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Qualitative and value production of tree species in mixed spruce-fir-beech stands under the conditions of the Western Carpathians

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Abstract

Value production is one of the most important information for comparing different tree species composition and management strategies in forestry. Although the value production of forest stands is affected by various factors thinning can be considered as one of the most important one. This paper aims at the evaluation of qualitative and value production in mixed Norway spruce (*Picea abies* [L.] Karst.), silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.) stands, which were managed by crown thinning for a period of 44 to 50 years and/or left to self-development. More than 1,500 individual trees aged from 61 to 132 years from 15 subplots established in western part of the Low Tatras Mts. and the Great Fatra Mts. in Slovakia were assessed. The proportion of stems in the highest quality A (stem quality classes) reached a low percentage, i.e. 12% in beech, 28% in spruce and 13% in fir out of the number of evaluated trees. The percentage of the highest quality log classes (assortments I + II) of beech ranged from 0 to 23% and of coniferous ones from 2 to 12%. Regarding the management method used, this percentage accounted for 0.1 to 23% for plot with self-development, whereas in plots with tending it was from 1 to 23%. Value production of coniferous tree species was always higher compared to beech, regardless of the management method. Regarding individual tree species, we found the highest value production in fir (81.4 € m^{-3}) and the lowest in beech (46.5 € m^{-3}).

Key words: Norway spruce; silver fir; European beech; stem quality; assortment structure; thinning

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1. Introduction

Extensive dieback of spruce monocultures in recent years (Hlásny & Sitková et al. 2010; Hlásny et al. 2017) or the high proportion of salvage cutting was evident due to abiotic (wind, drought) and biotic (bark beetles) harmful factors in Slovakia (Kunca et al. 2019) and also in other countries, for example in Czech Republic (Šimůnek et al. 2020). It result in establishment or formation of mixed stands (Pretzsch et al. 2014, 2015) which are generally considered to be more resistant (Vacek 2017; Vacek et al. 2020). This means especially the so-called Carpathian mixture of Norway spruce, silver fir and European beech. The mixed stand can make better use of the habitat and its available space (Bulušek et al. 2016), especially if the represented tree species have different biological properties and ecological requirements (Korpeľ 1989; Králíček et al. 2017; Vacek et al. 2017; Mikulenka et al. 2020).

The research of mixed stands focused mainly on monitoring the height or diameter growth of individual tree species (Künstle 1962; Monserud & Sterba 1996; Petráš et al. 2014a; Sharma et al. 2019). Attention was also paid to the evaluation of results of volume production and increments (Kennel 1966; Míchal 1969; Prudič 1971; Hink 1972; Pretzsch 1992; Pretzsch & Schütze 2009; Lebourgeois et al. 2014; Petráš et al. 2014b; Rößiger et al. 2019). By investigation the causes of different growth and production of mixed stands, most authors focused on site conditions, climate, tree species composition, social status of trees, method of mixture, historical land use and age of stands (Magin 1954; Kennel 1965, 1966; Hausser & Troeger 1967; Mitscherlich 1967; Hink 1972; Mettin 1985; Kramer et al. 1988; Pretzsch 2009; Pretzsch et al. 2010; Bosela et al. 2015; Slanař et al. 2017). Such results were mostly derived from measurements performed on simultaneous plots in homogeneous or mixed parts of stands. Relatively fewer results come from permanent research plots established and managed in young mixed stands (Štefančík 1977; Paumer 1978; Novák et al. 2017). More attention was paid to thinnings, or the long-term impact of tending on their structure, production and stability (Assmann 1961; Molotkov 1966; Leibundgut et al. 1971; Štefančík 1977; Hladík 1992; Štefančík & Štefančík 2001, 2002, 2003; Adamic et al. 2017; Hilmers et al. 2019).

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Only few authors evaluated by more detailed effect of tending (Štefančík 1977, 2004a, b) or different management (Štefančík et al. 2018) on quality classes. Rais et al. (2020) investigated beech sawn timber and Pretzsch & Rais (2016) compared the wood quality in monocultures with mixed stands. On the value production in mixed stands were focused papers by Petráš et al. (2015, 2016, 2017). Tree species diversity versus wood quality were studied by other authors (Hausser & Troeger (1967; Kramer et al. 1988; Benneter et al. 2018). Therefore, our intention was to fill the existing gaps and connect knowledge in this area to the value production of mixed spruce-fir-beech stands.

The aim of this work was to evaluate (i) quality of stem and stem damage, (ii) assortment structure, (iii) value production in mixed spruce-fir-beech stands, which were systematically managed for about 50 years and their comparison with stands without interventions. We hypothesise that coniferous tree species in mixed stands might produce higher value production in comparison to beech because better quality wood is expected to be produced.

2. Material and methods

2.1. Study area

Empirical material from repeated measurements on four series (Fig. 1) of 15 permanent research plots (PRPs), with different area from 0.10 to 0.56 hectare was an objective of the study. They were established in the 60s and 70s of the 20th century, was used for this purpose. Plots are located in the western part of the Low Tatras Mts. and the Great Fatra Mts (Fig. 1). They are at an altitude of 690–970 m and according to the phytocenosis they are classified into following forest types groups: *Fageto-Aceretum* (FAc), *Abieto-Fagetum* (AF) and *Fageto-Abietum* (FA). Plots are situated in the 5th and 6th forest altitudinal zone with an average annual temperature of 4.2–6.8 °C and an average annual precipitation between 900 and 1200 mm. The age of tree species (stands) at the time of the PRP establishing ranged from 15 to 80 years and/or 61–132 years at the last evaluation (Sharma et al. 2019). Tree species proportion on PRPs is in a wide range (Table 1).

Until the establishment of PRPs, almost no systematic tending interventions were carried out. If yes, then only a slight intervention solely for the purpose of removing dying and dead trees was carried out (Štefančík 1977). Measurements were repeatedly performed on all research plots and/or evaluations at regular 5-year intervals. So far, 10 or 11 measurements have been carried out. The area of the PRP varies between 0.10 and 0.56 ha. All living trees with a diameter of 3.6 cm ($d_{1.3}$) and more are registered by numbering on all plots. On the plots marked as H, Štefančík's free crown thinning is applied (Štefančík 1984) and plot 0 serves as the control (without interventions).

2.2. Data collection

In addition to standard biometric measurements (breast-height diameter and height of trees), the trees were classified according to their sociological status into the tree class 1–5 (according to Kraft 1884) and the quality char-

Fig. 1. Localization of mixed stands on four series of permanent research plots.

Table 1. Tree species composition according to basal area on investigated permanent research plots (PRPs).

PRP	Plot	Age [years]	Tree species [%] Spruce	Fir	Beech	Other	Altitude [m a.s.l.]	Soil type
Stará Píla	I – 0	17 – 21	16.1	33.9	50.0	—	690 – 720	Cambisol
		61 – 65	5.1	18.9	75.4	0.6		
	II – 0	17 – 21	19.6	60.1	19.6	0.7		
		61 – 65	26.9	30.0	31.1	12.0		
	I – H	17 – 21	1.6	54.8	43.6	—		
		61 – 65	6.0	53.7	40.3	—		
	II – H	17 – 21	55.6	24.4	17.8	2.2		
		61 – 65	43.5	11.4	34.3	10.8		
Motyčky	II – 0	41 – 48	15.7	50.9	23.5	9.9	810 – 870	Calcaric Cambisol
		86 – 93	18.8	20.8	47.8	12.6		
	I – H	41 – 48	13.2	51.8	27.3	7.7		
		86 – 93	17.2	30.9	41.0	10.9		
	III – H	41 – 48	13.3	49.2	26.4	11.1		
		86 – 93	18.9	30.5	37.7	12.9		
	IV – H	41 – 48	6.8	36.7	50.8	5.7		
		86 – 93	7.7	30.6	56.8	4.9		
Korytnica	I – 0	50 – 58	24.3	25.3	46.2	4.2	930 – 970	Cambisol
		100 – 108	30.5	17.8	48.0	3.7		
	III – 0	50 – 58	16.3	17.1	55.7	10.9		
		100 – 108	22.6	10.5	54.3	12.6		
	I – H	50 – 58	28.3	30.0	37.0	4.7		
		100 – 108	31.3	9.5	54.5	4.7		
	II – H	50 – 58	5.6	29.1	55.5	9.8		
		100 – 108	9.4	19.0	64.1	7.5		
	III – H	50 – 58	16.7	12.6	61.1	9.6		
		100 – 108	25.7	7.9	61.6	4.8		
Hrable	0	74 – 82	3.0	24.3	59.8	12.9	820 – 840	Dystric Cambisol
		124 – 132	—	17.9	80.5	1.6		
	H	74 – 82	9.9	40.5	35.8	13.8		
		124 – 132	1.6	39.5	58.7	0.2		

Spruce – *Picea abies* [L.] Karst., Fir – *Abies alba* Mill., Beech – *Fagus sylvatica* L., H – plot with crown thinning, 0 – plot with no intervention (control).

acteristics of the lower third of the stem were evaluated according to the following classification:

A – Straight, non-twisted stem, centric, without shape deformations and knots; suitable for sliced veneer production;

B – Stem with minor technical defects with solid and loose knots up to 4 cm (1–2 pieces per meter);

C – Stem with large technical defects, greater curvature, and twisted up to 4%, solid knots without limitation; unsound knots up to 6 cm for conifers and for deciduous species up to 8 cm; suitable especially for lower quality saw logs or cellulose;

D – Stem inferior to the class C, with the extensive rot, and only suitable as fuelwood.

Stem damage quite significantly predetermines the internal defects of the wood, such as rot and, in the case of beech, especially the false-heart. For this reason, not only the mechanical damage of the stems was evaluated, but also of the buttress and surface roots. During its detection, only its presence was recorded, regardless of size, intensity and position on the stem.

2.3. Data processing

From the latest measurements and evaluations of stems, the proportion of quality classes A–D and the proportion of damaged stems were calculated on each PRP. An average proportion was also calculated for each tree species. According to the models of tree assortment tables (Petráš & Nociar 1991; Petráš 1992), the assortment structure was calculated for each tree and tree species. To simplify the analysis and evaluation of results, all partial plots (subplots) with the same regime were merged. The mentioned models indicate the proportion of assortments in % for all tree species, depending on the tree diameter, the quality class of the stem, the occurrence of stem damage and, in the case of beech, on the tree age as well.

Assortments represent quality and diameter classes of logs. The quality classes of logs are characterized by the purpose of their end-use as follows:

Class	End-use
I	sliced veneers, special sporting and technical goods,
II	peeled veneers, matches, sporting goods,
III(A, B)	saw logs (IIIA – better quality, IIIB – worse quality), building timber and sleepers,
V	pulpwood, chemical and mechanical processing for cellulose and agglomerated boards production,
VI	fuelwood.

I–IIIB classes defined in the assortment tables model are also separated into 1–6+ diameter classes (1 – from 16 to 19 cm; 2 – from 20 to 29 cm; 3 – from 30 to 39 cm; 4 – from 40 to 49 cm; 5 – from 50 to 59 cm; 6+ more than 60 cm).

The assortment structure for homogeneous spruce, fir and beech stands was calculated according to the models of assortment growth tables (Petráš & Mecko 1995; Petráš et al. 1996), where the proportion of assortments in % depends on age and site index of stands.

The value of assortments was calculated as the product assortments volume and timber prices by log quality and diameter classes. Timber prices were taken from the state enterprise Forests on the Slovak Republic, Assortment price list published in 2014 (Table 2).

3. Results

3.1. Stem quality and damage

The quality and damage of stems was expressed as the proportion out of the number of trees on the PRP (Fig. 2).

The highest stem quality (A) in deciduous species (beech) was not found only on the PRP Stará Píla .

Within coniferous tree species (spruce, fir), trees with the highest quality were found only in two localities (Motyčky, Hrable). The proportion of stems in the highest quality A reached a low percentage, which did not exceed 12% for beech, 28% for spruce and 13% for fir. The higher percentage of spruce was influenced by the low number of trees (only 10% out of the total number of evaluated trees).

The proportion with the highest stem quality (A) for beech was less than 12%, with regard to two management variants monitored (tending – H, control – 0). The

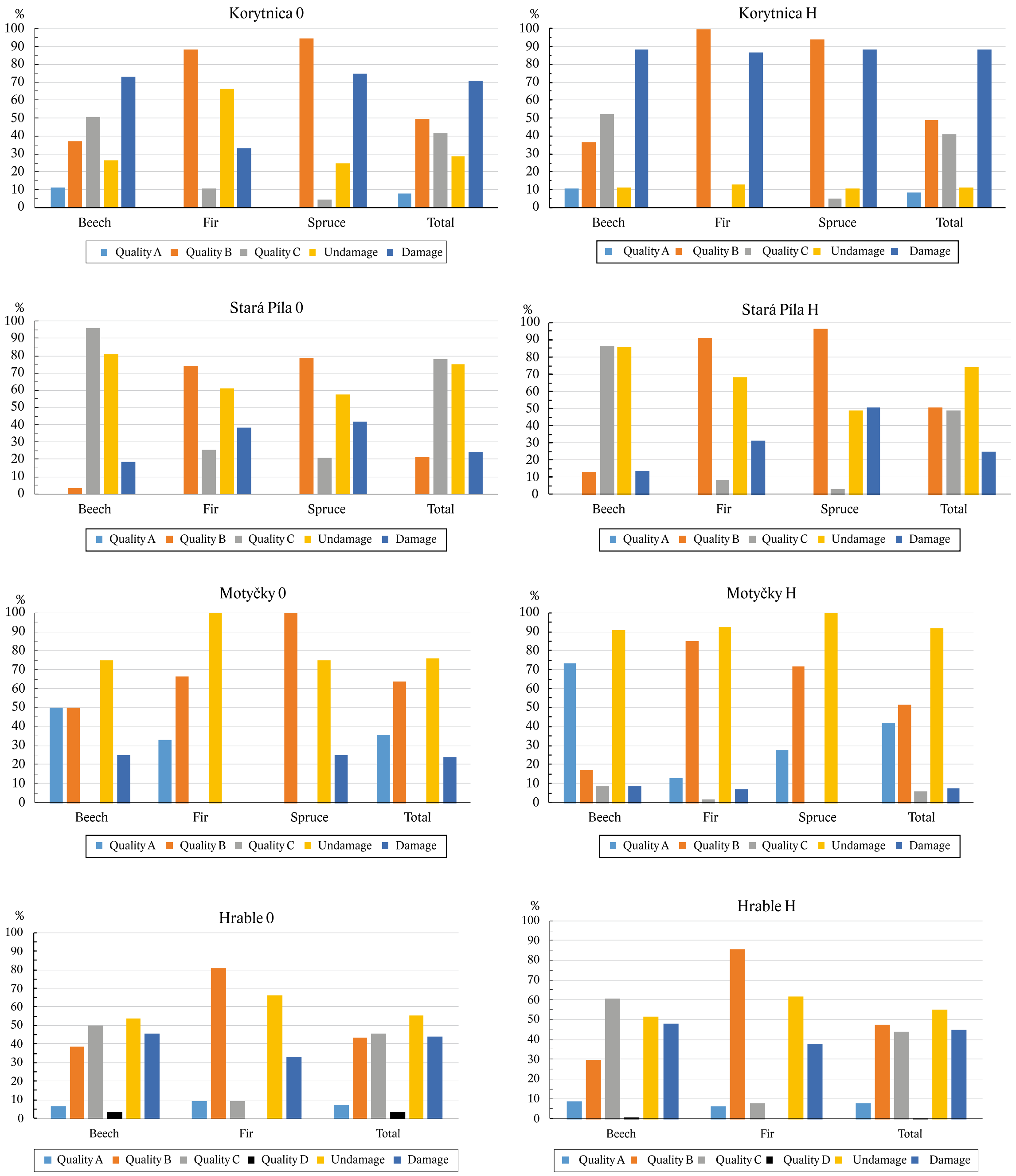

Fig. 2. Proportion of quality classes and damaged stems on given PRPs calculated from the number of trees of each tree species.

Table 2. Assortments prices (€ m^{-3}) by log quality and diameter classes of 1 – 6+ for spruce, fir and beech.

Tree species	I.4	I.5	I.6	II.2	II.3	II.4	II.5	II.6
Fir, Spruce	111	118	122	86	95	99	101	101
Beech	186	206	234	82	104	113	118	124
	IIIA.1	IIIA.2	IIIA.3	IIIA.4	IIIA.5	IIIA.6		
Fir, Spruce	37	80	84	85	85	84		
Beech	49	52	65	67	68	68		
	IIIB.1	IIIB.2	IIIB.3	IIIB.4	IIIB.5	IIIB.6	V	VI
Fir, Spruce	37	73	77	77	77	77	37	26
Beech	48	55	55	26	57	57	42	43

only exception is for the PRP Motyčky, where there was a higher proportion (50 to 74%). For conifers, the proportion of class A was from 6 to 28% in plots with tending and/or in control plots it was from 10 to 33%. In addition, highest quality of spruce did not occur in the control plot Motyčky, in contrast to the plot with tending, and/or it was completely absent in the PRP Hrable (the oldest plot) due to missing spruce proportion.

The proportion of trees with the stem quality B was always higher in coniferous species (67 to 100%) compared to beech (4 to 50%) in all plots (regardless of the management method). In total, with the exception for the control plot Stará Píla (the youngest) and control plot Hrable (the oldest), trees with the stem quality B (average quality) formed the highest percentage, with their proportion in plots with tending from 48 to 52%, and/or in control plots from 22 to 64%.

In total, the proportion of stems of quality C (worst) reached higher values in control plots (42 to 78%) compared to the plots with tending (6 to 49%). From the viewpoint of tree species, it amounted to 0 to 26% in coniferous species, or 0 to 96% in beech.

In total, the evaluation of stem damage showed everywhere always higher proportion of undamaged stems, which ranged from 11 to 92% (with the exception for the PRP Korytnica). Apart from the PRP Motyčky, the proportion of damaged stems found in control plots was always lower in comparison with the plots where thinning were carried out. In total, the proportion of damaged stems ranged from 8 to 45%, except for the PRP Korytnica, where it reached 71% in the control plot and up to 89% (Fig. 3) in the plot with tending. In the control plots, coniferous species were damaged from 25 to 75% and beech from 19 to 73%. In total, in plots with tending, it was 7 to 89% for coniferous species, and/or 9 to 88% for beech. According to species, we practically found the same damage in spruce (0 to 89%), fir (0 to 87% and beech (9 to 88%).

3.2. Assortment structure

The structure of assortments is evaluated by the proportion of quality classes of logs (Fig. 4). The proportion of the highest quality classes of logs (I + II) of beech ranged from 0 to 23% and in coniferous species from 2 to 12%. From the view the management method, the proportion in control plots varied from 0.1 to 23%, while in plots with tending it was from 1 to 23%.

The highest proportion of assortments was found for the class IIIA, where the proportion of saw logs was several times higher for conifers compared to beech. From the viewpoint of management (tending versus control), the proportion of this class was higher both for coniferous and beech.

The pulpwood proportion (Class V) was several times higher in beech compared to conifers. In terms of management, there was always higher proportion of this

Fig. 3. Damage to beech trees on the PRP Korytnica after rock landslide during the construction of a forest road (Photo: Igor Štefančík).

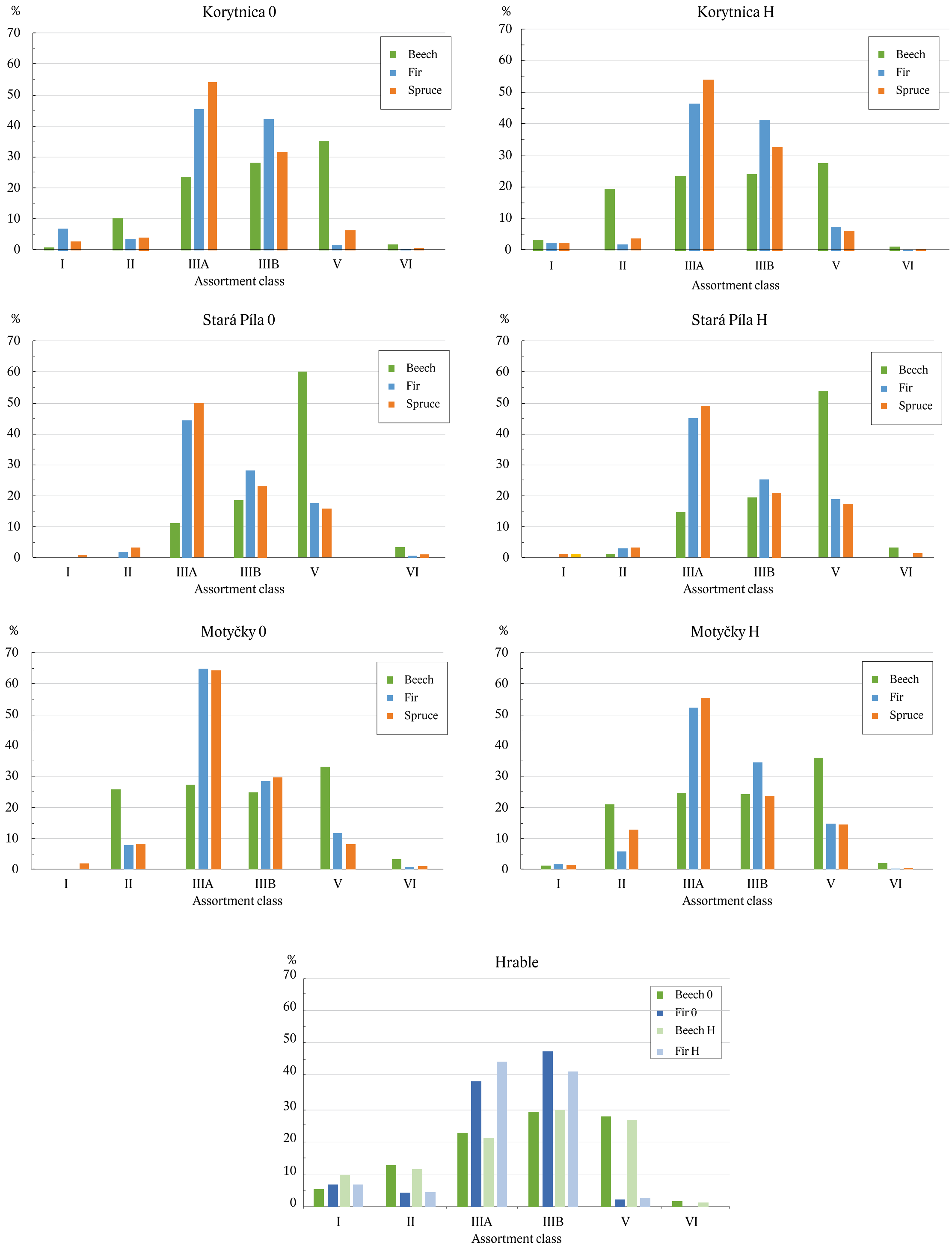

Fig. 4. Proportion of logs in assortment classes by tree species on PRPs.

class in plots with tending in comparison with the control plots, for coniferous tree species. In case of beech, it was found opposite relationship.

3.3. Value production

It is presented in € per 1 m^3 (Fig. 5). For control plot of beech it ranges from 47 to 51 € m^{-3}, and/or 65 to 81 € m^{-3} for coniferous species. In plots with tending, it varied from 47 to 61 € m^{-3} for beech, and for conifers it was from 66 to 80 € m^{-3}. From the mentioned above, it is clear that the value production of conifers was always higher compared to beech, regardless of the method of management. In terms of individual species, fir has the highest value production (81 € m^{-3}) and beech the lowest (47 € m^{-3}). As for beech, the mean value production for control plot was 54 € m^{-3} and 57 € m^{-3} for thinned plots.

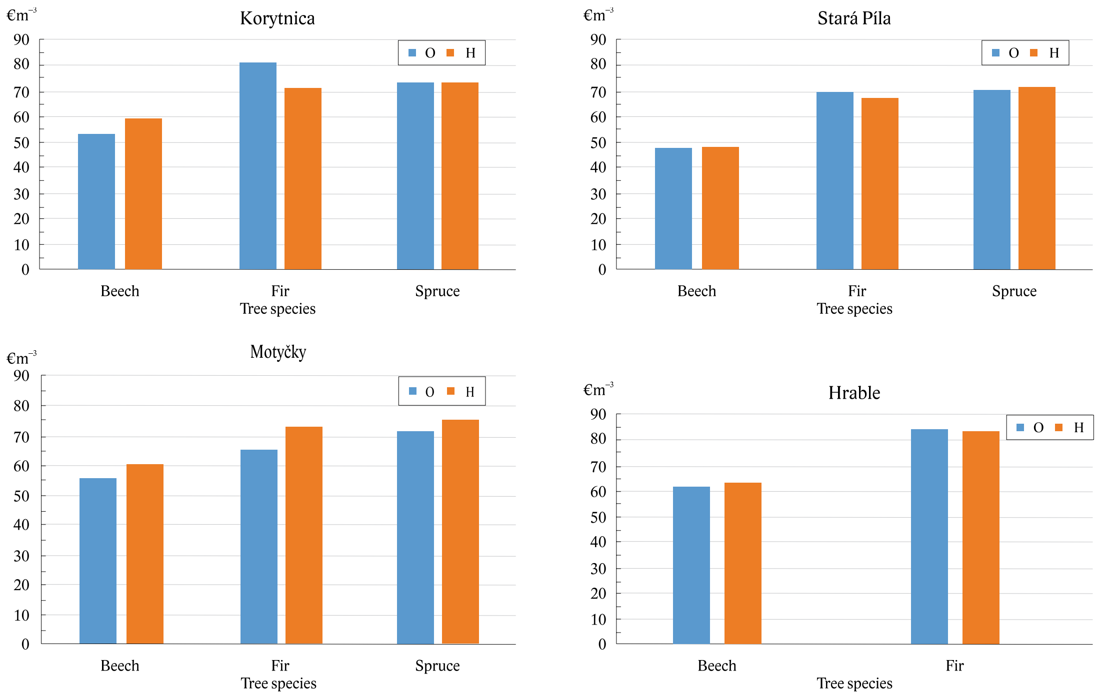

Fig. 5. Average value production on the PRPs by tree species and management.

Consequently, the mean value production for conifers was practically the same (72 and 73 € m^{-3}).

4. Discussion

4.1. Stem quality and damage

The proportion of the highest stems quality (A) reached a low percentage for all species on all plots. Similar results were found by Petráš et al. (2015) for mixed stands of spruce, fir and beech, when the proportion of beech in the highest quality class A was only 6.4%. Much higher values for beech, but in pure beech stands were reported by Štefančík et al. (2017). The proportion of 31 and 39% was found for control plots, and/or on a plot with crown thinning it was up to 57–69%. Similarly, Petráš et al. (2015, 2016) state a significantly higher proportion of up to 30% of the highest quality stems in homogeneous beech stands. In contrast, in mixed stands (beech with spruce and fir), they found 24% less stems of the highest quality (Class A) and 13% fewer stems of average quality (Class B) compared to pure stands. Our results confirmed worse stem quality of beech in mixed stands in comparison with pure ones. Wiedemann (1951) suggested this was due tu vertical and horizontal structure of mixed forests where less dense crown canopy enables longer survival and consequent branch roughening than in pure stands with their more concentrated single-layer canopy.

Stem damage will significantly reduce stem quality (Račko & Čunderlík 2011) and thus its proportion in the quality class A (Petráš et al. 2015). Results showed larger damage in plots with tending, which is related to the performance of felling interventions. As a result, stems are often damaged when they are pulled out of the stand. Spruce and beech in the growing season are particularly sensitive (Vacek et al. 2019, 2019a). Higher proportion of damaged spruce trees in mixed stands compared to pure ones was also found by Petráš et al. (2015). From the PRPs monitored, the proportion of damaged stems in the PRP Korytnica was significantly the highest, regardless of the management variant. The explanation is a little bit paradoxical. This PRP is located on a steep slope below the forest road. During the construction of this road in the past, larger rocks collapsed due to gravity and thus significantly damaged most trees by hitting the stems (Fig. 3). Beech stem quality can also be influenced by extreme slope, stem bending with skew tree should be caused by tree competition and plagiotropic growth of beech crowns (Bulušek et al. 2016). Furthermore, strong heliotropism negatively influences beech lengthwise and crosswise shape and also its spiral grain (Krammer et al. 1988; Pretzsch & Schütze 2009).

4.2. Assortment structure

The finding of the higher proportion of better assortments in plots with tending in comparison with control plots is also confirmed by our results from pure beech stands (Štefančík et al. 2018). For beech, they found 4 to 22% of I+II assortments from the stand volume of plots with tending, and/or 6 to 19% on control plots. For comparison, in mixed stands of spruce, fir and beech in this study, the classes I+II accounted for 1 to 23% for beech in the plots with tending, or 0.1 to 23% in control plots. We found lower values for fir (2 to 12%) and spruce (3 to 13%). Petráš et al. (2015) found similar values in mixed stands, i.e. 5% for beech and for fir and spruce 8% each. The importance of tending with an emphasis on its timeliness for achieving quality beech assortments is also stated by Klädtke (2002), who found a remarkable reduction in value production in the case of delayed thinning realisation.

The dominance of assortments IIIA and IIIB of coniferous species (spruce, fir) with the proportion of 30 to 50% is also stated by Petráš et al. (2015). These values are very similar to our results (22 to 57%). We found the lower proportion of IIIA and IIIB beech assortments (12 to 24% and/or 20 to 30%), which corresponds to the data published by Petráš et al. (2015), i.e. 18 and 27%.

4.3. Value production

The resulting effect of tending is reflected by value production, which depends on the stem quality and its damage, volume, assortment structure and prices, which are higher for valuable assortments and vice versa (Petráš et al. 2015). Results of value production showed higher values for spruce and fir, and lower for beech. This corresponds to the course of value production of trees by assortment tables and wood prices (Kulla et al. 2016). Hausser & Troeger (1967) reported that fir produces 9% greater value than spruce in mixed spruce-fir stands because of their greater diameter. At the same time, this is in accordance with the research results of Petráš et al. (2017), who determined the value production of different tree species, depending on the diameter, stem quality and damage as well. For mean diameters in the stands monitored by us, they state value production in damaged stands for fir in the range of 55 to 80 € m^{-3}, depending on the stem quality (A–C), for spruce 60 to 83 € m^{-3}, and/or 43 to 63 € m^{-3} for beech. A comparison of the value production of beech in pure stands (aged 83 to 105 years in the plot with tending) showed values of 71 to 82 € m^{-3}, which are higher values than in mixed stands (Štefančík et al. 2018). It is also related to the competition (intraspecific or interspecific) of tree species, which plays an important role in the quality of stems (Merganič et al. 2016; Höwler et al. 2019). This is in accordance with the statement about the poorer quality of beech in mixed stands compared to pure ones, and/or about its lower value production (Petráš et al. 2015, 2018). For comparison, Kożuch, Banaś (2020) reported the average price (value production) of 77.5 € m^{-3} for beech roundwood in Austria for the period of 2005–2018.

It can be stated that in terms of quality and value production, the cultivation of mixed (spruce, fir and beech) stands is justified and/or desirable. Firstly, from the aspect of increasing biodiversity (Bauhus et al. 2017), strengthening static stability (Pretzsch & Forrester 2017) and, last but not least, from an ecological point of view (Bauhus et al 2017a), especially in connection with the impacts of climate change on forest stands (Pretzsch et al. 2017; Bravo-Oviedo et al. 2018).

5. Conclusions

A comparison of the quality and value production of mixed spruce-fir-beech stands (aged 61 to 124 years) showed differences that depended on age, tree species composition and stand management. In general, a relatively low proportion of the highest quality assortments for all tree species was achieved, regardless of tending or self-development. In terms of the assortment structure, a slightly higher proportion was achieved in plots with long-term tending (44 to 50 years). Value production of conifers was always higher in comparison with beech, regardless of the management method. From the viewpoint of tree species, the highest value production was found for fir (81 € m^{-3}) and the lowest for beech (47 € m^{-3}). The hypothesis about pure value of beech in comparison to spruce and fir in mixed stands was confirmed, as we found a higher value production of conifers compared to beech in mixtures.

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