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Do stand structure and admixture of tree species affect Scots pine aboveground biomass production and stability on its natural site?

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Abstract

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The paper analyses stand structure and production on two experimental forest stand series of mature pure and mixed Scots pine stands, growing on natural Scots pine sites in the Czech Republic. Sessile oak was the main admixed species. In mixed stands, Scots pine constituted the dominant level of the stand, admixed species grew mostly as subdominants. Admixture increased stand densities and aboveground biomass production compared to pure stands. Sessile oak with the 20–30% number share within the Scots pine stand led to an increase of the Scots pine tree dimensions and mean stem merchantable wood (DBH ≥ 7 cm) volume compared to the pure Scots pine stand of similar density. The Scots pine and sessile oak slenderness ratios increased in mixed stands compared to monocultures, however, the stand mechanical stability was not threatened.

Keywords: *Pinus sylvestris*; sessile oak; Norway spruce; mixture; volume; stand indices

Climate change is causing an increase in summer heat waves in temperate forests (IPCC 2018). Prediction of forest growth and productivity is of crucial importance for foresters and environmental policy makers. For foresters, timber production determines economic returns and stand productivity is an important indicator of adaptation to climate change (IPCC 2014). Scots pine (*Pinus sylvestris* Linnaeus) is the most widely distributed pine and one of the most important timber species in Eurasia. Its natural range extends from Spain in the west (5°W longitude) to northern Manchuria and the sea of Okhotsk (130°E) in the east and from 70°N latitude in northern Scandinavia to 38°N in Turkey. Within this large geographical area mean annual temperatures vary between –10°C (Yakutiya, Russia) and > 13°C (southern Europe). This area includes regions and sites with highly contrasting fertility and nutrient availability (Oleksyn et al. 2002). In Central Europe, Scots pine naturally occurs on scattered and isolated extreme sites or on relict ones (Musil, Hamerník 2007). A wide range of site and stand conditions where Scots pine can successfully grow, its pioneer character, good usability of its wood, and simple silvicultural process led to the expansion of Scots pine stands to sites outside the area of its original occurrence in the past. Currently, Scots pine is the second most widespread commercial coniferous species with the proportion of around 16% in the Czech Republic (Ministry of Agriculture of the Czech Republic 2014) and is planted especially at lower altitudinal zones (up to ca. 500 m a.s.l.) on soils with lower fertility. In Poland, Scots pine with almost 60% of the tree species share (in 2016) be-

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came the main commercial tree (Milewski 2017). The Scots pine adaptability to a wide range of sites with distinct humid and nutrient conditions is enabled by its resistance to climate extremes. Thus, it appears as a stabilisation component of current forest stands (del Río et al. 2017).

A current departure from monoculture forest stands significantly increases the interest in mixed stands that better fulfil most of the expected forest functions compared to the pure ones (Pretzsch et al. 2015b; del Río et al. 2017; Zeller et al. 2017) and some mixed-species stands can outyield monocultures by up to 30% (Zhang et al. 2012; Bielak et al. 2014). A combination of more tree species with various ecological requirements often leads to higher resistance against unfavourable environmental factors (Griess, Knoke 2011). Increased attention has been devoted especially to Scots pine-Norway spruce (*Picea abies* (Linnaues) H. Karsten) mixtures for a long time (Vettenranta, Miina 1999), both tree species often occur together in naturally and artificially established forest stands. Previous studies analysing mixed Scots pine stands indicated a certain potential to increase the production yield of these stands and to create the more favourable stand structure compared to Scots pine monocultures without threatening the mechanical stability of forest stands (Poleno 1975; Pretzsch et al. 2013, 2015a; Bielak et al. 2014). For example, Bielak et al. (2014) in long-term (over 100 years) analysed stands in N-E Poland stated, that mixed stands of pine and spruce exceed the weighted mean of the pure stands' volume productivity on average by 41%. Scotch pine benefits from the mixture by 34% and Norway spruce by 83%. However, impact of admixture on aboveground biomass production, biodiversity, and resistance against unfavourable effects varies according to site conditions, social status of both tree species, and their proportion in the forest stand. In mixed stands (Scots pine-Norway spruce), Norway spruce shows an increasing diameter increment, however the potential of an increase in Scots pine increment is markedly lower (Valinger 1992; Bielak et al. 2014). Findings about the production potential of Scots pine and deciduous tree species mixed stands are scarce; e.g. mixing European beech and Scots pine indicates similar results like Scots pine-Norway spruce mixture (Pretzsch et al. 2015b).

In the Czech Republic, sessile oak (*Quercus petraea* (von Mattuschka) Lieblein) and Scots pine mixtures have not been evaluated very much so far, although both tree species have similar growth and site requirements. The properties of pine-oak mixed stands can change depending on site conditions, age of particular tree species, stand structure, and the social status of oak. Previous studies of the Scots pine-sessile oak mixtures comes especially from the German-speaking countries, where the non-native Scots pine stands are gradually transformed into mixed stands (Spathelf, Ammer 2015). Sessile oak increases its share in the forest stands either by natural (mostly spread by the Eurasian jay) (Mosandl, Kleinert 1998) or artificial regeneration (Schirmer et al. 1999; Noack 2008).

The objectives of this study are: (*i*) to analyse pure and admixed Scots pine stands growing on natural sites, (*ii*) to evaluate an admixture effect on aboveground biomass production and stability of mature Scots pine stands growing on natural Scots pine sites [*Pineto-Quercetum oligotrophicum* (*arenosum*)].

MATERIAL AND METHODS

Study sites. All measurements of Scots pine aboveground biomass and stand structure were conducted on two research series of plots (on five plots in total) located at the natural pine sites in a managed forest of the Municipal Forests of the Hradec Králové enterprise (Czech Republic). The forest type of both series was classified according to Viewegh et al. (2003) as *Pineto-Quercetum oligotrophicum* (*arenosum*). The series were established in forest stand parts of similar age (maximum difference of 11 years, which is in mature stand age commonly considered as even-aged), where other commercial tree species were present apart from Scots pine. Besides native species (sessile oak, Norway spruce), white pine (*Pinus strobus* Linnaeus) is one of the additional commercial species of the region. The details of the Marokánka (A) and Osada Kováků (B) series are described in Table 1. The particular research plots of each series were located in nearby vicinity (at a maximum distance of 400 m). The forest inventory on series A and B was performed in 2016 and 2017, respectively.

Measurement of forest structure. The forest structure was measured using the FieldMap® technology (IFER, Czech Republic). Each present tree on a plot with diameter at breast height (DBH, d) larger or equal to 7 cm (DBH ≥ 7 cm) was measured including dead standing trees. The tree species, possible injuries, tree coordinates, and DBH were estimated for each present tree. DBHs were measured to the nearest 0.1 cm. The height (h) of each tree was determined using an electronic laser

Table 1. Basic data of the study plots

Locality	Plot	Geographic coordinates	Altitude (m a.s.l.)	Soil type	$P_{ann.\ mean}$ (mm)	$T_{ann.\ mean}$ (°C)	Area (ha)	Age of stands (yr)
Marokánka	A1	50°10'N, 15°58'E	260	sandy soil, soil depth > 10 m; A-horizon: pH(H_2O) 3.4; nutrient content: 6,700 mg·kg^{-1} of N, 13 mg·kg^{-1} of P, 128 mg·kg^{-1} of K, 311 mg·kg^{-1} of Ca, 53 mg·kg^{-1} of Mg (Mehlich III method)	612*	8.5*	0.16	84
	A2						0.36	95
	A3						0.14	90
Osada Kováků	B1	50°11'N, 15°56'E	250				0.25	97
	B2						0.20	99

A1 – plot dominated by Scots pine, A2 – Scots pine-sessile oak mixed plot, A3 – plot dominated by sessile oak, B1 – plot dominated by Scots pine, B2 – Scots pine-sessile oak-white pine mixed plot, $P_{ann.\ mean}$ – mean annual precipitation, *1960–1990 period, $T_{ann.\ mean}$ – mean annual temperatures

hypsometer (Vertex® Laser VL5; Haglöf, Sweden) to the nearest 0.1 m on the Marokánka series (A1, A2, and A3). On the plots of Osada Kováků locality (B1, B2), from the capacity reasons the heights were estimated by the uniform height curve method applied for each species. On all plots, the presence of mistletoe in the Scots pine tree crowns was recorded.

Data processing. Spatial data were evaluated using QGIS software (Version 2.18, 2018). A function according to Näslund (1937) was used for height curve smoothing. Merchantable wood (DBH ≥ 7 cm) was calculated using Baumvolumen® software (Version 1.01, 2009) based on Bergel (1974).

For a dominant tree species, slenderness ratio (*h*/*d*) was calculated as a ratio of tree height to DBH. Stand diversity index (SDI) indicating the theoretical number of trees with mean diameter of 25 cm occurring in forest stand was calculated according to Reineke (1933) for particular present tree species on experimental plots. For computations, mean basal area diameter – d_g (Fabrika, Pretzsch 2013) was used (Eqs. 1 and 2):

$$\mathrm{SDI} = N \times \left(\frac{25}{d_g}\right)^{-1,605} \tag{1}$$

$$d_g = 2 \times \sqrt{\frac{g}{\pi}} \tag{2}$$

where:
N – number of trees per hectare,
g – mean basal area of tree species.

The total SDI value was calculated as a sum of SDI values of present tree species.

Hegyi's competition index (H_i) determining a competitive relationship between the trees based on their DBH and mutual distance was calculated according to Eq. 3:

$$H_i = \sum_{i=1}^{n}\left(\frac{d_i}{d_j} \times \frac{1}{\mathrm{dist}_{ij}}\right) \tag{3}$$

where:
d_i – diameter of a tree within a competition circle,
d_j – central tree diameter,
dist_{ij} – distance of d_i from the central tree.

A diameter of 5 m was applied and all Scots pines inside particular plots at a distance smaller than 5 m from the plot boundary entered into the calculations. These calculations were performed using R software (Version 3.4.4, 2018) using the siplab package. Afterwards, regression relationships between selected dendrometric parameters (DBH, *h*/*d*) and H_i value were investigated. Slenderness ratio (*h*/*d*) was not evaluated in the B series for the absence of individual tree heights. Confidence bands around the regression lines were estimated by a quantile regression method (Bassett, Koenker 1978) for quantiles 0.1 and 0.9 (i.e. τ = 0.10 and 0.90). The calculations and statistical evaluations were performed within each series in the R environment for statistical computing.

RESULTS

In both mixed stands (A2 and B2), Scots pines constituted the dominant level of the stands, admixed species grew mostly as subdominant (Figs 1–3). Admixture increased stand densities and total volumes compared to pure stands (Table 2). On the mixed A2 plot, the mean DBH of Scots pine was significantly higher than that on A1 plot ($P < 0.001$; Table 2). Conversely, the mean DBH of sessile oak was found significantly higher on A3 plot than on A2 plot ($P < 0.001$). On B1 plot, the most abundant Scots pine DBH occurred around the mean stem diameter (Fig. 2). On B2 plot, mean DBH and *h* of Scots pine were significantly ($P < 0.001$) higher than on B1 plot. The Scots pine mean stem volumes of 0.66, 1.00, 0.61, 0.66, and 0.91 m^3 were noted on A1, A2, A3, B1, and B2 plots, respectively. The

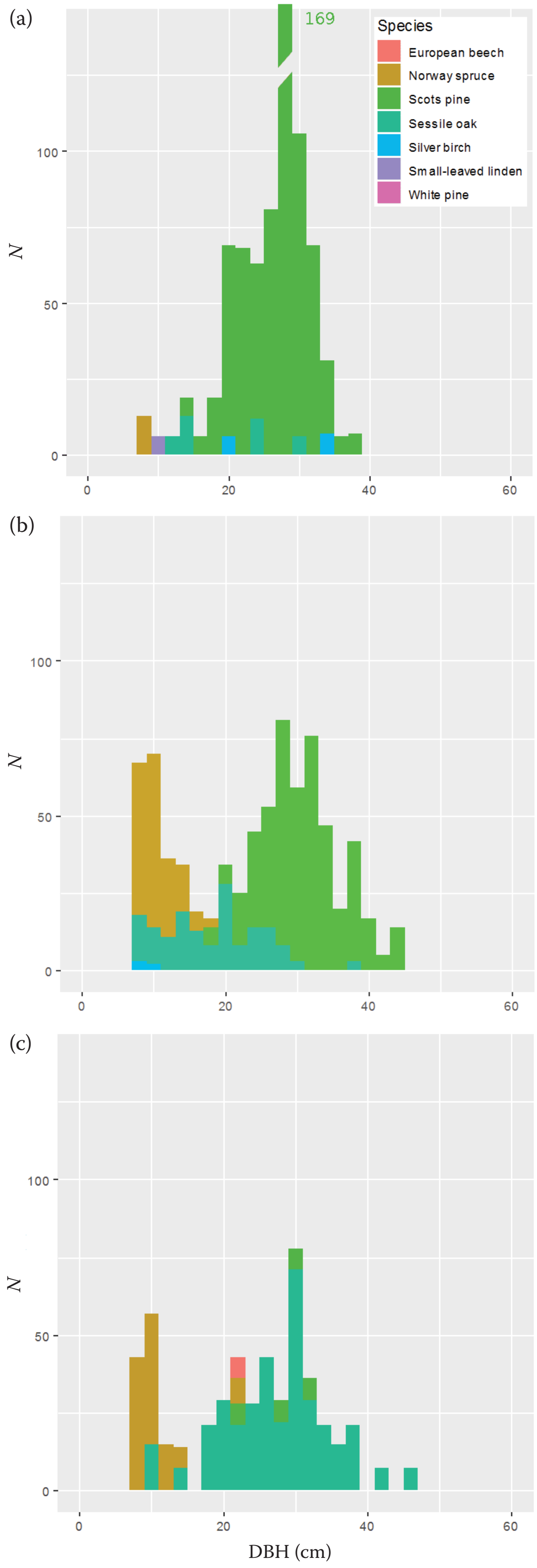

Fig. 1. Tree DBHs of A1 (a), A2 (b), and A3 (c) plots per hectare (diameter class width is 2 cm)

A1 – plot dominated by Scots pine, A2 – Scots pine-sessile oak mixed plot, A3 – plot dominated by sessile oak, *N* – number of trees per hectare

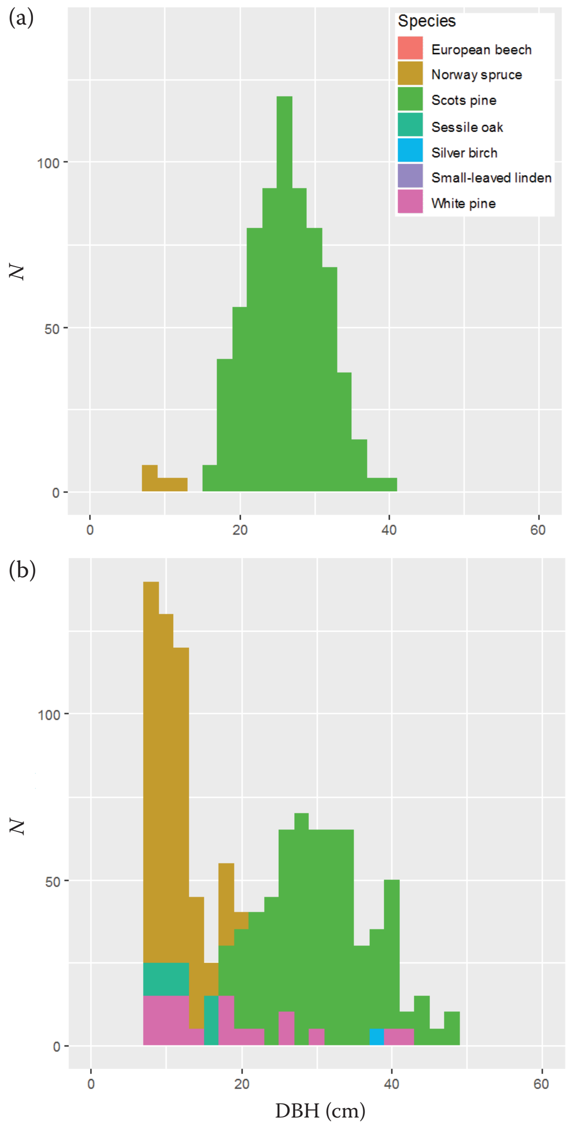

Fig. 2. Tree DBHs of B1 (a) and B2 (b) plots per hectare (diameter class width is 2 cm)

B1 – plot dominated by Scots pine, B2 – Scots pine-sessile oak-white pine mixed plot, *N* – number of trees per hectare

mean stem volume of B2 plot (0.91 m^3) was significantly higher ($P < 0.001$) than on B1 plot (0.66 m^3).

In view of stability, the *h*/*d* of Scots pine reached 91.8, 94.8, 78.4, 103.0, and 88.0 on A1, A2, A3, B1, and B2 plots, respectively. The *h*/*d* of Scots pine was insignificantly higher in mixed stand with oak (P = 0.08), while the *h*/*d* of conifer mixture B2 was significantly lower compared to B1 ($P < 0.001$). Conversely, the *h*/*d* of A3 plot (73.1) was significantly ($P < 0.001$) lower than on A2 plot (97.8) for sessile oak. Mistletoe occurrence of 65, 41, 27, and 57% was observed on A1, A2, B1, and B2 plots. In all investigated plots, the highest SDI was determined on B2 plot (Table 3).

In mixed stand, the slope of the height curves for sessile oak increased, whereas the effect was not

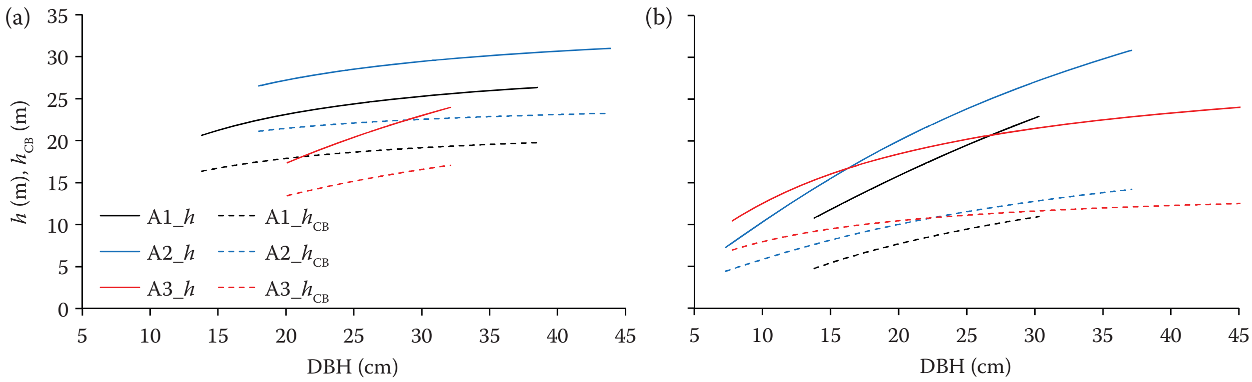

Fig. 3. Aligned height curves on A1, A2, and A3 plots for Scots pine (a) and sessile oak (b)

h – tree height, h_{CB} – crown base height, A1_h – height of the respective tree species on A1 plot, similarly A2_h and A3_h, A1_h_{CB} – crown base height of the respective tree species on A1 plot, similarly A2_h_{CB} and A3_ h_{CB}

Table 2. Stand characteristics of the research plots

Plot	Tree species	DBH (cm)	Stand density (No. of trees per hectare)	SC (%)	BA (m²·ha⁻¹)	BA (%)	h (m)	h_{CB} (m)	SV (m³·ha⁻¹)
A1	Scots pine	26.8	669	90.7	38.86	94.7	24.6	18.7	424.2
	sessile oak	20	38	5.1	1.3	3.2	16.2	8	12.6
	Norway spruce	8.1	13	1.7	0.06	0.2	7.4	1.5	0.2
	silver birch	26.6	13	1.7	0.75	1.8	23.4	12.3	9.6
	small-leaved linden	10	6	0.8	0.05	0.1	6.3	1.6	0.2
	total	26	738	100	41.02	100	23.7	17.6	446.8
A2	Scots pine	31.1	442	58.2	34.67	82.9	29.5	22.6	445.6
	sessile oak	18.4	156	20.5	4.65	11.1	17.9	9.3	21.1
	Norway spruce	10.4	153	20.1	1.37	3.3	10.4	2.6	50.7
	European beech	71.1	3	0.4	1.1	2.6	36.8	15.3	0.2
	silver birch	9	6	0.8	0.04	0.1	12	7.6	6.8
	total	24.3	760	100	41.83	100	23.1	15.8	524.4
A3	Scots pine	27.8	29	5.6	1.78	6.9	21.8	15.9	17.6
	sessile oak	27.5	357	70.4	22.65	87.8	20.1	11.2	252.8
	Norway spruce	10.5	114	22.5	1.1	4.3	9.3	1.7	5
	European beech	22.3	7	1.5	0.28	1	19.3	9.1	2.6
	total	23.6	507	100	25.81	100	17.7	9.2	278.1
B1	Scots pine	26.3	696	97.8	39.2	99.7	26.4	19.6	456.5
	sessile oak	–	–	–	–	–	–	–	–
	Norway spruce	9.4	16	2.2	0.1	0.3	9	2.2	0.5
	total	25.9	712	100	39.3	100	26	19.2	457
B2	Scots pine	30.7	580	51.6	45.1	84.2	27	19.9	534.9
	sessile oak	12.3	45	4	0.6	1.1	22.2	17.1	6.1
	Norway spruce	11.1	395	35.1	4.1	7.6	10.5	2.5	21.6
	silver birch	37.2	5	0.4	0.5	1	22	16	7.5
	white pine	18	100	8.9	3.3	6.1	23.6	17.9	37.2
	total	22	1,125	100	53.6	100	20.7	13.5	607.3

A1 – plot dominated by Scots pine, A2 – Scots pine-sessile oak mixed plot, A3 – plot dominated by sessile oak, B1 – plot dominated by Scots pine, B2 – Scots pine-sessile oak-white pine mixed plot, SC – stand composition, BA – basal area at breast height, h – tree height, h_{CB} – crown base height, SV – standing volume

observed for Scots pine (Fig. 3). The length of sessile oak crowns increased with DBH more intensively in mixed stand (A2) compared to the pure one (A3).

On A1 plot, Hegyi's competition index (H_i) of Scots pine ranged from 0.2 to 2.9. DBH decreased with increasing H_i (DBH = 33.50 – 4.51 × H_i), contrary, its slenderness increased (h/d = 75.86 +

Table 3. Stand diversity index of investigated research plots calculated according to Reineke (1933)

Tree species	A1	A2	A3	B1	B2
Scots pine	765.8	643.7	34.5	776.7	839.1
Sessile oak	28.3	14.9	5.9	–	15.2
Norway spruce	2.1	39.0	31.0	3.4	112.5
Silver birch	14.7	1.1	–	–	9.4
Small-leaved linden	1.4	104.6	438.7	–	–
White pine	–	–	–	–	72.6
Total	812.3	803.2	510.1	780.1	1,048.8

A1 – plot dominated by Scots pine, A2 – Scots pine-sessile oak mixed plot, A3 – plot dominated by sessile oak, B1 – plot dominated by Scots pine, B2 – Scots pine-sessile oak-white pine mixed plot

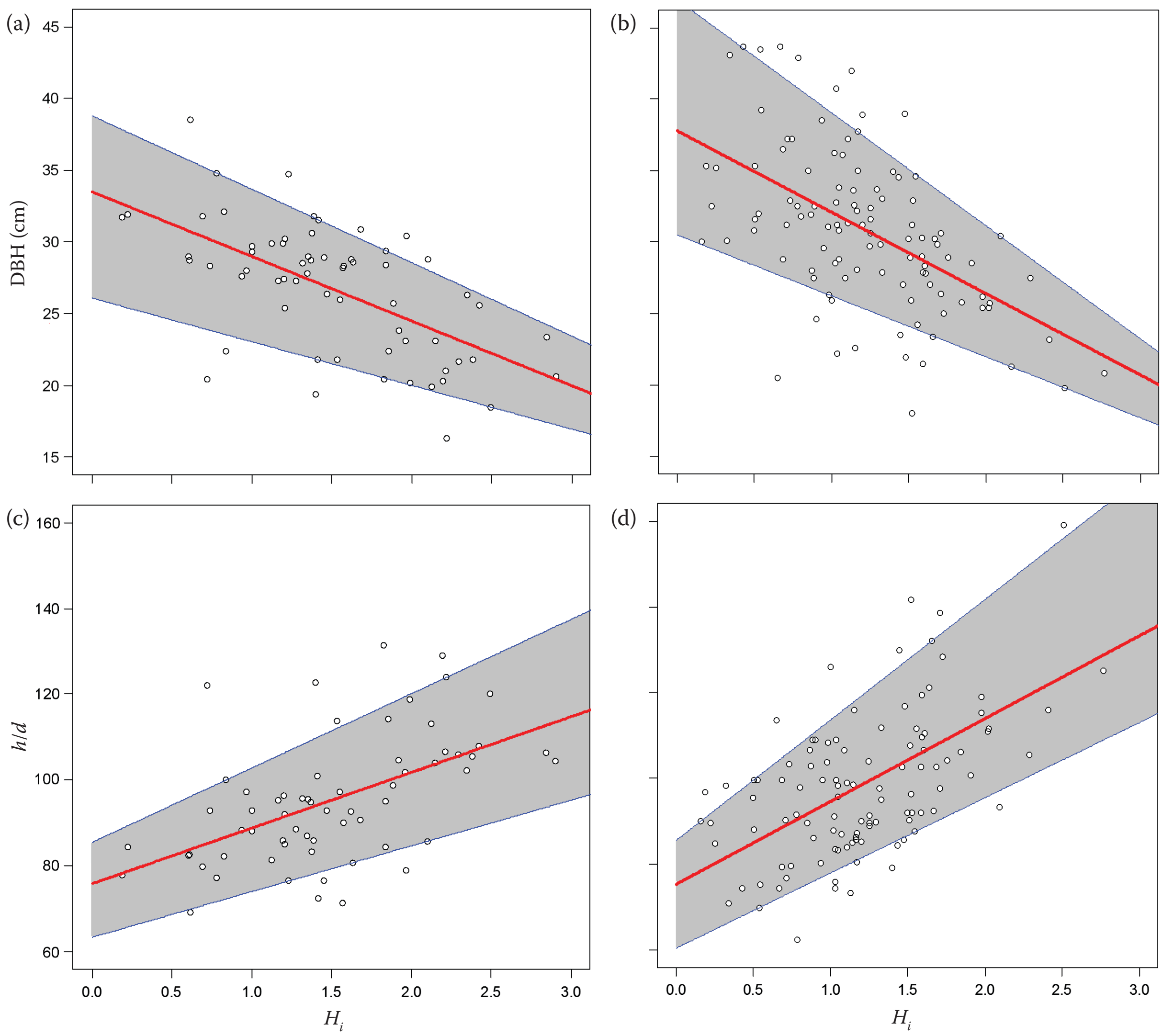

Fig. 4. The relationship between Hegyi's index (H_i) for 5 m distance and DBH (a, b) and slenderness – h/d (c, d) for Scots pine in A1 plot (a, c) and A2 plot (b, d)

h – tree height, *d* – diameter at breast height; red lines represent linear regression and the quantile regression bands with τ = 0.1 and τ = 0.9 are defined by blue lines

12.97 × H_i; Fig. 4). On A2 plot, Hegyi's index was in a similar range (0.2–2.8) like on A1 plot. However, the regression dependence between H_i and DBH (DBH = 37.78 – 5.69 × H_i) and slenderness (h/d = 75.34 + 19.30 × H_i) was steeper compared to A1 plot (Fig. 4). The A3 plot was deliberately omitted from H_i evaluation due to the low Scots pine presence.

On B1 plot, Hegyi's index varied from 0.2 to 4.0. A negative regression relationship between H_i and

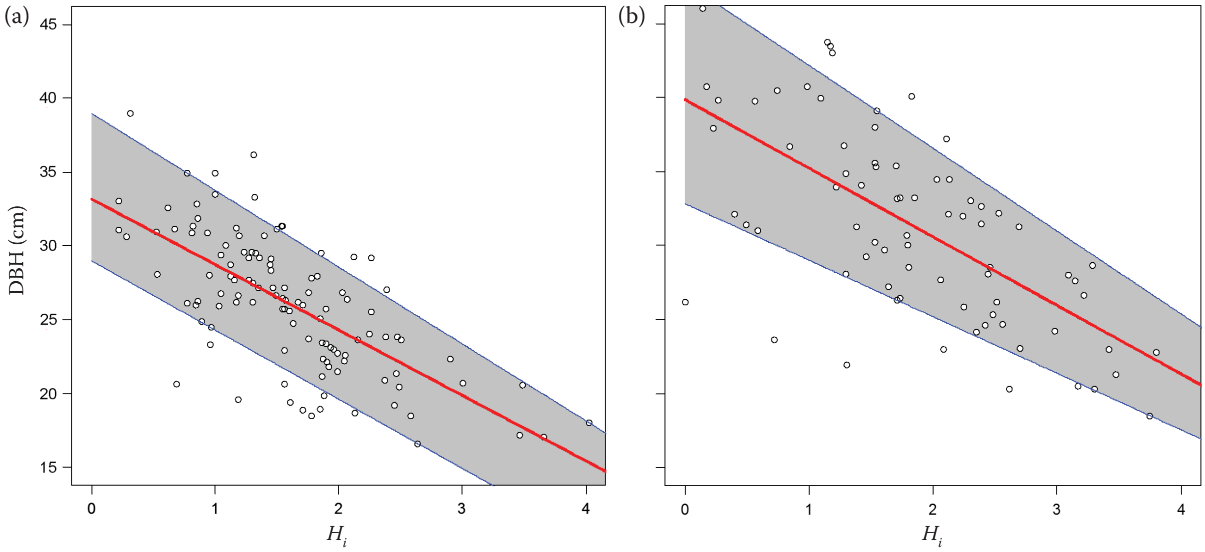

Fig. 5. The relationship between Hegyi's index (H_i) for 5 m distance and DBH for Scots pine in B1 (a) and B2 (b) plots
Red lines represent linear regression and the quantile regression bands with τ = 0.1 and τ = 0.9 are defined by blue lines

DBH was DBH = 33.17 – 4.43 × H_i (Fig. 5). On B2 plot, Hegeyi's index ranged from 0.1 to 3.8. A high negative regression relationship between H_i and DBH was also found there (DBH = 39.86 – 4.64 × H_i; Fig. 5).

DISCUSSION

In stand mixtures of a light-demanding species with Scots pine, the mutual effect of interspecific competition differs from that of Scots pine with shade-tolerant beech mixtures (Küsters et al. 2004; Pretzsch et al. 2016), where an increase in the structural heterogeneity of mixed stand was found compared to monocultures. A significant variability of site and stand conditions of the Scots pine-sessile oak (and another tree species) mixed stands makes it difficult to compare with the parameters of pure stands. The oak of the same age as Scots pine can either grow simultaneously with the upper-level pine or in an open stand, it can survive suppressed below the upper canopy layer for a long period. In the lower canopy layer, oak can also be markedly younger due to its origin from natural regeneration (Schröder et al. 2009). Shade-tolerant Norway spruce from natural regeneration may become a part of the lower stand layer of Scots pine stands later as well. Therefore, considering dimensions of the trees, suppressed Norway spruce of our trial probably came from natural regeneration.

In the stand mixtures, a mutual effect of tree species includes competition in above- as well as below-ground space. Scots pine belongs to deep-rooting tree species including also sessile oak (unlike Norway spruce). However, the Scots pine roots penetrate deeper than those of sessile oak on dry sandy soils (Jeník et al. 2014) corresponding to the analysed sites in this study. Furthermore, it was found that in mixed stands the sessile oak roots grow into smaller depths of soil than in sessile oak monocultures. Conversely, the Scots pine root system develops better in mixed stands compared to pure Scots pine stands (Kacálek et al. 2017). This fact may also affect the more frequent dominance of Scots pine in mixed stands. Scots pine and sessile oak differently respond to reduced water availability in spite of the shared forest sites and deep growing roots. A different effect of dry period on the properties of sessile oak and Scots pine wood was found in mixed and unmixed stands. Whereas a tree-ring density moderately increased in oak stands with water deficit in the soil, the Scots pine tree-ring density significantly decreased (Toigo et al. 2015).

Del Río and Sterba (2009) compared the Scots pine-Pyrenean oak (*Quercus pyrenaica* von Willdenow) mixed stands productivity based on forest inventory and modelling. In the mixed stands, Scots pine showed lower productivity and growth due to oak competition. Nevertheless, they recommended a 20 to 30% admixture of oak for the establishment of complex forest with minimum production losses. The growth of Scots pine of even-aged stands dominates until the middle age (from 60 to 80 years of age) and a competition potential of sessile oak gradually increases with increasing age of the stand (Schröder et al. 2009). According to Bartsch et al. (1996), sessile oak reacts positively to the Scots pine vicinity in mixed stands. In our study, the positive height increment of oak was confirmed. However, the mean stem volume attained only an approximately half value in the mixed stand. Conversely, the total production increment was noted in the mixed stands.

Scots pine litter is acidic and it usually creates less favourable humic forms that can increase the acidity of top soil layers. In the case of mixed stands dominated by Scots pine, the litter of particular tree species is blended and it can affect decomposition, leaching of substances from soil horizons, and the activity of soil microorganisms (Bergkvist 1987; Borken, Beese 2005). Thus, it can be one of the factors affecting tree growth responses in the stand. An admixture of another tree species favourably adjusts the topsoil horizon properties and enhances the soil microbial activity; such an influence depends on tree species and its representation in the stand. Nevertheless, only individual admixture of sessile oak and Norway spruce in the Scots pine stands resulted in minimal differences in the properties of top soil layer (Peřina 1973). A more obvious effect of stand mixtures was found on nutrient-poor sites (Kacálek et al. 2017), like on the sites in this study. Prietzel (2004) investigated the changes of humic characteristics in Scots pine stands with admixed European beech and sessile oak. He noted that the European beech showed a more favourable effect on the humus properties than the sessile oak. An improvement of soil conditions on Scots pine sites is slower under the influence of admixed sessile oak (Schua et al. 2007; Schröder et al. 2009). On sandy soils, a positive effect of admixed sessile oak on humus properties and vegetation was also reported by Błońska et al. (2013). The individual admixture of sessile oak in the upper canopy layer also has a positive effect on the nutrient cycle and biodiversity (Lehmann 2008). These changes can also be reflected in nutrient availability and they can be a factor increasing the biomass production of Scots pine stands with an admixture of other tree species.

Being distributed by birds and due to behavioural preferences of birds, mistletoe is commonly more frequent on dominant trees (Mellado, Zamora 2016). In the A series, a lower mistletoe occurrence on Scots pine was observed in mixed stand, contrary to the B series where a lower share of parasitized trees was in the pure plot. Besides the higher stand density of B2 plot being one of the possible factors influencing the resilience of pines against the pest, there is a lack of data on the bird nesting and movement within the stands, therefore the reason for the difference can hardly be judged. However, the presence of mistletoe significantly reduces tree increment (Bilgili et al. 2018; Kollas et al. 2018).

The Scots pine and sessile oak h/d increased in the mixed stand analysed in this study compared to monocultures; significantly for sessile oak. The steepness of the regression relationship between Hegyi's index and h/d in mixed stands also increased. However, no problem occurred in the point of view of stability, since the value above 95 is considered to be critical (Novák et al. 2013). Nonetheless, the result was absolutely opposite to the evaluation of beech and linden admixtures in Scots pine stand occurring on spoil-bank reclamations. In this case, Dragoun et al. (2015) found the highest coefficient of unstable stands in the unmixed stand (h/d was 120 for the most stable Scots pine-European beech variant). The resulting h/d will probably be more related to the stand density of the general level of main canopy than to the presence of another tree species in the stand.

The findings provide supportive data for the reasons for transformation of the large pine monocultures currently attacked by abiotic (mainly by drought) and secondarily by biotic factors – actually in Central and Northern Europe especially by *Ips acuminatus* (Gyllenhal, 1827) (Siitonen 2014), into more diversified mixed-species stands. The measure of species diversity increase would probably enhance ecological stability, biodiversity and range of goods coming from forest, which would together with increased standing volume make a grand benefit for the future ongoing climatic extremity (IPCC 2018).

CONCLUSIONS

The areas of natural Scots pine and sessile oak distribution partly overlap. Both tree species can create a wide range of stand mixtures with variable properties. The mixed stands of both tree species usually exhibit higher resistance to changing environmental conditions and to the occurrence of climate extremes. Thus, that can contribute to the higher stability of current forest stands. The wide ecological valence of Norway spruce makes it a common component of these stands. An analysis of stand structure and assessment of admixed tree species effect on productivity and stability of mature stands growing on natural Scots pine sites [*Pineto-Quercetum oligotrophicum* (*arenosum*)] revealed higher aboveground biomass production. The effect of mixtures on pine mistletoe occurrence remains ambiguous. Scots pine remains a dominant component of both analysed mixtures. In the A series, the lowest stand productivity was found according to expectations in the stand dominated by sessile oak.

Conversely, the 20% proportion of sessile oak in the Scots pine stand with similar stand density led to an increment of mean DBH, tree height, and mean stem merchantable wood (DBH ≥ 7 cm) volume of Scots pine compared to the pure Scots pine variant. Similarly, in the B series the increment of Scots pine DBH in mixed stand with the almost half share of other conifers was confirmed, the effect of spruce and white pine admixture on stand volume increase reached 33%. More than the marginal age difference of the stands, increased stand structure diversification and synergic effect of different tree species vicinity promoting growth seem to be the reason. The admixture increased the h/d of oak without threatening the stand mechanical stability.

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