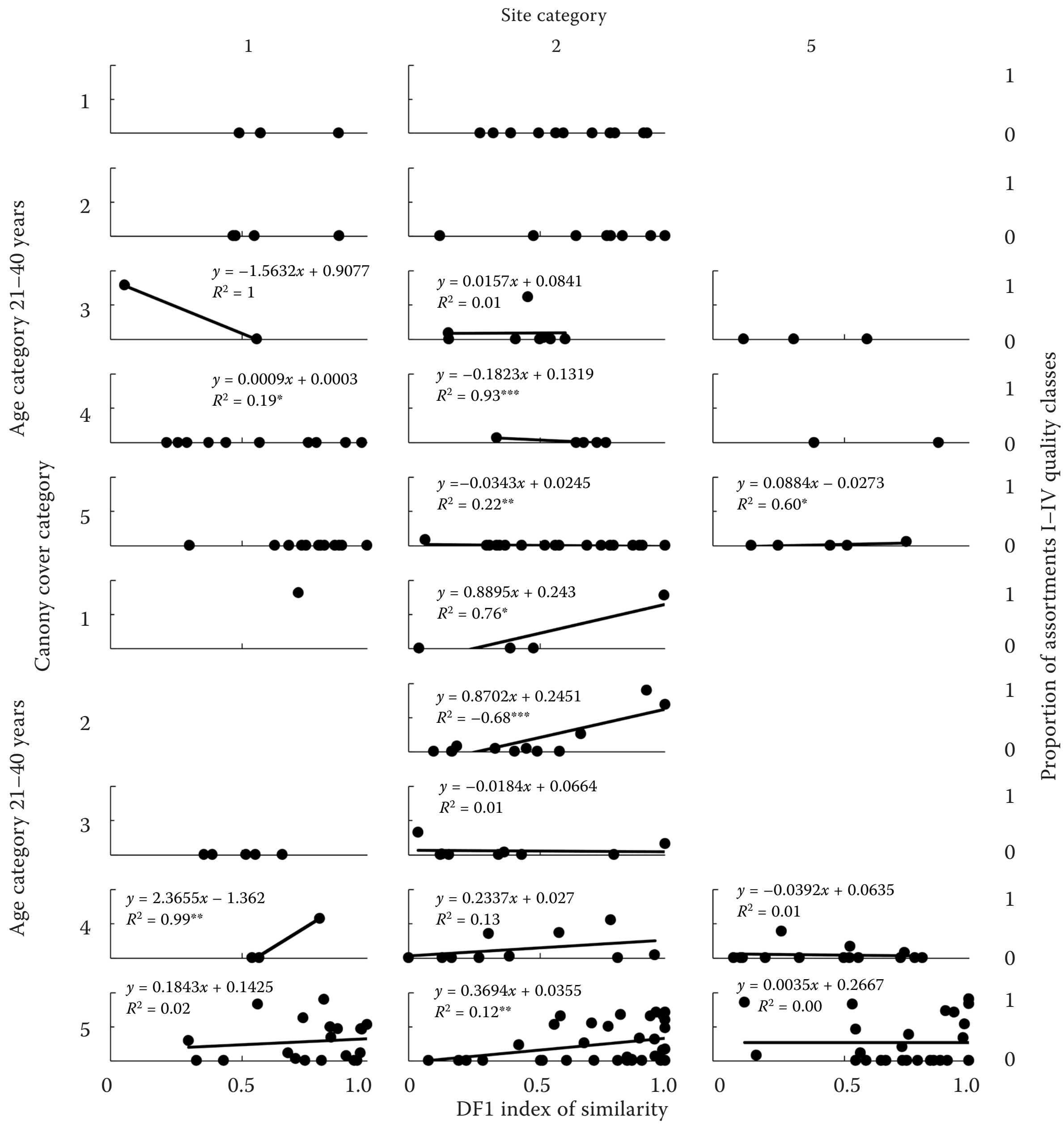

Fig. 3. Relationship between DF1 index of similarity (Canberra distance; Lance, Williams 1966) between the trees with diameter below 7 cm and the trees with diameter above 7 cm calculated from the number of trees per species and the quality of timber production (proportion of assortments in quality classes I–IV). Significance level: *90%, **95%, ***99%

analysis indicate the first type of the relationship in our data. However, the assessment encountered some inconsistencies, since the proportion of assortments is closely related to tree diameter (Petráš 2002; Danilovič 2008). The relationship between DF1 index of similarity and quality of timber production in average site category and 1–20 years age category was found to be negative (Fig. 3). This means that the quality of timber production increases as the value of DF1 index approaches 0, i.e. as the groups of young and old trees become more similar. However, in site category 2 characterised by low species richness and lower timber price, we found an opposite tendency towards the positive relationship (Fig. 3). The positive trend was revealed in almost all examined strata of the age category of 21–40 years indicating that the quality of timber production increases with the increasing difference between the group of young and old trees. This can be explained by increasing dimensions of trees with diameter above 7 cm, as well as by the effect of the applied management measures (Sanderson et al. 2002; Kareiva et al. 2007). Human-induced changes of forest stands in the form of tendings, thinnings, fellings, or plantings have a major effect on the forest structure (von Gadow et al. 2012). In general, the management treatments aimed at increasing forest production are regarded to cause the reduction of diversity (Neary 2002; Humphrey et al. 2003; Bruciamacchie et al. 2006; Gane 2007; Hawksworth, Bull 2007; Stupak et al. 2007; Lencinas et al. 2008). However, recently, several works documented a positive effect of forest management on diversity (Dykstra, Monserud 2007; Liang et al. 2007), especially if the principles of sustainable forestry and adaptive management strategies are applied, as their main goal is to optimise the relationships between management and the conservation of biological diversity (Lindenmayer et al. 2000).

CONCLUSION

The current trends in Central European forestry place strong emphasis on multipurpose utilisation of forests and their products. Due to this, objective analyses that deal with contradictory society demands, e.g. timber production and diversity, are required. The present study examined if there exists a relation between the quality of timber production and species and structural diversity of young even-aged forest stands at the age below 40 years. The results revealed a positive relationship between the diversity and the proportion of assortments in quality classes I–IV. This indicates that by promoting the diversity in young stands it is possible to increase the quality of timber production.

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