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ORIGINAL PAPER

Classification of tree species composition using a combination of multispectral imagery and airborne laser scanning data

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Abstract

Remote Sensing provides a variety of data and resources useful in mapping of forest. Currently, one of the common applications in forestry is the identification of individual trees and tree species composition, using the object-based image analysis, resulting from the classification of aerial or satellite imagery. In the paper, there is presented an approach to the identification of group of tree species (deciduous – coniferous trees) in diverse structures of close-to-nature mixed forests of beech, fir and spruce managed by selective cutting. There is applied the object-oriented classification based on multispectral images with and without the combination with airborne laser scanning data in the eCognition Developer 9 software. In accordance to the comparison of classification results, the using of the airborne laser scanning data allowed identifying ground of terrain and the overall accuracy of classification increased from 84.14% to 87.42%. Classification accuracy of class "coniferous" increased from 82.93% to 85.73% and accuracy of class "deciduous" increased from 84.79% to 90.16%.

Key words: object-based classification; tree species; aerial images; airborne laser scanning

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1. Introduction

A trend in forest mapping is the use of modern means of computer and digital measuring technique. This trend is also reflected in the field of remote sensing (RS) and digital photogrammetry, which methods are now irreplaceable in addition to the terrestrial methods of forest mapping and gathering the information about the forest for forest management purposes. The development of remote sensing technology, and remote sensing data itself, has allowed replace or combine the terrestrial methods with time and cost-efficient remote sensing methods, using the aerial photographs, satellite imagery or airborne laser scanning (ALS) data (Maltamo & Packalen 2014).

One of the most frequently used and effective methods of derivation of tree and stand characteristics from the remote sensing data is image segmentation and classification. Currently, the object-based image analysis (OBIA) is more preferred method than the pixel classification (Yu et al. 2006; Petr et al. 2010; Pippuri et al. 2016). Pixel classification is based on the classifying the individual pixels to particular classes in accordance to their digital numbers (DN). On the other hand, the OBIA method works with objects (segments), which are represented by clusters of pixels with similar properties (brightness, texture, homogeneity, size, shape, etc.) (Benz et al. 2004). The objects can better represent the real objects, which are the subject of forestry mapping (e.g. tree crowns, forest stands), what is confirmed in a number of previously published works (Blaschke 2010). Using the OBIA method, there were achieved better results of forest and landscape classification, in an average of several tens of percent (Cleve et al. 2008; Myint et al. 2011; Rittl et al. 2013). Worse results related to the accuracy of pixel-based classification were achieved due to the fact that inside the identified tree crowns may occur pixels representing the shadow, errors or noise, i.e. the "salt and pepper" effect (Heinzel & Koch 2012). This problem is even more severe when using RS data with very high resolution, which provide more detailed spatial and radiometric information about the displayed objects (Kim & Madden 2006; Myint et al. 2011).

At present, almost 90% of the mapping works in the Slovak Republic territory is carried out by photogrammetric methods (Halvoň 2011). Nevertheless, the common applications of remote sensing methods include classification of land cover, forest health, tree species composition and forest structure and texture (Wang & Boesch 2007; Bucha et al. 2010) are applied more in the research than in practice so far. Majlingová (2007) dealt with the classification of analogue colour infrared images followed by the subsequent surveys, respectively esti-

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**Corresponding author. Maroš Sedliak, e-mail: sedliak@nlcsk.org, phone: +421 45 5314 168* mating the tree and stand characteristics. Based on the results achieved, she indicated that the most appropriate resolution for the classification of tree species composition in mature stands is the spatial resolution of at least 1.6 m. She also highlights the importance of identifying a suitable scale factor (scale parameter) for segmenting the input images in Definiens eCognition software, with respect in particular to the stand age, tree species composition, and therefore the parameters of expected size of tree crown.

Kardoš et al. (2013) have studied the classification of tree species in the eCognition software on the unmanaged land with great diversification of tree species and diverse horizontal and vertical structure. They compared the impact of different types of spatial resolution and aerial imagery on their segmentation and classification results, using multiple classification techniques.

An important area of remote sensing, applied in the mapping of forests, is the ALS, which provides useful information on the forest as for the needs of forest management as for forest mapping (Wack et al. 2003; Andersen & Breindenbach 2007; Korpela et al. 2007). The ALS technology uses the reflection of laser ray from the object, and based on the relatively high density of the transmitted rays (up to several tens of points per 1 m^2), with a relatively high positioning accuracy of the reflection in the 3D space (X, Y, Z), it provides, in particular, an accurate position information on sensed objects, that allows determine their shape and position more precisely. This information is useful for the derivation of Digital Surface Models (DSM) or the shape of individual objects. In addition, it is also possible to evaluate the intensity of the reflected ray, which relates to the nature of the surface (foliage type, leaf size, leaf orientation) (Fassnacht et al. 2016). For forestry purposes, it is suitable to combine this data with radiometric qualitative information about the objects, determined e.g. from the multispectral images, which can increase the accuracy of tree crowns identification or derivation of other tree and stand characteristics (Kressler & Steinnocher 2006; Tiede et al. 2006; Sasaki et al. 2012; Debella-Gilo et al. 2013; Machala & Zejdova 2014; Pippuri et al. 2016).

Leppänen et al. (2008) used the ALS data in combination with CIR images to delineate the forest stands. CIR imagery improves the classification of different tree species types, the ALS data alone provides a good conditions for derivation of timber size and density. Wang et al. (2012) used a combination of aerial photography and ALS to derive the borders by the Gabor wavelets, while the key features were Curvature features, derived from ALS. Ørka et al. (2012) used the ALS data combined with LANDSAT-5 data for mapping the subalpine zone. Classification of the ALS data enabled the accurate depiction of the zone over a large area, without calibration based on the field measurements.

The aim of this study is to evaluate the impact of ALS data application, in combination with aerial multispectral imagery, on the accuracy of the classification of tree species composition (defined as two groups: coniferous and deciduous tree species) in conditions of close-to-nature mixed forests of beech, fir and spruce. The presumption is that the combination of both data sources will have a positive impact on the accuracy of group of tree species composition classification.

2. Material and methods

2.1. Experimental area

The experimental area is located in the territory of the "Pro Silva" demonstration object – Smolnícka Osada (48°44' N, 20°46' E) in Slovakia, where the close-to-nature forest management is carried out for more than 50 years (Fig. 1). The total extent of this area is 2,223 hectares. The area is located in Volovske vrchy orographic region. It has mountainous nature with altitudes in the range of 443 – 1,150 m above sea level. Regarding vegetation zones, the 5th (fir–beech) and 4th (beech) altitudinal vegetation zones prevail. Commercial forests represent 65% of the area, special purpose forests aimed at protection of genetic resources 24%, rest are protective forest. Tree species representation in the highest storey is as follows: *Abies alba* – 37%, *Fagus sylvatica* – 37%, *Picea abies* – 12%, *Pinus sylvestris* – 10%. Over all area, 50 circular verification plots with diameter 25 m were established to cover variability of stand characteristics (Fig. 1).

2.2. Remote sensing data

To obtain the multispectral aerial images with a spatial resolution of 9,000 × 6,732 pixels, there was used the Leica RCD30 camera. Aerial photography was carried out in September 2014, using the Cessna TU206F supporting device in an average flight altitude of 1,034 m. In further processing, the images were orthorectified and mosaicked, what resulted in creation of two raster layers – colour orthophoto (RGB) and colour infrared orthophoto (CIR) with a spatial resolution of 0.2 m and 16-bit colour depth, which served as the input data for the classification process.

The second input remote sensing data included the data from the airborne laser scanning (ALS), which was carried out in parallel with the multispectral photographs. To obtain the point clouds, there was the Leica ALS 70-CM laser scanner used, which at an angle of 49° (FOV) and 228.4 kHz (PRF) frequency ensured the density of 4.3 point/m^2. In the next working process, two raster files with 0.5 m resolution were calculated from the point cloud. The first one is the normalised digital surface model (nDSM), which is derived by subtracting the digital terrain model (DTM) from the digital surface model (DSM). Creating of digital models was carried out through hierarchic robust filtering techniques in

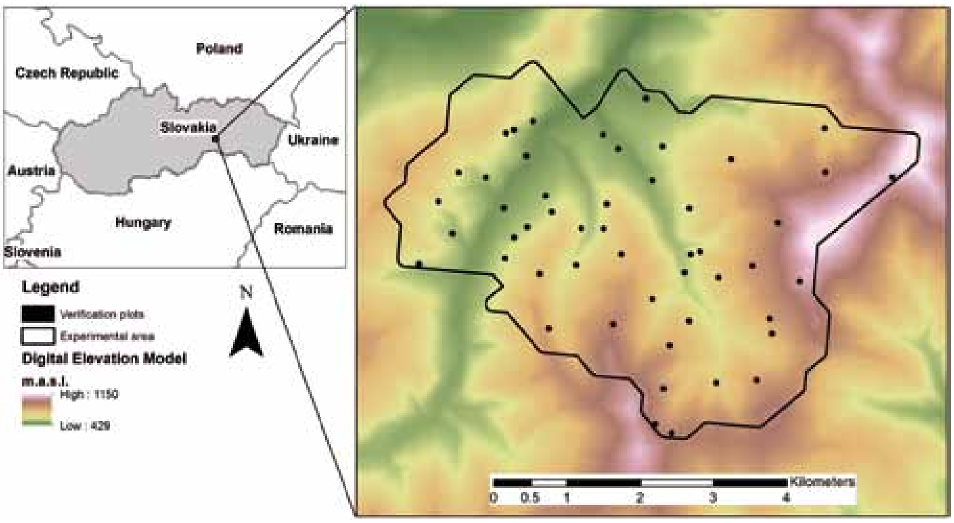

Fig. 1. Localization of experimental area and verification plots.

SCOP++ environment (Trimble). The second one is the intensity raster, which is created based on intensity values collected for every point in the point cloud. Creating of intensity raster was carried out using the geoprocessing tools in ArcGIS (ESRI).

2.3. Segmentation process

The first step in the process of group of tree species classification was the image segmentation. Segmentation was performed in eCognition Developer 9 software, using the "Multiresolution Segmentation" algorithm, which is based on Fractal Net Evolution Approach (FNEA) (Baatz & Schäpe 2000). Due to the large extent of the area and software limits for image processing, these images were automatically divided into 9 tiles.

To properly perform the segmentation process and therefore to obtain the purest representation of the displayed objects, it is very important to choose the right scale for image segmentation (i.e. scale parameter). Two other significant factors are the object shape and compactness that affect the homogeneity of the created segments. Their values vary between 0 and 1. Shape factor affects the shape of the segments, with emphasis on spectral homogeneity or objects shape. Compactness factor affects the smoothness vs. compactness of the objects shape (Myint et al. 2011). Segmentation scale value depends primarily on the spatial resolution of images inputting the segmentation process as well as the expected size of created segments (objects) (Majlingová 2007). The lower value of the scale parameter (e.g. 10) produces smaller size objects, while the higher value (e.g. 50) produces larger objects with greater heterogeneity of pixels within the object.

Owing to the size and heterogeneity of an area and forest, the shape factor was set to 0.1, i.e. with low weight to form the shape of segments, and thus greater weight to the spectral homogeneity of pixels. Compactness factor was set to the mean value (0.5), with no enhanced emphasis on compactness or smoothness of objects. These values were chosen regarding heterogeneous structure of forest (different size and shape of crowns). With determining the most accurate value of scale parameter for image segmentation and its verifying dealt several works in the past (Drăguţ et al. 2010; Myint et al. 2011; Kardoš et al. 2013; Drăguţ et al. 2014).

For the purposes of this study, there was selected the "Estimation of Scale Parameter" (ESP) tool, which is used to estimate the scale parameter for multiresolution segmentation in eCognition. ESP allows select the default value of scale parameter, step size of scale parameter value incrementing, the number of repetitions "," Shape and Compactness parameter values, on which iteratively performs segmentation of more-layered image at different levels of scale parameter, for which calculates the local variance of identified segments. Based on the graphic evaluation of the Local Variance (LV) and Rate of Change (ROC) calculations, which reflect the change of variance at different levels, it allows estimate the most appropriate scale parameter value for the image. The biggest changes of LV expressed by ROC values represent potentially the biggest changes in the meaning of segmentation and hence the representation of individual segments (Drăguţ et al. 2014).

ESP was set to calculate the segmentation for the initial value of the scale parameter (25) and then iteratively calculate with incrementing the parameter value up to value 150. Overall, there were calculated 126 segmentations. The tool is computationally demanding, therefore there was used the image subset with an extent of about 36 hectares, to calculate that properly represented the heterogeneity of the experimental area.

2.4. Classification process

The basis for assessment is the comparison of accuracy of tree species composition classification as on a basis of aerial multispectral imagery application as in combination with ALS data. There were performed two classifications based on a different data sources. At first, only the orthophoto images (3 RGB bands and 3 CIR bands) were used. At second, the combination of orthophoto images (3 RGB bands and 3 CIR bands) and raster layers derived from ALS data were used. These ALS-derived layers were represented by the nDSM layer, which represents the object height above the ground and Intensity layer that characterizes the reflection of surface.

For the both classifications of group of tree species, there was applied the standard nearest neighbour (SNN) classifier with setting the emphasis to mean values of pixels for each band of orthophoto image. Furthermore, in second case, there were classified those image segments using membership function, on the basis of the nDSM layer, which average height was less than 3 m. Those segments were assigned to the "Ground" class and they represented a surface of relief with low objects. Segments with an average height of 3 m or more were further assigned into 3 classes: "Deciduous", "Coniferous" and "Shadow", using another 7 layers, i.e. channels, (3 RGB, 3 CIR and Intensity layer).

The classification was carried out based on defining the characteristics of each class by creating the "Samples" (training sets), in which a characteristic samples (objects) were assigned. The weight of all layers in the classification process was set to 1.0.

2.5. Verification process

Evaluation of the classification accuracy was provided using the classification error matrix and calculation of classifications accuracy. For each classification and also the class, we calculated the Kappa coefficient (Dou et al. 2007), which indicates the proportionate reduction in error generated by a classification process, compared to the error of a completely random classification (equation 1).

$$K = \frac{P_0 - P_e}{1 - P_e} \qquad [1]$$

where P_o – the proportion of observed agreement,
P_e – the proportion of random agreement.

For determining the accuracy of the classifications, there was created a verification layer of tree species composition in the model area, on the basis of RGB and CIR orthophoto images. The verification layer consisted of 50 segments situated within the randomly generated circular plots in ArcGIS with diameter of 25 m, and with the total area of 24,200 m^2 (Fig. 1). To each segment or its part was assigned one of the specified classes (ground, shadow, deciduous, coniferous), based on visual assignment. This verification layer was used to determine the accuracy of both classifications.

3. Results

3.1. Segmentation results

The aim of the segmentation was to generate segments as good as possible to represent the reality displayed in the images. To determine the most appropriate scale (scale parameter) for the multiresolution segmentation the Estimation of Scale Parameter (ESP) tool was applied. Graphical representation of the Local variance (LV), Rate of Change (ROC) calculations and detail of ROC are shown in Fig. 2. In accordance to calculation results, there was chosen the segmentation scale parameter with value of 125, where is the highest value change of the ROC.

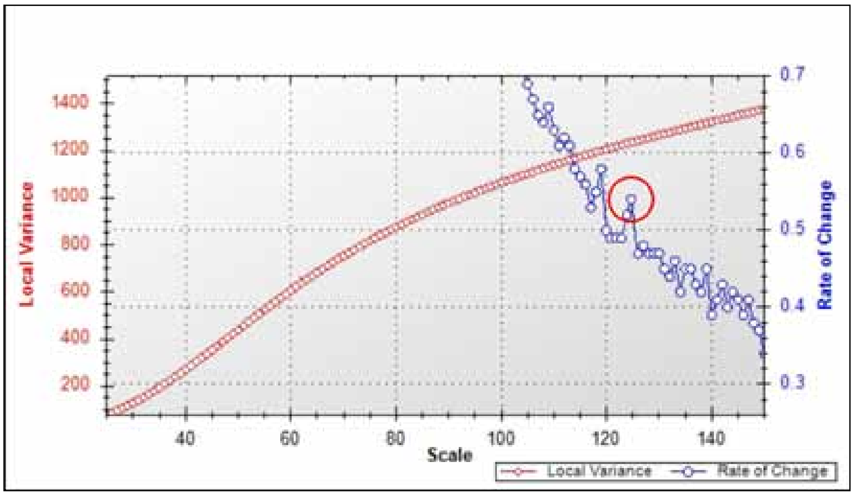

Fig. 2. Visualisation of Rate of Change in Estimation of Scale Parameter (ESP) environment (value 125 is in circle).

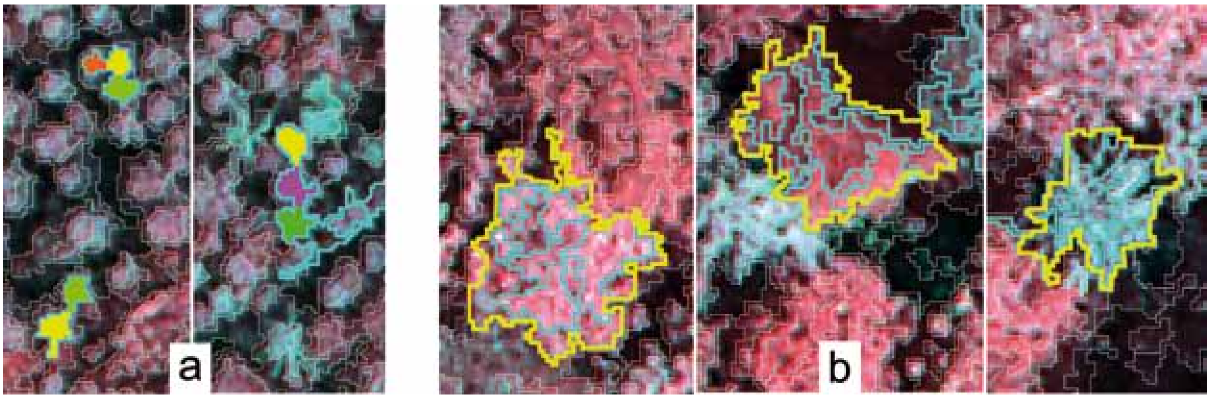

Fig. 3. Results of segmentation, a: in one segment (blue line) is more than one crown (coloured polygons); b: mature canopy (yellow line) consists from more than one segment (blue lines).

The segmentation result was visually compared with the orthophoto images. The results are characterized with over-segmentation of objects in the regions with mature forests (with broad crowns), i.e. in an average, one crown consists of several segments (Fig. 3b). Nevertheless, those results are acceptable, in accordance to the extent of the territory, heterogeneity of tree crowns, illuminated and shaded parts of the tree crowns and the variable quality of orthophoto images on a large area. In contrast, the segmentation of younger stands, characterized with smaller tree crowns, was more accurate in terms of the size. The youngest stands with the smallest crowns were characterized with under-segmentation, i.e. one segment contained more crowns of the same group of tree species (Fig. 3a). In terms of tree crowns canopy closure, also the determination of the shape of individual tree crowns was difficult, especially for young deciduous trees with a full canopy closure.

3.2. Classification results

Into the class "Coniferous", there was assigned 1,102.99 hectares (50% of the whole experimental area). 942.96 hectares (42%) was assigned into the "Deciduous" class. 151.63 hectares (7%) was assigned into the "Ground" class and only 25.48 hectares (1%) into the "Shadow" class (Fig. 4).

To "Ground" class (yellow coloured), there were classified the areas representing mainly the landscape outside the forests such as roads and grasslands. Inside the forest the "Ground" class objects were found in the gaps of tree crowns and in stands with low stocking and opened canopy closure. The largest areas of "Ground" were located in the eastern part, on the ridge, where there are damaged stands with lower stem density. Identifiable are also the part of forest roads over which there are not the tree crowns. In the territory, it is possible to distin-

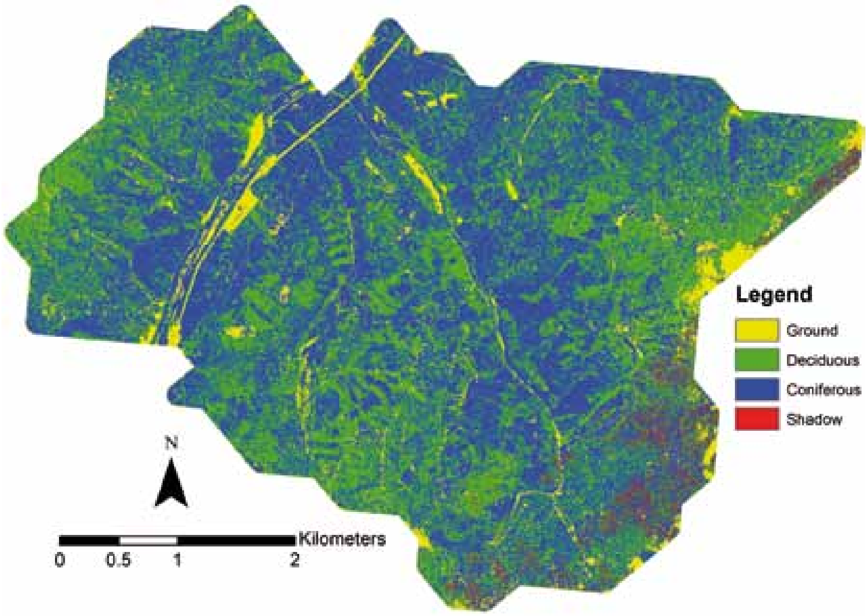

Fig. 4. Classification result of experimental area.

guish the spatial distribution of deciduous (green colour) and coniferous trees (blue colour). Red colour represents the class "Shadow". It is represented primarily in the north-eastern and south-eastern parts of the territory, which is associated with worse quality of the underlying multispectral imagery of this area, where some flight lines were realized in different time.

The results of classification without the use of ALS data are shown in the classification error matrix (Table 1) and results with the use of ALS data are shown in the classification error matrix (Table 2). Tables show area conjunction (m^2) of each class derived based on classification process and reference data. For each classification class, there was calculated User's Accuracy (UA) and for each class of reference data was calculated Producent's Accuracy (PA). UA expresses the probability that a pixel is included in the class truly represents this class also in the field. PA expresses how many proportions of reference pixels were assigned to the class.

The results of classification (with the use of ALS data are shown in the classification error matrix in m^2 (Table 2).

The overall classification accuracy, without the use of ALS data, was lower (84.14%), when compared to accuracy of the classification with application of ALS data (87.42%). Improvement of overall accuracy by 3.28% represents 792 m^2 large area of verification layer. Improvement represents 72.92 hectares of total area and correct classified area is 1,943.40 hectares large. The value of Kappa coefficient, expressing the correlation between the reference data and classification results, and excluding the matches by chance, increased from 0.7080 to 0.7774. Increasing this value means that the ALS data application in the classification process removed 6.96% of the errors that would be produced by random classification process.

In the classification without application the ALS data, there was classified c.a. 5.5% (1,345 m^2) of the total experimental area into one of two classes of group of tree species, although in the verification layer those areas were assigned to the "Ground" class. Applying the ALS data, there was correctly classified the area of 1,167 m^2 and user accuracy reached 81.60%. Area with extent of 263 m^2 was classified incorrectly and assigned to another class of group of tree species. The reason could be the position shift between the orthorectified aerial images and point cloud of ALS data, which differ in the way of surface scanning. The farther are the objects displayed in the image from the flight path, the greater is the position error of identical objects from the point cloud.

At the same time, the representation of "Shadow" class was reduced of approximately 183 m^2. This is attributed to the shift of this area to "Ground" class. In the shaded parts of the area, there could not be identified whether it is a ground or vegetation, while with the use of ALS data a part of this area was identified as the "Ground". Due to the high precision of the laser data and the use of multiple remote sensing materials, the area assigned to the "Ground" class, and overlaying with the "Shadow" class of the verification layer, was considered for correctly classified.

In terms of the classification of tree species composition accuracy, the User's Accuracy (UA), expressing the probability that the pixel included in the class truly represents this class also in the field, increased by 5.36% in case of deciduous and by 2.80% in case of coniferous. The kappa coefficient increased from 0.7245, respectively 0.7362, to value of 0.7667, respectively 0.7676. The producer`s accuracy (PA), expressing the accuracy with which the reference pixels have been included in the class decreased in case of "Deciduous" and "Coniferous" classes, due to the incorrect classification of the "Ground" class, which was identified as the "Deciduous" or "Coniferous" class, in comparison with the verification layer. The reasons for this misleading assignment as well as the reduction of the accuracy of shadow classification were described above.

Table 1. Error matrix of classification without using airborne laser scanning data in m^2.

	Class	Reference data					UA
		Ground	Deciduous	Coniferous	Shadow	Total	[%]
Classification results	Ground	**0.00**	0.00	0.00	0.00	0.00	—
	Deciduous	547.81	**8194.61**	810.72	111.02	9664.16	84.79
	Coniferous	597.35	1754.56	**11591.57**	34.30	13977.78	82.93
	Shadow	0.00	1.16	0.00	**672.20**	673.36	99.83
	Total	1145.16	9950.33	12402.29	817.52	**24315.30**	—
PA	[%]	0.00	82.36	93.46	82.22	Overall accuracy: 84.14	

UA (User's Accuracy) – the probability that the pixel included in the class truly represents this class also in the field;
PA (Producent's Accuracy) – proportion of reference pixels which were assigned to the class.

Table 2. Error matrix of classification with using airborne laser scanning data in m^2.

	Class	Reference data					UA
		Ground	Deciduous	Coniferous	Shadow	Total	[%]
Classification results	Ground	**1167.05**	109.99	153.11	0.00	1430.15	81.60
	Deciduous	16.10	**8192.19**	768.66	109.60	9086.55	90.16
	Coniferous	160.52	1703.92	**11400.94**	34.02	13299.40	85.73
	Shadow	0.00	1.16	0.00	**489.78**	490.94	99.76
	Total	1343.67	10007.26	12322.71	633.40	**24307.04**	—
PA	[%]	86.86	81.86	92.52	77.33	Overall accuracy: 87.42	

Slightly different surface area of the classes in a comparison of the two classifications is caused by the slight variations in the geometry of the objects.

4. Discussion and conclusions

In this paper we present the use of ALS data and evaluation of their contribution in the process of object-oriented classification of tree species composition of diverse forests in eCognition Developer 9 software. Comparison of classification accuracy values, with and without ALS data application, confirmed its increase and positive contribution in case of ALS data application in the classification of tree species composition, in this case to the deciduous and coniferous tree species.

To derive the appropriate values of scale parameter for image segmentation in eCognition Developer 9, was used the ESP tool, which by comparing the local variance values for each value of scale parameter set derives the Rate of Change value. The scale parameter value for the images with a spatial resolution of 0.2 m, to determine the species composition assigned to deciduous and coniferous trees) was set to value 125. Since the ESP tool is computationally demanding, scale parameter identification was carried out only on the subset of the images. Kardoš et al. (2013) recommended set the scale parameter in the range of 30–40 for images with a spatial resolution of 0.2 to 0.5 m. The achieved accuracy of identification of various tree species ranged from 48% to 84%. In our study the greater value of scale parameter was sufficient. At this value, the individual tree crowns were divided into several segments according to the illumination of the crown, but they quite accurately represented the shape of the crown in the higher parts of the stands. Thus, in the subsequent classification, there did not occurred potential problem with incorrect identifying the tree crowns outlines.

According to the results of accuracy of both classifications, it can be stated that the use of ALS data in the classification process improved the accuracy of the group of tree species identification. In addition to improving the overall accuracy of the classification, it is evident that also the accuracy of classification of the two main groups (classes) of stand vegetation (deciduous and coniferous) was increased. The degree of compliance, expressed by Kappa coefficients were also improved for both classes, for "Deciduous" from 0.7245 to 0.7667 and for "Coniferous" from 0.7362 to 0.7676. Kappa coefficient K=0 means a random classification and K=1 means a perfect agreement. These values represent a very good level of consistency according to the classification made by Landis & Koch (1977).

In terms of the distinguishing between the classes of group of tree species, seems to be the combination of CIR and RGB images to be very useful. The CIR images alone are applicable for tree species identification (Holmgren et al. 2008), on them can be better identified the coniferous. RGB images provide further spectral data in individual channels useful for the classification process to help to distinguish the tree species especially in the less illuminated or shadowed parts of the crown or stands. Adding the nDSM and Intensity layers to the classification process provides additional information on position, respectively the nature of the surface of the object, which has a positive impact on the accuracy of classification, in accordance to the results achieved. The appropriateness of using the ALS data for the object-oriented classification is confirmed by the work of Pascual et al. (2008) and Tomljenovic et al. (2016). Zhang et al. (2013) reached the highest classification accuracy of forests using a combination of aerial images and ALS data – DEM, Intensity and topographic information. Fassnacht et al. (2016) published, the most suitable RS data for tree species identification are hyperspectral images, but for classification of forest with a small number of tree species is suitable to use combination of ALS data and multispectral images. This combination seems the best for Slovak conditions too, because hyperspectral images are not usually available for forest sector.

The problematic part of the classification process and use of a combination of different data sources remains their mutual spatial (position) shift. Orthorectified images display objects in the image the more distorted the more rugged is terrain and the farther away are the objects from the axis of the airplane during the scanning. This is reflected in an unnatural shape of the crown. On the other hand, the point cloud of laser scanning is characterized precisely determined position of each ray reflected by the object in the 3D space (X, Y, Z), and therefore, in the point of greatest distortion of the images, occurs the spatial displacement between the images and the ALS layers. Practically this is manifested by the fact that while a certain area has been classified as "Ground", in the distorted image it corresponded to one or more tree crowns, which were further classified into classes "Deciduous" or "Coniferous".

According to the authors, for possible further improvement of the classification results would be appropriate to use nDSM layer for definition and derivation of several vertical layers of stand vegetation. It would be useful to define individual classes and training sets (samples), and further provide a classification for each layers. Such a process is likely to improve the classification of tree species in the lower parts of forest stands, often represented by darker (shaded) parts of the image. Utilisation of research plots established in the field seems to be a suitable basis for the creation of a reference layer of tree species, distinguishing the different types of trees.

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ORIGINAL PAPER

A comparison of different tending variants in beech stands by the crown thinning and from the view of their quantitative and qualitative development

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Abstract

Impact of tending on dvelopment of beech (*Fagus sylvatica* L.) pole timber stands was analysed using different variants of the free crown thinning, i.e. the original method developed in Slovakia at the end of 1950s. Four variants of this method were compared: (i) – the free crown thinning on the whole area, the method of promising trees, later the method of target trees at stand age of 58 years. (ii) – the free crown thinning on non-whole area, tending realised inside of growth space of target trees only, the method of target trees, salvage cutting on the whole area. (iii) – the free crown thinning on non-whole area, the method of promising trees (the method of target trees at stand age of 58 years) realised on circular plots with diameter 4 m and spacing 8 m (distance between centre of circular plots). (iv) – combined selective method, thinning from below and the free crown thinning by method of target trees was used by the first thinning, in next thinning only the free crown thinning on whole-area was used, method of target trees. The structure (diameter and height) of the stand, the quantitative production parameters had been observed for a period of 30 years. Small differences were found in diameter and height structure between the variant (iv) and other three ones. Comparison of quantitative production pointed out minimum differences in favour of the variant (iv) compared to the other ones. The same results were also obtained in the qualitative production, especially for selective quality (target trees).

Key words: *Fagus sylvatica*; crown thinning; stand structure; production; target trees

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1. Introduction

European beech (*Fagus sylvatica* L.) is a native tree species in Slovak forests (Vladovič 2003), and currently occupies about 33% of the forest land (Green Report 2015). Its future proportion is expected to be 36% (Vladovič 2003). Thanks to its favourable biological and ecological characteristics (Barna et al. 2011) and high productivity (Chunyu Zhang et al. 2010; Petráš & Mecko 2010), it has its irreplaceable position in the forests of Slovakia. In foreign countries (Germany, Denmark, Switzerland, France), attention has been paid to the knowledge of structure and development of beech stands for more than 100 years (Schädelin 1934; Badoux 1939; Pardé 1981; Utschig & Küsters 2003). In Slovakia, systematic research began much later, only at the end of the 1950s of the last century (Štefančík 1964).

In the past, greater attention has been paid to the tending of beech stands and its impacts on quantitative production (Vyskot et al. 1962; Assmann 1968; Réh 1968; Šebík 1971; Kennel 1972; Štefančík 1974, 1984; Polge 1981; Pardé 1981; Šebík & Polák 1990; LeGoff & Ottorini 1993; Dhôte 1997; Pretzsch 2005). Among these, different variants of low thinning (Foerster 1993; Utschig & Küsters 2003) and also crown thinning (Assmann 1968; Šebík & Polák, 1990; Hoffmann 1994; Štefančík et al. 1996; Pretzsch 2005), both on the single tree or stand level (Diaconu et al. 2015), were observed and compared mutually.

In addition, there were numerous works that investigated the impact of tending on beech stands quality, or on beech wood itself (Šebík 1970; Štefančík 1975, 1976, 1981, 2014; Keller et al. 1976; Ferrand 1982; Kató & Mülder 1983; Korpeľ 1988; Mlinšek & Bakker 1990; Hein et al. 2007; 2011; Poljanec & Kadunc 2013; Štefančík & Bošeľa 2014). At the same way, the impact of management on the quality of beech assortments (Cameron 2002) and their resulting financial evaluation (Knoke & Wenderoth 2001; Julien et al. 2013), or value production (Petráš et al. 2016), was observed. Consequently, Sedmák et al. (2012) proposed the mathematical model of the stem quality. Relationship between the quality of timber production and the species and structural diversity of forest stands was studied by Merganič et al. (2016). From this perspective, tending of beech stands focuses primarily on growing a sufficient number of individuals of the highest quality – the target trees (Altherr 1971; Štefančík

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1984; Kató & Mülder 1983; Mlinšek & Bakker 1990). These trees represent qualitative production which is of prime interest in beech stands, while ensuring a high level of value production of mature stands (Hein et al. 2007).

Although a number of site, natural and environmental factors (Vacek et al. 1996; Vacek & Hejcman 2012; Vacek et al. 2014), and genetic properties and traits (Ducros et al. 1988; Hansen et al. 2003; Gömöry & Paule 2011; Gömöry et al. 2013) affect the growth and development of beech stands, the methods of their management (Poleno & Vacek et al. 2009), or the methods of their tending represented by the type and intensity of tending interventions (Assmann 1968; Šebík 1971; Štefančík 1974; LeGoff & Ottorini 1993; Dhôte 1997; Utschig 2000; Pretzsch 2005; Tufekcioglu et al. 2005; Saje et al. 2013; Diaconu et al. 2015) remain one of the most important factors.

We can state that knowledge from long-term investigated experiments abroad (Pretzsch et al. 2014) and in Slovakia (Štefančík 2015) has been summarized up to now. Based on these results, we can conclude that crown thinnings are more appropriate than low thinnings for tending of pure beech stands (Dhôte 1997; Boncina et al. 2007; von Lüpke 1986; Guericke 2002; Štefančík 2015). However, changed natural conditions (climate change) also reflected themselves in the growth of beech stands (Pretzsch et al. 2014) as compared to the last decades. This requires new approaches in the management system of not only beech stands (Štefančík 2015).

At present, even in tending (management) of beech stands we can often encounter with combined methods in terms of the concept of "Freestyle silviculture" (Boncina 2011; Diaci et al. 2011). This is based on a free application of different methods, taking into account the economy and the condition of stands.

The paper aimed at comparison of different tending variants in the beech stand using the free crown thinning (whole area, non-whole area, methods of promising and target trees) for a period of 30 years. We focused on stand structure, parameters of quantitative (number of trees, basal area, merchantable volume, increments) and qualitative production (mass and selective stem quality). Special attention was paid to the trees of selective quality (promising and target trees).

2. Material and methods

2.1. Study area

A series of permanent research plots (PRP) Štagiar served as a research object on the territory of the University Forest Enterprise under the Technical University in Zvolen (N = E = 48°38´ and 19°02´). This locality is situated in central Slovakia and belongs to the climate district B5, slightly damp sub-area and slightly warm area. The stand was 38 years old when the experiment started, and in growing phase of pole timber (dbh from 7.6 to 8.1 cm) from natural regeneration. Beech represented the main species (94%) and admixed tree species (oak, birch, aspen and fir) were also presented. At present, the proportion of beech represents 96%. Basic PRP characteristics are shown in Table 1.

Table 1. Basic characteristics of the series of permanent research plot (PRP) Štagiar.

Characteristic	PRP Štagiar
Establishment of PRP	1984
Age of stand [years]	38 (in 1984)
Site index	26
Geomorphologic unit	Kremnické vrchy
Exposition	West
Altitude [m]	620
Inclination [degree]	15–20
Parent rock	Andesites
Soil unit	Cambisol
Average annual temperature [°C]	6.6
Sum of average annual precipitation [mm.year^{-1}]	900–950

Almost no interventions were performed until the time of PRP series establishment. If there were any interventions, it was only a weak local intervention solely into the suppressed level in the form of selective felling (Štefančík 1974).

The PRP series consists of four subplots (each with an area of 0.25 hectares) which are arranged side by side (along the contour line) and always separated from each other by a 15 meters wide isolation belt of trees at least. The centre of each subplot is marked with a so- called cross-cutting belt having a width of 10 m (an area of 0.05 ha). All living trees with the diameter of 3.6 cm and greater ($d_{1,3}$), or those trees which reached the specified diameter during the measurements, are registered with numbers on all these subplots.

Four variants of the free crown thinning are investigated on these plots (Štefančík 1984):

Subplot I – the free crown thinning on the whole area, the method of promising trees, later the method of target trees at stand age of 58 years.

Subplot II – the free crown thinning on non-whole area, tending realised inside of growth space of target trees only, the method of target trees, salvage cutting on the whole area.

Subplot III – the free crown thinning on non-whole area, the method of promising trees (the method of target trees at stand age of 58 years) realised on circular plots with diameter 4 m and spacing 8 m (distance between centre of circular plots).

Subplot IV – combined selective method, moderate low thinning and the free crown thinning by method of target trees was used by the first thinning, in next thinning only the free crown thinning on whole-area was used, method of target trees.

2.2. Data collection

Standard biometric measurements of quantitative parameters (diameter $d_{1.3}$, tree height and height of the crown base, the dimensions of the crown in horizontal projection) were conducted on each subplot. To estimate qualitative production, trees were classified by silvicultural (biological) and commercial (technical) classification.

The silviculture quality classification included:

a) sociological position of trees according to Štefančík (1974);
1. dominant tree
2. co-dominant tree
3. suppressed tree still vital to reach the stand crown level
4. suppressed tree but not vital to reach the stand crown level
5. dying or dead suppressed tree

b) stem quality grades;
1. straight high-quality stem without knots, with no visible external damage
2. average-quality stem, curvature allowed only in the higher one third part of the stem, low number of small knots (1 or 2 pieces per running meter) is allowed, with no external damage (fungi, insects, necrosis)
3. low-quality stem with high number of knots (more than 2 pieces per running meter), with twisted or stem with curvature, with external visible damage (fungi, insects, necrosis)

c) crown quality: According to the size: 1. appropriate-sized symmetric crown; 2. smaller-sized suppressed, but able to regenerate; 3. overlarge-sized crown; 4. small-sized, unable to regenerate.

For suppressed trees (3rd – 5th sociological class), crown is assessed using only three quality grades: 1 – good, 2 – average, and 3 – bad.

Concerning the commercial quality assessment, only the low part (low half) of the stem to the height of the crown base was assessed using the following classes: 1 – high quality (A), 2 – average quality (B), 3 – lower quality (industrial wood) (C), and 4 – firewood (D).

Repeated measurements of parameters and evaluation of quality traits has been performed at regular five-yearly intervals on all plots. So far, seven biometric measurements and tending interventions were implemented. Field-Map technology determined the position of living trees in a polar coordinate system (x, y).

2.3. Data processing and analyses

Quantitative characteristics from experiments were processed by standard biometric and statistical methods in terms of usual methodologies for the research on thinnings (Štefančík 1974) using Excel software package, QC Expert (Kupka 2008) and growth simulator Sibyla (Fabrika 2005). Indices of diameter and height differentiation for individual PRP were calculated according to Füldner (1995). Tree volume was calculated using the volume equations published by Petráš & Pajtík (1991). The quantitative production was calculated according to standard methods and formula (Priesol & Polák 1991). Index of total stand (both for basal area and volume) was calculated as a share of total production (basal area or volume) at the age of 68 years (last measurement) to total stand at the age of 38 years (first measurement, before realised thinning).

At each repeated measurement and for each subplot, measured tree heights were especially equalized by a function developed by Michailoff (1943):

$$h(d) = 1{,}3 + b_1 \cdot e^{\left(\frac{-b_2}{d}\right)} \qquad [1]$$

wherein, b_1, b_2 – the parameters of the regression function; d – diameter $d_{1,3}$ [cm]; h – height [m].

Crown width, crown length, slenderness quotient, live crown ratio (crown length to tree height), crown projection area and crown surface area (hereafter crown area), crown volume and basal area were derived. Based on four crown radii, the mean crown width (CW) was calculated:

$$CW = \Sigma\, CR_{1-4} / 2 \qquad [2]$$

wherein, CR is crown radius.

Crown length was defined as the vertical distance from the crown base to the top of the crown. Slenderness quotient represents tree height and dbh ratio. The hundred largest trees (with the largest dbh) per hectare were selected to calculate slenderness quotient (h/dbh ratio). Crown projection area (using the formula for a circle) and crown surface area (CA) was calculated as (Kramer 1988; Fichtner et al. 2013):

$$CA = \pi CR/6CL^2\ [(4CL^2 - CR^2)^{3/2} - CR^3)] \qquad [3]$$

wherein, CR is crown radius and CL is crown length.

Crown volume (CV) was calculated as (Assmann 1968) for broadleaved tree species:

$$CV = \pi/8\ (CW^2 . CL) \qquad [4]$$

wherein, CW is crown width and CL is crown length.

To determine the statistical significance of differences among selected parameters, one-factor analysis of variance ANOVA from the programming package QC Expert, Version 3.1 was used.

Data obtained from the silvicultural and commercial stand quality assessment served for the calculation of average silvicultural quality. This calculation was done separately for the stem and crown as the arithmetic mean of quality traits. Changes in the average silvicultural quality for two time periods (the first and last time period) were compared by means of the index "*pom*", which reflects the dynamic changes in the silvicultural quality (Štefančík 1974):

$$pom = \frac{Kv}{kv} . 100 \qquad [4]$$

wherein, Kv – is average quality at the beginning of time periods being compared and kv – is the average quality at the end of time periods being compared.

If the average quality for the given period improved, then *pom* > 100, or if the quality worsened, then *pom* < 100. Average stem and crown quality (grade) was calculated for the whole (main) stand, and also separately for the crown stand level (1st and 2nd sociological class), or suppressed stand level (3rd to 5th sociological class). Similarly, we proceeded in evaluation of the commercial quality according to the methodology by Štefančík (1974, 1976).

3. Results

3.1. Stand structure

At the beginning of the research, the structure (diameter and height) of all subplots was in fact equal. Values of the mean diameter (d_g) of following subplots I, II, III and IV (8.1 cm, 7.6 cm, 7.9 cm and 7.7 cm) and also of the mean height (h_g) – 13.3 m, 12.7 m, 12.4 m and 12.4 m confirmed it. The differences among them were minimal and statistically insignificant (for $\alpha = 0.05$). However, after 30 years of tending, statistically significant differences ($p<0.05$) were found only between the subplot IV ($d_g = 18.8$ cm, $h_g = 22.8$ m), and other three plots I, II, and III, at the mean diameter (16.1 cm, 15.3 cm and 16.2 cm) and mean height (19.8 m, 19.2 m and 20.6 m).

Slight differences in stand structure for a period of 30 years were also confirmed by the indices of diameter diversity (TM_d), whose values were very similar (from 0.437 to 0.551). The lowest value was determined for the subplot IV, where stand´s suppressed level was removed at the beginning of the investigation. This was evident even after 30 years. And, it was also proved by the values of height differentiation index (TM_h). These values were lowest on the subplot IV (0.297), i.e. the small height differentiation. Other three subplots (I, II, III) reached values ranged from 0.371 to 0.466, i.e. medium differentiation. Height structure have been documented on the Fig. 1, where the percentage of relative height position was at the beginning and end of the investigated period. At the beginning of the research, the proportion of the crown stand level (1st and 2nd sociological class) ranged between 30 and 38%. During 30 years, it has changed mostly on the subplot IV when it increased to 47% while on other three subplots it was around 30%.

3.2. Quantitative production

Development of stand characteristics during the investigated period was presented in Table 2. At subplots establishment, the initial number of trees (N) on all subplots (except for the subplot III) was higher than 5000 tree ha^{-1}. Basal area (G) ranged from 24 to 27 m^2 ha^{-1} and the merchantable volume (V_{7b}) ranged from 102 to 141 m^3 ha^{-1}.

After 30 years, the lowest number of trees remained on the subplot IV (25% out of the initial number of individuals); then it remained 33% on the subplot I; 35% on the subplot II and 38% on the subplot III. The highest values of basal area were found on the subplot III and/or the subplots IV, as for the merchantable volume. On the

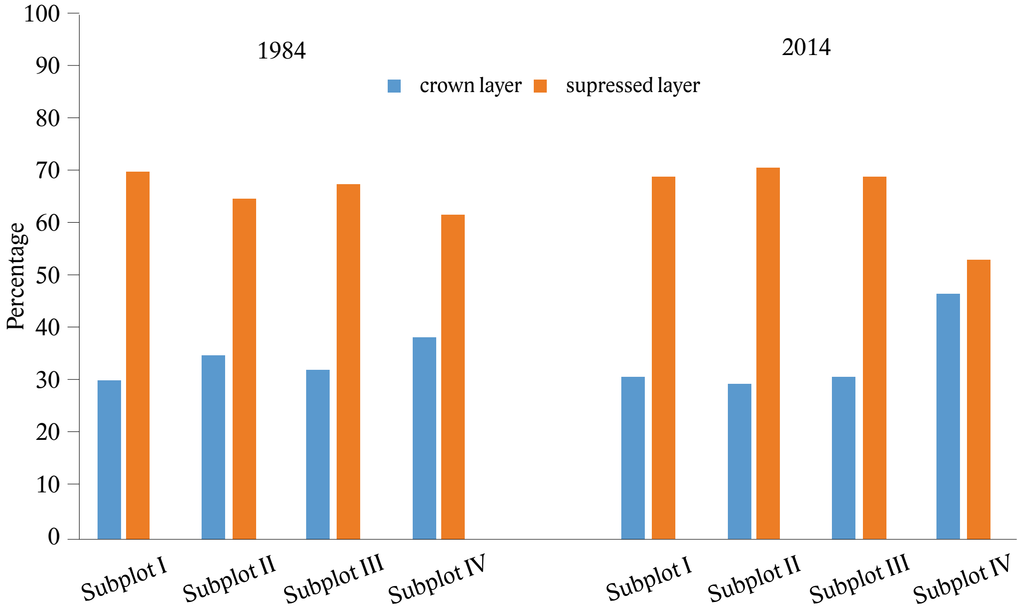

Fig. 1. Relative frequency according to growth classes.

contrary, the lowest values were found on the subplot II, although there was the highest number of trees. Better overview of the overall quantitative production provides Table 3.

When analysed the total decrease of trees (thinnings, autoreduction, abiotic factors) for 30 years by the G and V_{7b} parameters, we found the highest decrease on the subplot I where the whole area tending and the method of promising trees were applied. Therefore, in comparison with non-whole area tending (subplots II and III), or combined tending (subplot IV), it was necessary to remove more trees in the context of positive crown level intervention. On the contrary, the smallest decrease was recorded on the subplot III, where non-whole area intervention was performed only on circle plots around promising trees (with a diameter of 4 meters). These differences were not large because of the stand age of 68 years.

Concerning the total production (by G and V_{7b}), the highest values were recorded on subplots with the highest total decrease, i.e. subplots I and IV. This indicates that intensive tending had a positive effect on the total quantitative production. It was also confirmed by the index values of total production growth for the investigated period. The highest index was found on the plot IV. The same statement also applied to the values of the current annual basal area increment (i_G) and volume increment (i_{V7b}) in each 5-year periods (Fig. 2).

Total current volume increment for the investigated period was highest on the subplot IV (15.4 m^3 ha^{-1} year^{-1}) and lowest on the subplot II (12.8 m^3 ha^{-1} year^{-1}). The total mean volume increment reached following values: subplot IV (8.1 m^3 ha^{-1} year^{-1}), subplot I (7.8 m^3 ha^{-1} year^{-1}), subplot III (7.6 m^3 ha^{-1} year^{-1}) and subplot II (7.1 m^3 ha^{-1} year^{-1}).

Table 2. Development of measured parameters on subplots.

Subplot	Stand parameter	Age [years]	Total stand abs ha^{-1}	Decrease (Secondary stand)			Thinning intensity		Main stand abs ha^{-1}
				thinning living trees	dead trees	other decrease			
					%		abs ha^{-1}	% together	
I	N tree ha^{-1}	38	5,348	15.2	—	—	812	15.2	4,536
		53	2,668	3.6	4.5	1.0	244	9.1	2,424
		68	1,972	2.2	6.1	1.0	184	9.3	1,788
	G m^2 ha^{-1}	38	27.3	15.8	—	—	4.3	15.8	23.0
		53	31.0	6.1	1.5	0.2	2.4	7.8	28.6
		68	38.6	4.0	0.7	1.6	2.3	6.3	36.3
	V_{7b} m^3 ha^{-1}	38	141	16.4	—	—	23	16.4	118
		53	255	6.5	1.1	0.1	20	7.7	235
		68	396	4.3	0.1	1.1	22	5.5	374
II	N tree ha^{-1}	38	5,576	7.8	—	—	436	7.8	5,140
		53	3,124	6.0	11.4	0.5	560	17.9	2,564
		68	2,152	1.3	7.2	—	184	8.5	1,968
	G m^2 ha^{-1}	38	25.4	11.5	—	—	2.9	11.5	22.5
		53	29.6	8.3	2.3	0.3	3.2	10.9	26.4
		68	36.9	1.5	1.1	—	0.9	2.6	36.0
	V_{7b} m^3 ha^{-1}	38	112	14.4	—	—	16	14.4	96
		53	226	8.7	0.3	0.3	21	9.3	205
		68	357	1.4	0.2	—	6	1.6	351
III	N tree ha^{-1}	38	4,832	5.5	—	—	264	5.5	4,568
		53	3,052	5.5	7.2	0.8	412	13.5	2,640
		68	2,112	0.4	13.0	0.4	292	13.8	1,820
	G m^2 ha^{-1}	38	23.9	7.5	—	—	1.8	7.5	22.1
		53	33.6	9.9	1.2	0.2	3.8	11.3	29.8
		68	39.1	1.5	1.8	0.2	1.4	3.5	37.7
	V_{7b} m^3 ha^{-1}	38	114	8.6	—	—	10	8.6	104
		53	274	11.0	0.1	0	30	11.1	244
		68	408	1.8	0.4	0.1	9	2.3	399
IV	N tree ha^{-1}	38	5,175	51.5	—	—	150+2,517	2.9+48.6	2,508
		53	1,804	9.3	0.7	0.2	183	10.2	1,621
		68	1,401	3.9	3.0	—	97	6.9	1,304
	G m^2 ha^{-1}	38	24.3	24.0	—	—	1.3+4.5	5.2+18.9	18.5
		53	30.0	10.9	0.2	0.1	3.4	11.2	26.6
		68	38.0	4.6	0.7	—	2.0	5.3	36.0
	V_{7b} m^3 ha^{-1}	38	102	11.6	—	—	6.8+5.1	6.6+4.9	90
		53	264	11.4	0.1	0	31	11.5	233
		68	424	4.8	0.2	—	21	5.0	403

Comment: On the subplot IV the first data relates to thinning intensity of the free crown thinning and the second one (after +) of the low thinning.

Table 3. Development of quantitative production of the stand for 30 years.

Subplot	Age [years]	Total production				
		N	G		V_{7b}	
		[tree ha^{-1}]	[m^2 ha^{-1}]	index of total stand	[m^3 ha^{-1}]	index of total stand
I	38–68	5,348	58.9	2.160	530	3.764
II	38–68	5,576	56.7	2.231	480	4.282
III	38–68	4,832	55.3	2.316	520	4.577
IV	38–68	5,175	58.2	2.392	551	5.430

Explanatory notes: N – Number of trees, G – Basal area, V_{7b} – Merchantable volume.

3.3. Analysis of silvicultural interventions

First three interventions (till the stand age about 50 years) and/or first four interventions in the case of the subplot IV, were strongest on all the subplots (except for the subplot III). Intensity of intervention (out of the basal area) ranged from 11 to 24%. On the contrary, intensity on the subplot III did not exceed 10% during the entire 30 years of tending, which is a logical consequence of the fact that there were only interventions on small growth subplots and not on the whole area. This area, however, had the highest decrease by autoregulation (self-thinning), which represented 8% out of the basal area total production. The highest decrease due to thinning was found on the subplot IV (37% out of the basal area total production).

A certain proportion of thinning was caused by a sanitation selection due to beech bark necrosis disease. However, the positive crown level selection was always prevailing on all subplots. The first thinning on the subplot IV was the only exception, where the suppressed trees were removed up to the 78% out of the basal area and/or 43% out of the merchantable volume.

3.4. Qualitative production

3.4.1 Selective quality of the stand

Development of the trees of selective quality (promising and target) is shown in Table 4.

Table 4. Development of the trees of selective quality on PRP Štagiar.

Subplot	Age [years]	Number of trees [tree ha^{-1}]	Basal area		Merchantable volume	
			[m^2 ha^{-1}]	% out of main stand	[m^3 ha^{-1}]	% out of main stand
I	38	316	5.2	22.7	38	32.5
	53	284	10.8	37.7	107	45.3
	68	160	10.5	28.8	124	33.0
II	38	180	2.2	9.8	14	14.9
	53	180	6.0	22.7	58	28.6
	68	176	10.4	28.9	119	33.8
III	38	208	2.9	13.3	20	19.7
	53	176	6.5	21.9	65	26.8
	68	156	9.6	25.5	117	29.4
IV	38	209	2.7	14.5	18	19.9
	53	208	7.2	27.0	72	30.8
	68	200	12.5	34.7	156	38.7

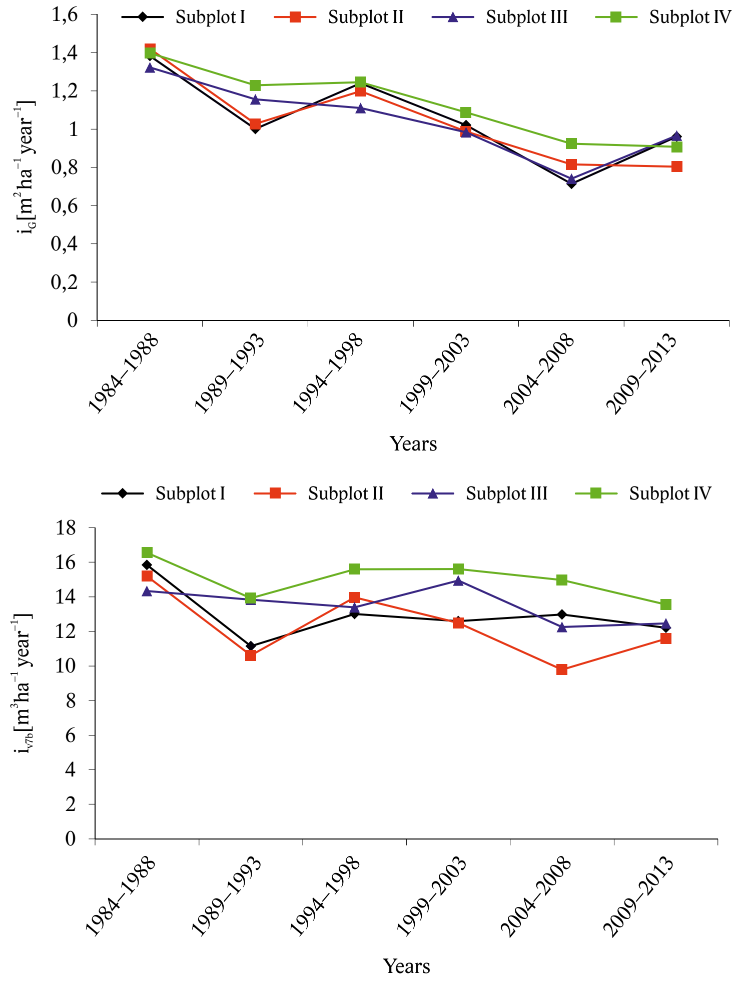

Fig. 2. Current annual basal area increment (i_G) and current annual merchantable volume increment (i_{V7b}).

Promising trees (subplot I and III) and target trees (subplot II and IV) were selected at the beginning of the research at the age of 38 years. Subplots with an initial method of promising trees transformed into subplots with a method of target trees (TT) from the stand age of 58 years. It explained marked decrease in the number of trees of selective quality on those subplots aged 68 years.

After 30 years, the TT method has been already applied on all subplots, and it shows that the highest number of TT at age of 68 years was on the subplot IV. At the same time, the quantitative parameters (basal area, merchantable volume) were the highest on this subplot. This was also confirmed by their percentage of the main stand and their values of crown parameters.

Table 5 shows the selected parameters of target trees crowns after 30 years of tending. Values obtained were more or less balanced, and/or some values (crown surface area, crown projection area, crown volume) were highest on the subplot IV, although the differences were not significant among subplots (for $\alpha = 0.05$).

3.4.2 Mass quality of the stands

3.4.2.1 Silvicultural quality of the stand

Silvicultural quality of the main stand, the crown stand level (1st and 2nd sociological class) and suppressed stand level (3rd to 5th sociological class) was presented in Table 6.

At the beginning of the research, the stem and crown quality of crown level trees was better than the quality of suppressed ones. Regarding the stem, average values of the stand ranged from 2.38 to 2.70 and/or from 1.84 to 2.64 for the crown. Here, the effect of the first combined thinning became evident for the subplot IV, where suppressed trees were removed, which generally has the worst crown quality in uncultivated stands.

After tending (30 years) interventions, the stem quality of the main stand deteriorated on all subplots. At the same time, we found decrease of the crown quality on all the subplots (except for the subplot I). It was surprising mainly for the subplot IV.

Table 5. Characteristics of target (crop) trees at the age of 68 years after 30 years of investigation.

Characteristic	Statistics [mean (coefficient of variation)]			
	Subplot I	Subplot II	Subplot III	Subplot IV
DBH [cm]	28.3^{a} (14.5)	27.4^{a} (12.8)	27.0^{a} (15.1)	27.0^{a} (14.9)
Height [m]	24.3^{a} (5.4)	24.0^{a} (5.2)	24.9^{ab} (5.4)	25.6^{bc} (3.7)
Stem slenderness	0.81^{a} (7.9)	0.83^{ab} (7.7)	0.87^{bc} (6.5)	0.87^{bc} (6.9)
Crown width [m]	5.7^{a} (14.4)	5.6^{a} (16.0)	5.3^{a} (13.9)	5.7^{a} (16.5)
Crown length [m]	11.6^{a} (12.4)	11.6^{a} (12.4)	12.0^{a} (15.3)	12.1^{a} (11.6)
Crown ratio	0.48^{a} (9.2)	0.48^{a} (10.2)	0.48^{a} (12.2)	0.47^{a} (10.2)
Crown surface area [m^2]	138.6^{a} (24.0)	135.7^{a} (25.7)	132.7^{a} (21.6)	143.2^{a} (22.3)
Crown projection area [m^2]	26.3^{a} (28.4)	25.5^{a} (33.3)	22.7^{a} (26.8)	26.3^{a} (33.8)
Crown volume [m^3]	155.5^{a} (36.7)	150.5^{a} (43.8)	137.3^{a} (31.9)	160.6^{a} (38.1)

Comment: Note: The values with the different letters are significantly different on the level $\alpha = 0.05$.

Table 6. Silvicultural (biological) quality of the stand for the period of 30 years.

Subplot	Age [years]	Silvicultural quality	Crown level	Suppressed level	Total stand
I	38	stem	2.307	2.808	2.656
		pom	100	100	100
		crown	2.062	2.889	2.639
		pom	100	100	100
	68	stem	2.478	2.955	2.808
		pom	93.1	95.0	94.6
		crown	1.754	2.981	2.602
		pom	117.6	96.9	101.4
II	38	stem	2.410	2.857	2.700
		pom	100	100	100
		crown	2.010	2.914	2.596
		pom	100	100	100
	68	stem	2.563	2.977	2.856
		pom	94.0	96.0	94.5
		crown	1.771	3.003	2.642
		pom	113.5	97.0	98.3
III	38	stem	2.274	2.891	2.692
		pom	100	100	100
		crown	1.890	2.851	2.540
		pom	100	100	100
	68	stem	2.593	2.962	2.848
		pom	87.7	97.6	94.5
		crown	1.800	3.006	2.635
		pom	105.0	94.8	96.4
IV	38	stem	2.279	2.673	2.379
		pom	100	100	100
		crown	1.697	2.247	1.837
		pom	100	100	100
	68	stem	2.507	2.886	2.709
		pom	90.9	92.6	87.8
		crown	1.781	2.976	2.417
		pom	95.2	75.5	76.0

The main stand contained the highest proportion of stems with the best quality (1st and 2nd grade) on the subplot IV (27%) and the lowest proportion on the subplot II (14%). Investigation of the long-term changes merely in the stand level (1st and 2nd sociological class) showed decrease of the stem quality on all the subplots and thus in the entire stand, as well.

By comparison with other subplots, the proportion of trees with the best crown quality (1st grade) was best again on the subplot IV (18%), while on the remaining subplots it was equal (11%).

3.4.2.2 Commercial quality of the stand

In terms of the qualitative production and/or subsequent assortment classification, the lower half of the thickest stems was crucial. In the crown level (1st and 2nd sociological class), a comparison of the commercial quality of the lower half of stem after 30 years of tending (Fig. 3) pointed to quality improvement (especially in a the first quality grade) in opposite to the beginning of research on all the subplots.

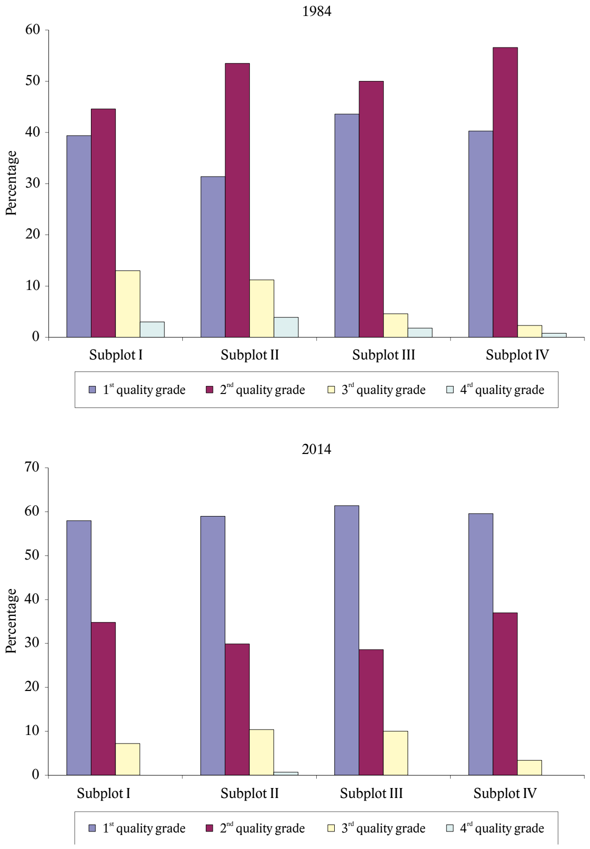

Fig. 3. Lower half of stem according to number of trees, crown level trees only in 1984 and 2014.

In this analysis, we have also investigated the basal area percentage of only the lower half of stem from crown level trees and for each quality grade (Fig. 4). The highest percentage of the first quality grade was on the subplot IV (68%), but the percentage was only slightly lower (61 – 65%) on the remaining subplots. When ascertained the crown quality of the crown level trees (from the number of trees), it was found that values were virtually identical (about 60%). This corresponded to the fact that the same type of thinning was being applied on all the subplots.

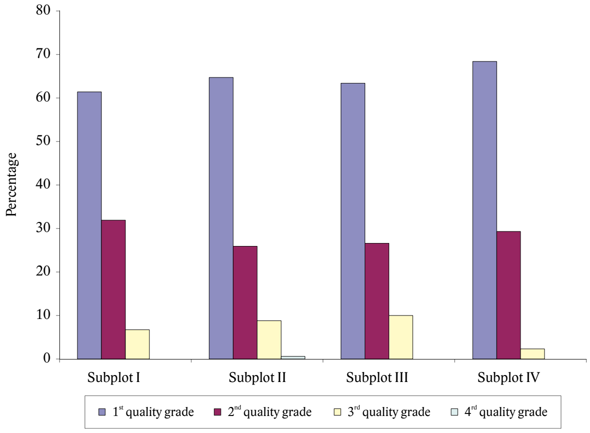

Fig. 4. Lower half of stem according to basal area, crown level trees only in 2014.

4. Discussion

Proper timing is crucial for the effectiveness of not only beech stands tending. Our experiment was established in the stand without prior tending at age of 38 years. The stand age can be considered adequate at the beginning of experiment, although there are known field trials where tending of beech stands began in the young growth stage (Réh 1968, 1969; Jurča, Chroust 1973; Tufekcioglu et al. 2005). Establishing of experiments is considered optimal not later than in the small pole stage (Šebík 1971; Štefančík 1974; von Lüpke 1986; Utschig & Küsters 2003). However, there are known experiments with the beginning of tending at the stage of pole timber (Štefančík 1974; Klädtke 1997). The question is whether this will be reflected on the quantity and value production of stands. Present knowledge on delayed tending in beech stands (Réh 2004; Štefančík 2013) point out that the desired dimensions (parameters) in terms of quantity of production can be more or less also achieved by delayed tending. However, it depends on the site and tending method and/or a type of thinning (Štefančík 2013a). It is also similar in case of qualitative production, where it is required to start with tending with moderate interventions early. This is confirmed by Korpel′s results (1988), who found out significantly higher number of individuals of the highest quality aged about 40 years at systematic and intensive tending from the stage of young growth in comparison with the stand with delayed (neglected) tending. This is evidenced by the conclusions of Mlinšek & Bakker (1990), who analysed 50 target beech trees aged from 140 to 150 years on two sites in Slovenia. The results showed that the trees with even and moderate radial growth produced most knot-free wood. Trees that first had narrow annual rings at a young age and then suddenly produced wide annual rings had excellent shape of the stem, but produced less knot-free wood compared to trees with moderate radial growth.

Our experiment does not include a control subplot (without interventions), which is generally a rule at comparative experiments. At present, however, there are results of numerous and long-term experiments (Utschig & Küsters 2003; Pretzsch 2005), which clearly demonstrated the justifiability and advantages of crown level thinning against to plots without intervention. The results of many authors (Hein et al. 2007; Boncina et al. 2007; Štefančík 2015) confirmed that crown level thinning with positive selection are the most appropriate methods especially for growing of selective quality stands. The method of candidates (Schädelin 1934; Leibundgut 1966; Réh 2004), promising trees (Štefančík 1984) or target trees (Boncina et al. 2007; Diaconu et al. 2015; Štefančík 2015) is preferred. Advantages of the target trees method were also confirmed by Hein et al. (2007), who based on a 35-year research found a higher stem quality and/or net value production on plots with thinnings and selected target trees in comparison with plots where interventions according to Assmann´s optimal basal area were performed. Apart from the mentioned methods of tending in beech stands, in Germany were developed another thinning interventions in the past. These methods were focused on "light increment utilisation" of beech stand. Freist (1962) recommended more intense crown thinning at stand age of 40 to 50 years, with the aim to cultivate of 100 target trees at the end of rotation (140 years) with its target dbh of 60 cm or more. Similarly, the model of "stand opening" (Lichtwuchsmodell) according to Altherr (1971) assumed basal area of 20 m^2 ha^{-1} at stand age 70 years, with target dbh of 35 to 40 cm. The method of "group selection thinning" according to Kató & Mülder (1983) should be considered as one of variant performed by our experiment (non-whole tending). The crucial difference between target tree cultivation applied in our subplots and the mention two methods is evident. Namely, Altherr´s model and "Gruppendurchforstung" (Kató & Mulder 1983) allows an irregular arrangement of target trees in stand.

In our experiment, the target trees were selected at the age of 38 years and/or 58 years. This is in compliance with the recommendations by Štefančík (1975), who states that the target trees need to be selected at the age of 60 years or no later than in the middle of rotation age. Bončina et al. (2007) selected target trees at the age of 70 years and their number depended on the intensity of thinning to be carried out in the coming years. Different opinions are available, related to a desired number of crop trees in beech stands. For example, Abetz (1979) and Altherr (1981) recommended 110 trees ha^{-1}. A higher number of these trees was pointed out by Spellmann & Nagel (1996) and Guericke (2002) representing 250 and 100 – 300 selected and marked crop trees, respectively. Later on, due to the development of the crown surface area a decreasing number of crop trees from 200 to 80 stems ha^{-1} with advancing age was registered. In Switzerland, Kurt (1982) presented 80 – 120 target trees for beech with desired parameters in relation to DBH as given by yield tables. Based on the study in 20 stands in Switzerland, Leibundgut (1982) recommended 210 crop trees for beech at a top height of 35 m. A lower number of crop trees is typical and common in France, ranging from 80 to 100 trees ha^{-1} (Bouchon et al. 1989). A similar opinion was published by Klädtke (2002), who pointed out that the selection of more than 100 crop trees is not recommended, because the probability of red heart formation increases strongly due to a much longer production time. In Slovakia, a model of the future mature beech stand (stand age 110 – 130 years) was developed by Štefančík (1984). This model presents 5 variants depending on the site conditions (acid and fertile). The number of target trees ranged from 121 to 217 stems ha^{-1}, within the mean spacing between target trees of 7.6 m. Ascertained numbers of target trees in our experiment are consistent with the mentioned model.

Tending intensity also plays an important role. Based on the assessment of the results of 130 years old experiment on a PRP Elmstein 20 (Germany) Utschig & Küsters (2003) stated that the final economic evaluation showed production of more valuable assortments when applying more intense thinnings. This more or less compensated higher production of wood obtained by applying moderate interventions. Similarly, based on research in beech and spruce stands, Spellmann & Nagel (1996) recommended early and intense crown level thinnings. In our experiment, the most intensive interventions were performed on the subplot I (38.3% out of the total basal area production) and subplot IV (38.1%), i.e. where the most favourable values of target tree were found. This is consistent with the knowledge that more intense interventions support an increase in diameter increment of target trees (Klädtke 1997; Boncina et al. 2007). This was confirmed by our experiment as well, when the maximum diameter increment of target trees was recorded on the subplot IV where the most intensive tending was applied. Total volume increment on the subplot IV was 8.1 m^3 ha^{-1} year^{-1} and/or or 7.8 m^3 ha^{-1} year^{-1} on the subplot I. Klädtke (1997) states lower value of 6.0 m^3 ha^{-1} year^{-1}.

Comparable results were also obtained from the assessment of the stem quality. Concerning the stand level, Badoux (1939) discovered 28 – 35% of stems with the highest quality on the plot with crown thinning. This proportion is lower in comparison with our results from investigated PRP where it reached about 60% of the number of trees and 65 to 70% out of the basal area. However, in assessing the mass stem and crown quality (the stand as a whole) no improvement was recorded in 30 years. It was unexpected on subplot IV, where all suppressed trees were removed at the beginning. We explained it by the fact that the number of suppressed trees increased on this subplot from the beginning of this investigation (as a consequence of height movements for 30 years). This participated in the deterioration of the average quality of the main stand. This is due to the fact that suppressed trees, which are numerous and generally in inferior quality, are taken into account. The second reason is the fact that the stand has been affected by quite intense necrotic disease of beech bark (Mihál et al.. 1998; Cicák & Mihál 2001). We explained this stem deterioration as a result of beech bark disease caused by necrosis, which also affected many crown level individuals (even target trees) and thus worsened the silvicultural quality of the stand as a whole and the crown layer, as well. Regarding the quality of crown, improvement occurred everywhere during 30 years (except for the subplot IV), where very slight deterioration was recorded.

Another situation arose with the crown quality of the crown level (target) trees, where improvement was recorded (except for subplot IV) everywhere. This is related to the concept of applied the free crown thinning, where the positive selection at the crown level is the primary goal (Štefančík 1984).

Our investigated parameters for the stem and crown quality were influenced mainly by the occurrence of necrotic disease of beech bark in the late eighties of the last century. This tracheomycosis disease weakened the stands' vitality. As a result, there had been several stem breaks on places with extensive necrosis. Detailed research on their occurrence on this PRP (Cicák et al. 1998; Mihál et al. 1998; Cicák & Mihál 2001) proved a 97% share of trees with different degrees of necrotic disease. The lowest index of necrotic disease occurrence was observed on the subplot IV where the highest number of target trees is located. This relates to the fact that target trees had a lower proportion of trees with the necrosis (Cicák et al. 2003). That assessment was repeated later in 1996 and 2000, i.e. at age of 50 and 54 years. The results again showed better values for the index indicating the necrotic disease of target trees in comparison to other trees in the stand (Cicák et al. 2003). Despite the fact that beech bark disease affected some target trees (Štefančík 2015), so they had to be cut from a health reasons, their current number can be considered sufficient and promising. In relation to the method of tending, the research results of a necrotic disease of beech bark found virtually no differences between the stands with thinning and stands without tending applied (Štefančík & Leontovyč 1966; Štefančík 1974; Cicák et al. 1998; Mihál et al. 1998). However, the finding that the target trees were significantly less damaged and/or had the smallest proportion in the highest grades of damage (from 9.1% to 14.5%), while damage amounted to 40.3% (Cicák et al. 1998) on not intervened subplots, is important. This confirms the utility of tending in such affected stands, too.

5. Conclusion

Comparison of four different tending variants by means of the free crown thinning was conducted for the beech stand established at the age of 38 years. Tending was performed by the method of promising (20 years) and target trees (30 years) with whole and non-whole areas approach (small growth plots). More marked differences among investigated variants did not show themselves at the stand age of 68 years (after 30 years of systematic observation). In terms of quantitative characteristics (number of trees, basal area, the merchantable volume, diameter and volume increment), slightly higher values were obtained from the variant where suppressed trees were removed from the stand at the beginning of the experiment and tending continued by the method of target trees on the whole area. Comparison of mass quality (the entire stand) did not show a beneficial effect on the stem and crown quality. One reason lies in the fact that the stand had been affected by the necrotic disease of beech bark. However, different results were obtained when comparing the stand´s selective quality by means of target trees. Also, in this case, better results were achieved for the subplot IV with the mentioned variant of tending. Due to the stand age (about 70 years) and duration of investigation period (30 years), we can assume that more significant differences may be visible in older age in favour of one of these variants. However, the longer investigation period is needed to draw objective conclusions of this experiment. On the other hand, the results presented show that rather satisfactory results can be achieved in the stand affected by the mentioned epiphytosis in terms of quantity and quality of production. Tending focused on the support of trees with selective quality (promising, target), combined with a treatment (sanitary selection and individuals affected by necrosis) in beech stands has its meaning and achieves a positive effect even in the case of beech necrotic disease.

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ORIGINAL PAPER

Structure and dynamics of spruce-beech-fir forests in Nature Reserves of the Orlické hory Mts. in relation to ungulate game

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Abstract

Knowledge of the structure and dynamics of near-natural mixed forests is a key factor for ecologically oriented management of forest ecosystems. The development of these model forests mostly takes place continually without any pronounced disturbances. Natural regeneration can be locally limited by ungulate browsing. The paper was focused on the structure and development of forest stands with emphasis on natural regeneration in relation to ungulates in Černý důl Nature Reserve and Trčkov National Nature Reserve situated in the Orlické hory Mts., Czech Republic. The case study was conducted in a spruce-beech-fir forest stand on four permanent research plots (PRP) of 0.25 ha in size. PRP are situated in the same stand and in comparable site and stand conditions, but two PRP has been protected against game by fencing since 1985–1989. The stand volume ranged from 478 to 565 m^3 ha^{-1} in age 143 – 156 year. The results showed that the diversity of tree layer was higher by 19.8% (48.0% in species richness) in the stands protected by fence. In the phase of natural regeneration, the species composition, stand structure and number of recruits were poorer on unfenced PRP (7,990 recruits ha^{-1}) compared to fenced PRP (13,160 recruits ha^{-1}). Admixed silver fir and rowan were completely eliminated by browsing (to 94 – 100% of individuals). Growth analyses statistically confirmed that ungulates were a significant limiting factor for successful forest development ($P < 0.001$).

Key words: browsing damage; natural regeneration; protected areas; *Fagus sylvatica*; *Picea abies*; *Abies alba*

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1. Introduction

Natural and semi-natural mixed forests are currently very intensively studied subject (Paluch 2007; Kucbel 2010; Liira et al. 2011; Králíček et al. 2017; Meier et al. 2017). In comparison with managed stands, these forests have many-times higher species diversity (Lindenmayer & Franklin 2002; Bauhus et al. 2009), self-regulatory ability (Korpeľ 1995) and stability against external influences (Knoke et al. 2008; Liira et al. 2011).

The ecosystem management in forests of protected areas is based on the highest possible utilization of natural processes (Korpeľ 1995; Vacek et al. 2012, 2015). When defining the methods of their care, it is necessary to know how the forest would have spontaneously developed at given sites in the past (Klopcic & Boncina 2011). It is possible especially only in an original or natural forest where developmental processes not disturbed by primary anthropogenic activities are taking place (Tabaku 2000). In most cases it is admissible or desirable to assist the nature by suitable close-to-nature management (Lindh & Muir 2004). It will shorten the time to achieve the target situation when the forest can be fully left to spontaneous development in line with the requirements for nature conservation (Bebber et al. 2005; Götmark 2009). But these should not be the systems with a sequence of sustainable practices known from the conventional management of commercial forests (Remeš et al. 2015; Bílek et al. 2015).

Pronounced differences between natural and commercial forests consist not only in management but also in the context of the time dynamics of forest stands. In commercial forests the particular silvicultural practices are strongly focused on wood production (Štefančík et al. 2014; Cukor et al. 2017). Their rotation cycles are usually realized in 25 – 150-year cycles while developmental cycles in some regions of natural forests can take even thousands of years (Seymour & Hunter 1999). Mixed forests of European beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* [L.] Karst.) in the studied nature reserve in the Orlické hory Mts. are characterized by the long developmental cycle lasting for 350 – 400 years (Vacek et al. 2014a). It is determined particularly by the lifetime of fir as a tree

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**Corresponding author. Zdeněk Vacek, e-mail: vacekz@fld.czu.cz* species with the longest longevity. Two generations of beech are accomplished within one generation of fir or spruce (Korpeľ 1995).

Forest ecosystems are subjected to temporal changes and various stressors while the temporal stability in response to these external factors is an important aspect of their functions (Mazancourt et al. 2013). The dynamics of natural forests could not continually take place without rather pronounced anthropogenic and biogenic disturbances (Vrška et al. 2009). Nevertheless, disturbances caused by climate extremes, air pollution, bark beetles, windstorms or fires do not avoid natural forests (Borůvka et al. 2005; Zielonka et al. 2010; Král et al. 2015; Bošela et al. 2016). Among these disturbances the ungulates are considered as the most important driver of the metacommunity structure of temperate forests that is able to substantially influence the regeneration process and subsequently the forest development (Senn & Suter 2003; Suzuki 2013; Mattila & Kjellander 2017). Due to the slow growth of trees (Ammer 1996) mountain areas are more vulnerable to browsing losses than forests at lower altitudes (Motta 2003). In addition, the red deer (*Cervus elaphus* L.) population in the studied area is secondarily high. The present hunting management, supporting high population densities of ungulates, is a significant threat to biological diversity of mixed forests (Schulze et al. 2014). Moreover, even low densities of ungulates may have pronounced impacts on natural regeneration, hence on forest development (Jorritsma 1999). In the last decades, a decrease in the fir representation in favour of beech regeneration has been observed in the Krkonoše Mts. and Orlické hory Mts. (Hofmeister et al. 2008; Vacek et al. 2015). A decrease in the percentage of fir due to browsing by game, and also of other tree species preferred by game such as sycamore maple (*Acer pseudoplatanus* L.), rowan (*Sorbus aucuparia* L.) European ash (*Fraxinus excelsior* L.) and beech to a lesser extent, was confirmed also in other areas of central Europe (Motta 2003; Diaci et al. 2010; Konôpka & Pajtík 2015; Meier et al. 2017). Nevertheless, because of the lack of long-term researches the effects of ungulate impacts on mixed forest stands have been still relatively little known (Vacek et al. 2014a).

The main objective of this paper was to evaluate the structure and development of four forest stands in a fenced and unfenced part of the core area of spruce-beech-fir forest stands in the Černý důl Nature Reserve (NR) and Trčkov National Nature Reserve (NNR) in the Orlické hory Mts. Protected Landscape Area (PLA). The aim were to (1) determine and compare the diversity, structure and production of near-natural mixed forests after 25 – 30 years game-proof fenced enclosure and (2) quantify the influence of ungulates on growth of natural regeneration differentiated by tree species.

2. Material and Methods

2.1. Description of the study area

The present study was conducted on four permanent research plots (PRP) (GPS 1: 50°12´05˝ N, 16°31´10˝ E; 2: 50°12´03˝ N, 16°31´14˝ E) situated in the Černý důl NR and two PRP (GPS 3: 50°18´51˝N, 16°25´06˝ E; 4: 50°18´48˝ N, 16°25´05˝ E) in the Trčkov National NNR in the Orlické hory Mts. PLA, west of the frontier between the Czech Republic and Poland (Fig. 1). The protection of this locality was declared in 1954 for Černý důl NR on an area of 26.4 ha, respectively in 1982 for Trčkov NNR on 65.1 ha in order to conserve the autochthonous spruce-fir-beech population at an altitude of 740 – 920 m a.s.l. Average annual temperature of this locality is 5.5 °C and annual precipitation amount is around 1000 – 1220 mm. The length of the growing season ranges around 110 days. The bedrock is built of migmatites and orthogneisses, Cambisols are a prevailing soil type.

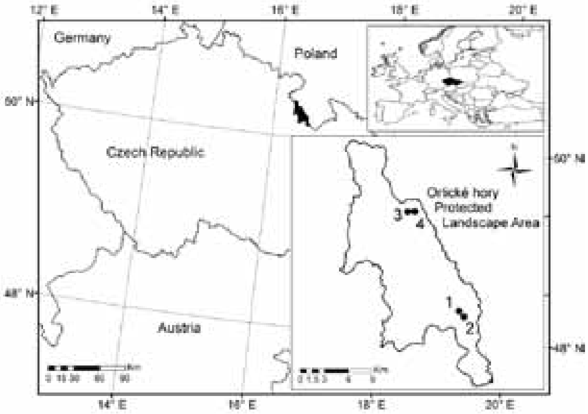


Fig. 1. Localization of autochthonous mixed stands on permanent research plots 1 – 2 in the Černý důl Nature Reserve and 3 – 4 in the Trčkov National Nature Reserve.

A dominant tree species in the reserve is Norway spruce (*Picea abies* [L.] Karst.; 63.7 – 77.0%), the percentage of European beech (*Fagus sylvatica* L.) is 20.5 – 33.9%, of silver fir (*Abies alba* Mill.) 0.9 – 1.7%, while rowan (*Sorbus aucuparia* L.) and sycamore maple (*Acer pseudoplatanus* L.) account for less than 1%. The nucleus of the reserve consists of herb-rich to acid beech forests and fir-beech forests belonging to the sub-alliance *Acerenion, Eu-Fagenion* and the alliance *Luzulo-Fagion*. The remaining two thirds of the reserve are mostly composed of secondary spruce forests (the alliance *Piceion excelsae*). Standardized game stocks in the reserves are as follows: 8 – 32 heads of red deer (*Cervus elaphus* L.), 32 – 77 head of roe deer (*Capreolus capreolus* L.*)* and 16 heads of wild boar (*Sus scrofa* L.) per 1000 ha. Nevertheless, the actual stock of game is much higher in red deer (51 heads) and wild boar (43 heads).

PRP are situated in the same forest stand on a moderate slope (11 – 17°) with an altitude from 795 to 835 m a.s.l and prevailing north exposure, in similar site and stand conditions. Due to insufficient regeneration, two PRP (1, 3) has been protected against game by fencing since 1985–1989. Unfenced PRP (2, 4) are located at 5 – 15 m outside the game-proof fenced enclosure. According to the Czech typological system it is forest type 6S – fresh spruce-beech forests (*Piceeto-Fagetum oligomesotrophicum*). The age of the particular tree layers on PRP is comparable: 49–56/102–113/187–195.

2.2. Data collection

Field-Map technology (IFER – Monitoring and Mapping Solutions Ltd.) was used to establish PRP of 50 × 50 m in size (0.25 ha). The measured characteristics on a tree layer were position, crown projection, diameter at breast height (dbh ≥ 4 cm; accuracy to 1 mm), tree height and distance of live crown base to the ground level (accuracy to 0.1 m). The position, crown height and width were measured in natural regeneration (h ≥ 50 cm, dbh < 4 cm). Damage by browsing were investigated in all recruits by tree species on unfenced PRP. In juvenile stages stem samples were taken for growth analyses, five samples in the game-proof enclosure and outside this enclosure in the proximity of PRP. The height of recruits and their age were determined in 5-cm sections.

2.3. Data analysis

Basic stand characteristics were quantified from recorded dendrometric data for the tree layer. Tree volume was calculated by using volume equations published by Petráš & Pajtík (1991). To assess the stand diversity the following indices were computed by software Sibyla 5 (Fabrika et al.): Arten-profile index (Pretzsch 2001), diameter and height differentiation index (Füldner 1995), species diversity index (Shannon 1948), species evenness index (Pielou 1975), species richness index (Menhinick 1964) and total diversity index (Jaehne & Dohrenbusch 1997).

In all individuals of natural regeneration and tree layer the spatial distribution was evaluated according to index of non-randomness (Pielou 1959; Mountford 1961), aggregation index (Clark & Evans 1954), index of cluster size (David & Moore 1954) and Ripley's *L*-function (Ripley 1981). The criteria of diversity indices are shown in Table 1. The software PointPro 2 (Zahradnik & Pus) programme was used for the computation of horizontal structure. The test of significance of the deviations from the values expected for a random point pattern was done by Monte Carlo simulations. The mean values of *L*-function were estimated as averages of *L*-functions computed for 1999 randomly generated points. Along with the measurements of horizontal structure on the PRPs, stand density, crown projections area and crown closure were also calculated.

Situational maps were created in the ArcGIS 10 programme (Esri). Statistical analyses were processed in the Statistica 13 software (StatSoft, Tulsa). Data were logarithmized to obtain the normal distribution and tested by the Kolmogorov-Smirnov test. Differences in species diversity, frequencies of height and diameter classes between PRP and also in the mean height of recruits damaged by browsing and those with normal growth without browsing were tested by one-way analysis of variance (ANOVA). Significant differences were consequently tested by post-hoc Tukey test.

3. Results

3.1. Tree layer biodiversity

In the framework of species diversity, richness (*D;* X = 0.454, SD = ±0.096) and heterogeneity (*H´;* 0.373, ±0.061) showed medium diversity (Table 2), respectively evenness reached rich diversity (*E;* 0.665, ±0.138). The vertical structure composed mainly of three storeys was highly diversified on these plots (*A;* 0.680, ±0.087), especially on fenced PRP 1 close to selection structure. Height and diameter differentiation indicated forest stands with high structural differentiation on fenced PRP (*TM;* 0.500, ±0.034) or medium on control unfenced PRP (*TM;* 0.405, ±0.024). From the aspect of total diversity, there was very diverse structured stand on fenced PRP 1, a diverse structure was typical for forest stands on PRP 2 and 3 and structure on unfenced PRP 4 was uneven (Table 2). In all the above-mentioned cases, with the exception of species evenness (lower by 11.9% due to

Table 1. Overview of indices describing the biodiversity and their common interpretation.

Criterion	Quantifiers	Label	Reference	Evaluation
Horizontal structure	Index of non-randomness	α (P&Mi)	Pielou (1959); Mountford (1961)	mean value $\alpha = 1$; aggregation $\alpha > 1$; regularity $\alpha < 1$
	Aggregation index	R (C&Ei)	Clark & Evans (1954)	mean value $R = 1$; aggregation $R < 1$; regularity $R > 1$
	Index of cluster size	ICS (D&Mi)	David & Moore 1954	mean value $ICS = 0$; aggregation $ICS > 0$; regularity $ICS < 0$
Vertical diversity	Arten-profile index	A (Pi)	Pretzsch (2001)	range 0–1; balanced vertical structure $A < 0.3$; selection forest $A > 0.9$
Structural differentiation	Diameter dif. Height dif.	TM_d (Fi) TM_h (Fi)	Füldner (1995)	range 0–1; low $TM < 0.3$; very high differentiation $TM > 0.7$
Species diversity	Heterogeneity	H' (Si)	Shannon (1948)	minimum $H' = 0$, higher H' = higher values
	Evenness	E (Pi)	Pielou (1975)	range 0–1; minimum $E = 0$, maximum $E = 1$
	Richness	D (Mi)	Menhinick (1964)	minimum $D = 0$, higher D = higher values
Complex diversity	Stand diversity	B (J&Di)	Jaehne & Dohrenbusch (1997)	monotonous structure $B < 4$; uneven structure $B = 6–8$; very diverse structure $B > 9$

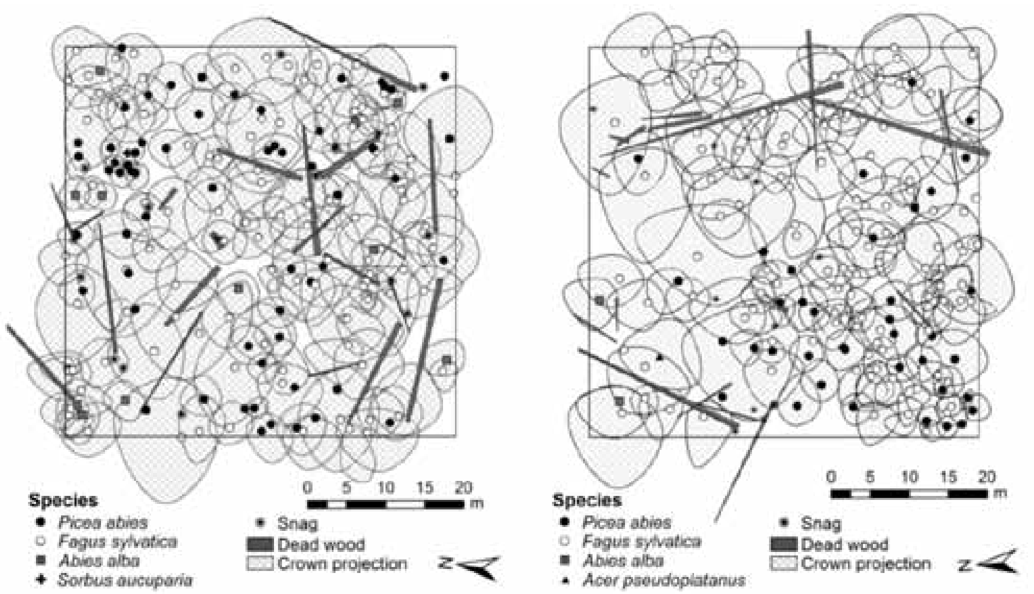
more tree species), the studied structural indices were more favourable on fenced plots compared to control plots. A comparison of both type of PRP showed that the biodiversity (without aggregation indices) was in average higher by 19.8% in the stands protected by fencing after 25 – 30 years (in 2014), respectively there were significant differences ($F_{(1,26)} = 4.18$, $P < 0.05$) excluding species evenness. The highest positive differences were observed in tree species richness (48.0%) and height differentiation (26.0%).

Table 2. Indices describing the diversity of tree layer of mixed stand on permanent research plots 1–4.

PRP	*D* (Mi)	*H´* (Si)	*E* (Pi)	*A* (Pi)	TM_d (Fi)	TM_h (Fi)	*R* (C&Ei)	*α* (P&Mi)	*ICS* (D&Mi)	*B* (J&Di)
1	0.478	0.448	0.773	0.789	0.549	0.513	0.936	1.195	0.186	9.382
2	0.427	0.399	0.820	0.737	0.428	0.366	1.035	1.179	0.110	8.202
3	0.589	0.366	0.481	0.615	0.474	0.463	1.068	1.232	0.035	8.772
4	0.320	0.280	0.587	0.577	0.415	0.414	1.042	1.085	−0.246	7.818

Explanatory notes: *D* – index of species richness, *H´* – index of species heterogenity, *E* – index of species evenness, *A* – Arten-profile index, TM_d – diameter differentiation index, TM_h – height differentiation index, *R* – aggregation index, α – index of non-randomness, *ICS* – index of cluster size, *B* – total diversity index.

Fenced PRP 1 **Unfenced PRP 2**



Fenced PRP 3 **Unfenced PRP 4**

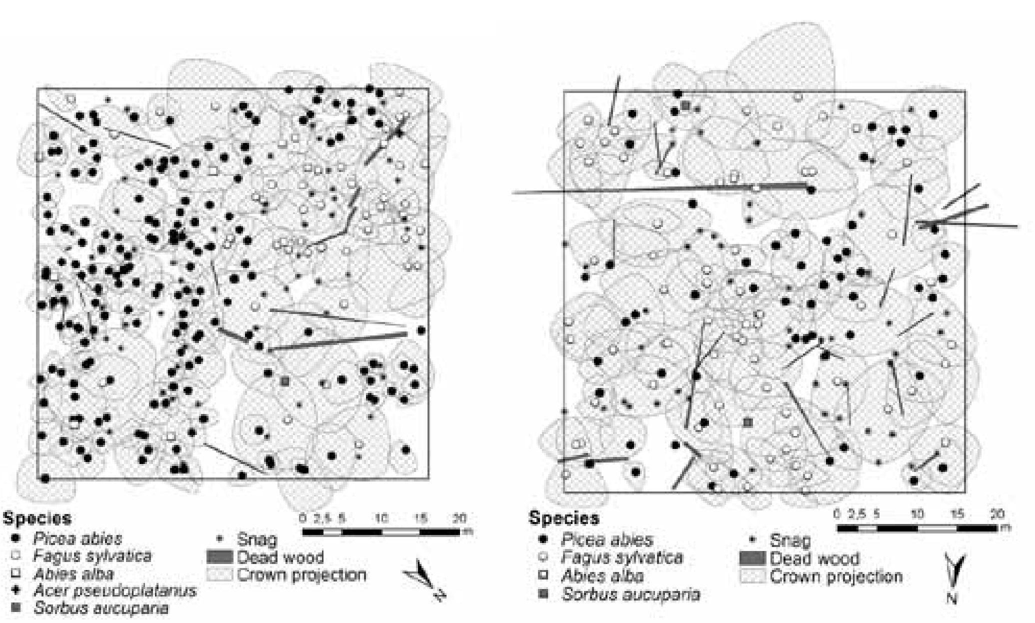
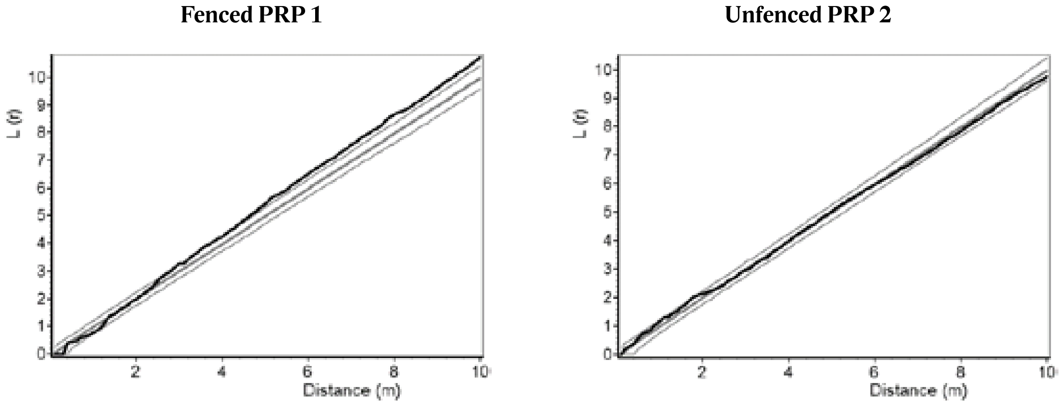


Fig. 2. Horizontal structure of the tree layer of mixed forest on permanent research plots 1–4.

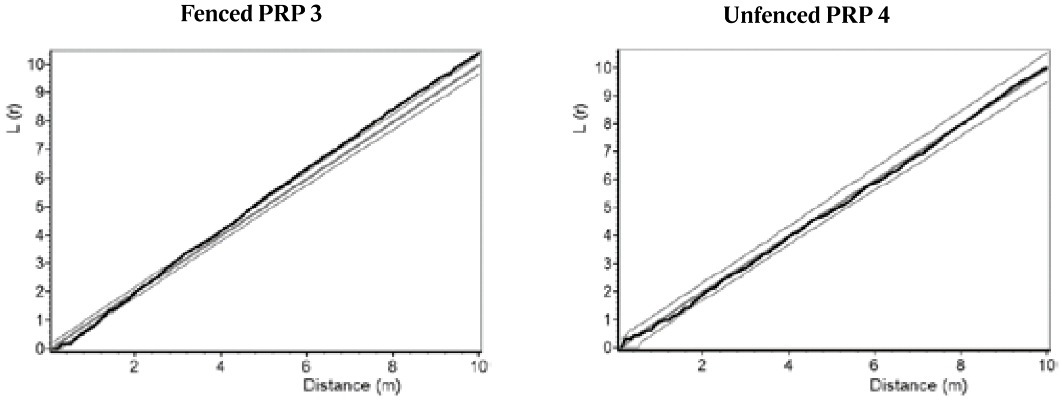
The horizontal structure of tree layer was random on fenced PRP (Fig. 2) according to computed structural indices (Table 2). Based on *L*–function, the random distribution of tree layer individuals was revealed within a spacing (distance) to 3 – 4 m, farther it was aggregated. Concretely the analysis of individuals of the overstorey (h > 20 m) showed their prevailing random distribution ($\alpha = 0.05$). Aggregation was typical of the understorey, only on PRP 1 the *R* index showed a random structure. In the understorey the distribution of individuals was random to a distance around 2 m while it was aggregated at a larger spacing. The distribution of all individuals of tree layer on unfenced control PRP was random (Fig. 3, Table 2). The overstorey pattern was regular by *R* and *ICS* indices while it was random by the α index on PRP 2. Aggregation was found out in the lower tree layer similarly like in fenced PRP but it was far from being so pronounced (a lower number of individuals growing up to the registration boundary). Based on *L*–function, the regular distribution of overstorey individuals was revealed within a spacing to 6 m, farther it was random. The spatial pattern of intermediate and suppressed individuals was random to a distance of 1 m, and clumpy at a larger spacing. Differentiation according to tree species on all PRP shows the random distribution of spruce and beech by all above-mentioned indices, respectively the spruce had a tendency toward aggregation in smaller spacing.

3.2. Stand structure and production

The stand density index (SDI) of tree layer on fenced PRP was 0.74, the area of crown projections amounted to 3.91 ha and canopy cover was 0.92. The stand volume ranged 478 – 558 $m^3\,ha^{-1}$ (spruce 46 – 73%, beech 15 – 38%, fir 12 – 16%, rowan and sycamore <1%; Table 3). The number of tree layer individuals was 816 trees ha^{-1} and basal area was 47.6 $m^2\,ha^{-1}$ in average. Periodic annual increment in 2014 was 7.5 $m^3\,ha^{-1}\,y^{-1}$ and mean annual increment 3.5 $m^3\,ha^{-1}\,y^{-1}$. SDI on unfenced PRP was lower by 11% (0.66) and the area of crown projections by 29% (2.78 ha), but the canopy cover was similar (0.93) compared to fenced PRP. The higher stand volume reached 559 $m^3\,ha^{-1}$ (spruce 37 – 73%, beech 27 – 53%, fir 9%, sycamore and maple <1%). The number of tree layer individuals was 516 trees ha^{-1}, that it is difference by 25% compared to fenced PRP, but mean basal area was only by 2 $m^3\,ha^{-1}$ lower. Periodic annual increment in 2014 was 6.5 $m^3\,ha^{-1}\,y^{-1}$ and mean annual increment 3.7 $m^3\,ha^{-1}\,y^{-1}$.


Fenced PRP 1

Unfenced PRP 2


Fenced PRP 3

Unfenced PRP 4

Fig. 3. Spatial pattern of mixed stand on permanent research plots 1 – 4 expressed by *L*–function; the black line represents the *L*–function for real distances of trees; the bold gray line represents the mean course for random spatial distribution and the two thinner central curves represent 95% interval of reliability; when the black line of tree distribution on the PRP is below (under) this interval, it indicates a tendency of trees toward regular (aggregation) distribution.

Table 3. Overview of stand parameters of mixed stand on permanent research plots 1–4.

PRP	t	dbh±SD	h	h_{95}	f	v	N	G	V	HDR	PAI	MAI
	[y]	[cm]	[m]			[m^3]	[trees ha^{-1}]	[m^2 ha^{-1}]	[m^3 ha^{-1}]		[m^3 ha^{-1} y^{-1}]	
Picea abies												
1	147	34.1±19.7	16.34	31.9	0.613	0.914	240	21.8	220	47.9	2.75	1.50
2	156	38.1±24.5	17.30	38.7	0.657	1.295	160	18.0	207	45.4	2.10	1.33
3	156	25.5±17.0	13.01	35.5	0.868	0.577	708	36.2	408	51.0	5.10	2.62
4	165	41.6±25.6	18.66	43.0	0.657	1.667	240	32.4	400	44.9	4.40	2.42
Fagus sylvatica												
1	126	22.6±14.8	12.07	27.7	0.889	0.430	420	16.8	181	53.4	3.45	1.44
2	140	25.5±18.5	13.14	31.0	1.001	0.675	444	22.7	300	51.5	3.45	2.14
3	119	24.1±12.8	17.67	26.1	0.544	0.439	192	8.7	84	73.3	1.65	0.71
4	131	25.3±13.5	17.67	29.5	0.625	0.555	272	13.6	151	69.8	2.35	1.21
Abies alba												
1	169	48.2±29.5	17.60	32.8	0.607	1.948	40	7.0	78	36.5	1.20	0.46
2	170	73.9± 9.8	36.85	38.2	0.399	6.299	8	3.4	50	49.9	0.55	0.29
3	181	55.8±30.8	24.96	36.9	0.529	3.229	20	4.5	65	44.7	0.80	0.36
Total												
1	143	28.7±18.7	13.80	30.4	0.761	0.679	704	45.6	478	48.1	7.45	3.35
2	148	30.4±21.5	14.61	35.1	0.865	0.916	616	44.7	565	48.1	6.15	3.82
3	153	26.1±16.9	14.20	32.5	0.791	0.601	928	49.6	558	54.4	7.55	3.64
4	156	33.7±20.7	18.05	38.5	0.659	1.062	520	46.4	552	53.6	6.75	3.54

Explanatory notes: *t* – average stand age; *dbh±SD* – mean quadratic dbh ± standard deviation; *h* – mean height; h_{95} – top 95 % height; *f* – form factor; *v* – average tree volume; *N* – number of trees per hectare; *G* – basal area; *V* – stand volume; *HDR* – slenderness quotient; *PAI* – periodic annual increment; *MAI* – mean annual increment.

On fenced PRP the representation of diameter classes showed a left-sided pattern and generally corresponded to the shape of Liocourt curve (compared to unfenced PRP) with the highest frequency in the 4 – 12 cm classes. On PRP 1 spruce representation in diameter classes was uneven, and the beech diameter structure also indicated the curve of an optimum structure of selection forest. Reverse situation was on PRP 3. Interspersed fir as 20 – 40 trees ha^{-1} occurred in diameter class 1 and then in the diameter range of 44 – 80 cm (the advanced growing-up stage was completely missing there). Fir and spruce make up the overstorey with maximum height of 36.9 and 40.3 m, respectively. In unfenced PRP, similarly like in PRP 1 and 3, a geometrically decreasing tendency was found out in diameter classes, but not so relevant (especially on PRP 4; Fig. 4). Spruce dominant position was documented by a maximum height of 44.5 m. Mean dbh on fenced PRP was 27.4 cm (±17.8) while on unfenced PRP it was higher by 4.7 cm (32.1 cm, ±21.1). The recruits of fir, sycamore and rowan not reach the registration boundary due to missing of advanced natural regeneration. A comparison of the average frequencies

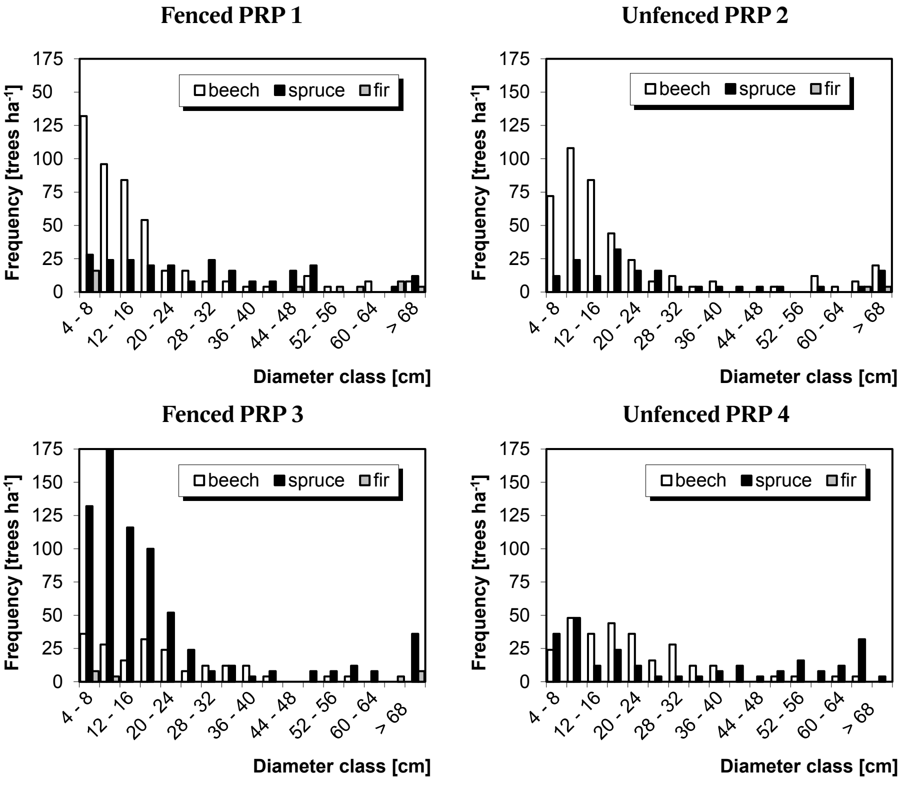


Fig. 4. Frequency of diameter classes of tree layer differentiated by main species on permanent research plots 1–4 in 2014.

of all individuals on both PRP in the initial diameter classes suggests a statistically significant difference ($F_{(1, 18)} = 4.3$, $P < 0.05$) in favour of fenced stands.

3.3. Natural regeneration and damage by game

On fenced PRP, in advance growth ($h \geq 50$ cm) there were 24,468 individuals of natural regeneration (beech 77%, spruce 17%, fir 3% and rowan 3%) on PRP 1 and 1,852 recruits (spruce 58%, beech 21%, fir 16% and rowan 5%) on PRP 3. Natural regeneration with distinct height and diameter differentiation was produced there as a result of the minimum pressure of ungulates (Fig. 5). The height structure of natural regeneration showed a left-sided pattern and by their height the majority of the trees belonged to the 50 – 60 cm class. The spatial distribution of natural regeneration was significantly aggregated on all plots ($\alpha = 0.05$) with higher tendency of clumpiness on unfenced PRP. On unfenced PRP 2 there were in total 15,292 recruits ha^{-1} as advance growth recruits (beech 95%, spruce 5%, rowan < 1%), while fir did not reach the height of 50 cm. On PRP 4 number of recruits was 688 recruits ha^{-1} (spruce 53%, beech 40%, rowan 4%, fir 3%).

A comparison of the height structure on PRP 1 and 2 showed that the average frequency of recruits in all height classes was similar ($F_{(1, 24)} = 1.0$, $P > 0.05$), but the frequency of recruits exceeding the height of 100 cm was demonstrably higher on fenced PRP 1 ($F_{(1, 14)} = 7.3$, $P < 0.05$). On PRP 2 recruits higher than 100 cm account only for 1.2% of the total number (180 recruits ha^{-1}), on PRP 1 it was 22.5% (5,512 recruits ha^{-1}), i.e. 30.6 times more, but in the total number only 1.6 times more. Compared PRP 3 and 4, it was 2.7 times higher total number on the fenced PRP. On fenced PRP 3 recruits higher than 190 cm (grow up from game browsing) was 40.1% (364 recruits ha^{-1}), while on unfenced PRP 4 only 11.3% (40 recruits ha^{-1}) due to the strong pressure of game. Compared locality Černý důl, the mean height of all individuals was significantly higher ($F_{(1, 39\,758)} = 1\,016.3$, $P < 0.001$) on PRP 1 (X = 82.7, SE ±0.3) than on PRP 2 (68.6 cm, ±0.3). Similar situation was in Trčkov ($F_{(1, 2\,538)} = 407.3$, $P < 0.001$). The greatest damage by browsing was caused to fir (browsing in 100% of recruits) and rowan (in 94% of recruits). Beech was damaged to a smaller extent (in 56 % of recruits) and the smallest damage was observed in spruce (in 18 % of recruits). Natural regeneration of sycamore maple was completely browsed by brown hare (*Lepus europaeus* Pallas).

A comparison of the mean heights of individuals in the game-proof fenced enclosure and the heights reduced by browsing outside (Fig. 6) showed a significant influence of ungulates ($F_{(1, 98)} = 39.5$, $P < 0.001$). At the juvenile stage (ca. under 5 years) the studied tree species was not significantly damaged by game ($F_{(1, 18)} = 2.7$, $P > 0.05$). As soon as they exceed the height of the herb layer, they are exposed to regular browsing and they nearly stop growing. A difference in height at the age of 10 years was already statistically significant ($F_{(1, 18)} = 81.3$, $P < 0.001$). For instance, in the Černý důl NR beech at 20 years of age on the fenced plot had the mean height of 211 cm (±13), but with heavy browsing by game its height was only 73 cm (±15), i.e. 34% of the current height (in spruce 29%). Fir and rowan were not analysed because of their limited number in this locality. In Trčkov NNR fir at 20 years of age on the fenced plot had the mean height of 224 cm (±7), but with repeated browsing its height was only 63 cm (±9), i.e. 28% of the current height (in beech 32%, in spruce 49%). The highest damages differences were observed in fir.

4. Discussion

Changes in species composition and structure are the basic component of forest dynamics (Fürst et al. 2007; Klopcic & Boncina 2011), but in the last several centuries (Linder & Östlund 1998).These factors include unfavourable development of ungulate game population and high damage to forests. Game management is often preferred over forestry (Ambrož et al. 2015; Konôpka et al.

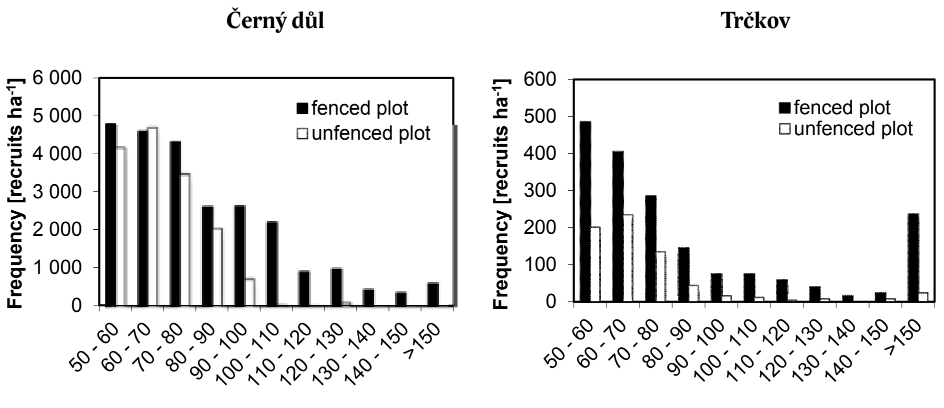


Fig. 5. Frequency of height structure of natural regeneration per hectare on reserves Černý důl and Trčkov (fenced plots 1, 3; unfenced plots 2, 4).

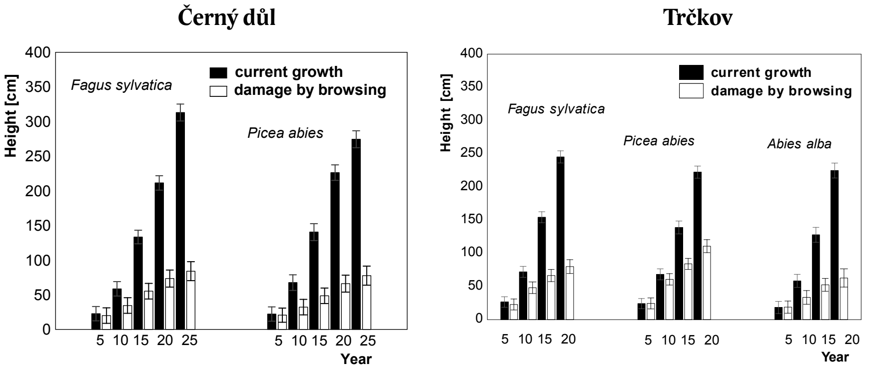


Fig. 6. Development of mean height growth of recruits (average values of current trend in comparison with decreased growth due to browsing), error bars indicate standard errors.

2015), that it leads to disproportionate damage by browsing in stands, especially in terms of a natural regeneration failure. The development of near-natural mixed spruce-fir-beech forests may however take place only without any stronger anthropogenic disturbances (Vrška et al. 2009). Research on the structure and development of mixed forests in the Orlické hory Mts. has been conducted since 1951 (Vacek et al. 2017a). The present research plots comprise mountain spruce-beech-fir forests with the species composition near-natural forests (beech 55%, spruce 33%, fir 12%), representing an optimum model of forest stand for the fulfilment of various functions and being extraordinarily resistant to disturbances (Ammer 1996). Nevertheless, these forests have been influenced quite substantially to the detriment of fir (Hofmeister et al. 2008) and by high population densities of ungulates (Vacek et al. 2014a).

The spatial distribution of parent stand trees on the studied PRP documented a random pattern similarly like in natural spruce-fir forests in the Carpathian Mts. (Paluch 2007), mixed forests in Lower Austria (Splechtna et al. 2005) or mixed forests of the Boubín virgin forest (Šebková et al. 2011). Spatial analyses showed that the overstorey was distributed randomly with a tendency toward regularity but the trees in lower storeys showed a clumpy pattern. According to others studies from Central Europe significant clumpiness occurred in small trees but large trees showed a regular pattern while the horizontal structure of parent stand was random in general (Szwagrzyk & Czerwczak 1993; Bílek et al. 2011). On fenced PRP a higher tendency toward aggregation was observed in the lower storey which is a result of the successful growth of clumpy natural regeneration in the crown canopy gaps (Zeibig et al. 2005). Natural regeneration was strongly aggregated, especially on unfenced plots due to lower number of recruits, that it corresponds with other researches from Sudetes Mts. (Vacek et al. 2014b; Bulušek et al. 2016).

On both plots there are the autochthonous spruce-fir-beech stand with rich high spatial and age differentiation, which is composed of three layers sometimes intermingling with each other to create the almost selection structure, especially on fenced plots. In Poland in the Bieszczady National Park similar stands were described by Jaworski et al. (2002) or in the Karkonoski Park Narodowy by Vacek et al. (2010). After 25 – 30 of protection by fencing, structural and species diversity were significantly more favourable on fenced plots compared to control plots. The highest differences reached in species richness and height differentiation in favor of the fenced stands. Very diverse structure of fenced forest stand was also observed from other research in the Trčkov NNR (*B;* index 8.61) compared to lower complex diversity in unfenced stand (*B;* 7.66; Vacek et al. 2013), such as in other mixed not fenced spruce-beech forest in Orlické hory Mts. (*B* 6.57 – 8.05; Králíček et al. 2017). Study forest stands with pronounced age, spatial and species differentiation are generally considered as ecologically stable (Klopcic & Boncina 2011).

Breast height diameter of trees was considered by Nilsson et al. (2002) as one of the important features of old near-natural forest stands. PRP comply with the reference value of 10 – 20 trees ha^{-1} with dbh > 70 cm. The fir occurred mainly in large diameter classes while smaller dimensions prevail in beech. The trend of fir representation is very negative for further development (Klopcic et al. 2010) because it may lead to the suppression of fir trees in forest stands for a long time (Ferlin 2002). An evident decrease in fir in mixed forests was observed also in Slovakia (Štefančík 2006; Saniga et al. 2013) and in other areas (Vrška et al. 2009; Ficko et al. 2010). Different results were reported by Paluch (2007) from near-natural mixed forests in the Carpathian Mts., where the fir had higher representation in lower diameter classes. High share of fir in juvenile development phases was observed in Tyrol or Krkonoše Mts., but it was caused also due to protection by fencing (Vacek et al. 2015; Meier et al. 2017). The trend of spruce representation in diameter classes was similar at the compared localities. The stand volume on PRP ranged between 478 m^3 ha^{-1} and 565 m^3 ha^{-1}, respectively. If compared with the Belevine locality in Croatia as reported by Čavlovič et al. (2006), the stand volume on PRP 2 was much higher (by 161 m^3 ha^{-1}), and similar values (543 m^3 ha^{-1}) were reported by Paluch (2007). Higher values found Saniga (1999) in Slovak old-growth Dobročský forest, which consists of spruce, fir, beech and sycamore (600 – 853 m^3 ha^{-1}). Distinctly higher stand volumes were also reached by mixed stands in the Serbian reserve Račanska Šljivovica, where the stand volume was 800 m^3 ha^{-1}. In addition, the stand volume in this reserve has been slightly increasing in the last years (Pantič et al. 2011), and so its trend was similar to that expected on the studied PRP. Contrary to the stand volume, the basal area on the particular PRP was almost identical (47 m^2 ha^{-1} ±2). In comparison with the basal area from forest stands in Belevine in Croatia (Čavlovič et al. 2006), the basal area was higher by 26% while the lower value (36 m^2 ha^{-1}) was reported by Paluch (2007) from near-natural forests in the West Carpathians.

The total number of recruits from natural regeneration ($h \geq 50$ cm) was lower by 38% on unfenced PRP 2 (15,292 recruits ha^{-1}) compared to fenced PRP 1 (24,468 recruits ha^{-1}) but the abundance of recruits exceeding the height ≥ 100 cm was almost 32 times higher on fenced PRP 1. Other researches confirmed that deer optimum browsing height is around 100 cm from the ground level (Renaud et al. 2003; Konôpka & Pajtík 2015). On unfenced PRP 4 regeneration density was lower even by 62% compared to fenced PRP 3, but the number of regeneration reached on locality Trčkov only 1,277 recruits ha^{-1}. High differences between studied localities can be caused by less favourable stand and habitat conditions for the regeneration, such as adverse relief, dense vegetation cover or higher canopy cover of tree layer (Štícha et al. 2010; Malík et al. 2014; Vacek et al. 2017b). Losses caused by browsing substantially influence the species composition at the cost of fir and rowan (Motta 1996, 2003; Konôpka & Pajtík 2015), which were completely eliminated on unfenced plots. With heavy damage by game the recruits of beech or spruce reach only one third of the height in comparison with the recruits on fenced PRP. In terms of game species, the main browsing losses are caused by deers compared to wild boards (Ambrož et al. 2015). According to Vrška et al. (2001), despite disputable results the complete fencing of spruce-fir-beech natural forests is currently the only solution ensuring their relatively natural spontaneous development. Similar conclusions were also documented by Olesen & Madsen (2008) from Denmark and by Harmer (2001) from the United Kingdom, who recommended protecting the natural regeneration in these forests by fencing. In the Alps, Ammer (1996) and Senn & Sutter (2003) identified the problem of ungulate population densities that were the highest since the 19th century and substantially influenced the dynamics of natural regeneration. Similar problem was observed in Slovakia, where stock of red deer increased by 199% in period 1960–2013 (Konôpka et al. 2015).

In the Czech Republic number of hunted game increased since 1966 (to 2015) from 63 to 100 thousand heads of roe deer (+58%), from 7 to 24 thousand heads of red deer (+243%) and especially from 3 to 185 thousand heads of wild boar (+6,067%; data FRGMI). On the other hand, the main browsing losses on regeneration are caused by deer compared to wild boards (Ambrož et al. 2015). In details, over last 15 years in Královehradecký region, where Orlické hory Mts. are situated, game stock increased by 17% for roe deer, by 34 % for red deer and by 89% for wild boards. In a Natural Forest Area Orlické hory Mts. the highest negative changes since 1980 were observed for wild boards (+780%) and then for roe deer (+15%; Mikeska et al. 1999; data FRGMI, FMI). The highest damage is caused by the high stock of red deer. In February, stock of red deer in study locality regularly amounts to 80 heads per 1,000 ha due to game migrating from Poland, because game is not fed there (Vondřejc 2008). Nevertheless for the successful growth of natural regeneration 5 – 30 heads of red deer per 1,000 ha are recommended (Vera 2000). Therefore, the basic principle is a significant reduction of all ungulate species to the ecologically tolerable levels, but this goal is still not fulfilled. The mechanical protection of stands, which reaches up to 50 ha in the Orlické hory Mts., is still a necessary complementary measure. Already in the 1980s, nature conservation agencies of the Czech Republic acceded to the fencing of the core parts of the reserves, where the ungulate damage to forest stands was far behind tolerable level. This relatively costly fencing measure sought to ensure the successful development of regeneration of tree species threatened by game (Vacek et al. 2012).

5. Conclusion

The studied nature reserves belong to the most valuable remnants of natural mixed forests in the area of the Orlické hory Mts. It is advisable to ensure that the dynamics of these richly structured forests with all their specificities would continually take place without any greater anthropogenic disturbances. Research has confirmed a hypothesis about the long-term negative effects of wildlife on structure and development of the studied autochthonous stands. Damage caused by browsing was significant limiting factor for the height growth of natural regeneration. The stands on the unfenced plot were lacking the phase of natural regeneration. With respect to its numbers and tree species composition, mainly fir, rowan and sycamore, were missing. On the contrary, density of recruits was more influenced by habitats and stand conditions than by game browsing.

For the conservation of these valuable forests it is necessary to find efficient methods for the protection of regeneration processes. The basic recommendation is to modify the tree species composition in favour of the abundant natural regeneration of beech and to consequently protect the admixture of heavily browsed tree species. A certain measures are also the establishment of overwintering enclosure for game or reintroduction of large predators. In many cases the only possible solution is reducing of ungulate populations and additionally long-term protection by fencing. Game management and forestry must be implemented in such a way that there is harmony between them.

Acknowledgments

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ORIGINAL PAPER

Quantitative analysis of litter-fall in hornbeam-oak-pine stands in the Lviv Roztoche region

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Abstract
The aim of the article is to find out if there is a difference between amount of litter-fall in hornbeam-oak-pine stands according to regeneration (naturally and artificially) and age of the stand (middle-aged, mature). We analysed the annual dynamics of litter-fall (litter) and its fractions (needles of Scots pine; leaves of common oak; leaves of associate species; twigs; bark; pine cones; acorns of common oak; seeds of other species; acorn cups, winged seeds; lichens, mosses) in middle-aged hornbeam-oak-pine stands which were regenerated naturally or artificially on the cutover sites following two-stage uniform shelterwood felling and clearcutting, as well as in a mature parent stand (control plot) in the Lviv Roztoche region. Two peaks of organic matter fall have been revealed on both the control plot and the experimental plots: the largest one in October and much lower in May. It was found that the annual mass of litter was 5.8 – 6.6 tons per hectare, the annual weight of litter in the middle-aged hornbeam-oak-pine stands was greater than in the mature stands. Annual dynamics of certain fractions of litter in the stands is preconditioned by the specificity of functioning of the relevant bodies of the trees.

Key words: hornbeam-oak-pine stands; natural and artificial forest; mass of litter; fractions of litter; annual dynamics

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1. Introduction

The litter-fall of forest stands substantially affects the structure of forest floor, biotic cycling of mineral elements, intensity of mineralization of the dead organic residues and the composition of mineralization products (Bodnar 2007; Bodnar 2000; Bublinec 1994; Fischer & Binkley 2000; Gorshenin & Shvydenko 1977; Kremenetska 2000; Lukac & Godbold 2011; Melehov 1980; Novák et al. 2013; Pogrebnyak 1968; Rybak 2004). It is found that the mass of litter in forest stands varies significantly. It depends on many factors: forest stand composition and productivity, the presence of other components of forest stands (underbrush, advance growth, and grass cover), the number of vertebrate and invertebrate animals, climatic and soil-hydrological conditions, weather conditions, etc. (Gorshenin 1977; Kacálek et al. 2013; Novák et al. 2014, 2015; Kovalevskyi 1952; Melehov 1980; Pogrebnyak 1968, ICP Forest 2005). The amount of litter-fall is related to these climate-soil factors, as the total mass of litter is directly proportional to the fertility of the soil. Through its effects on ground vegetation, litterfall is also closely related to biodiversity issues. This research tests the following hypotheses:

1. In the Lviv Roztoche region is the difference between the litter-fall in naturally and artificially regenerated hornbeam-oak-pine stands.
2. In the Lviv Roztoche region is the difference between the litter-fall in naturally and artificially regenerated (middle-aged) and mature (old) hornbeam-oak-pine stand.

The objective of the study was to reveal the peculiarities of annual dynamics of litter-fall, its fractional composition in middle-aged and mature hornbeam-oak-pine stands regenerated naturally or artificially in Lviv Roztoche area and its comparison to findings in other temperate forests in Europe.

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2. Material and methods

The objects of the research were the hornbeam-oak-pine forest stands of natural and artificial origin formed after the harvest cutting in the research and production permanent area of the Department of Forestry, Ukrainian National Forestry University (UNFU). The permanent study area was established in 1962–1963 under the supervision of prof. M. Gorshenin (Gorshenin 1972) in the hornbeam-oak-pine stand of the Stradch Production and Training Center of UNFU.

The type of forest (Pogrebnyak 1955): moist fresh hornbeam-pine fairly fertile oak forest type, the type of soil: soddy low-podzolic loamy sand on the sands of glacial and eluvium origin (Pieshko 1972). The composition of the stand before cutting: 70% of *Pinus sylvestris,* 30% of *Quercus robur* and folowed individual trees: *Carpinus betulus, Picea abies, Acer platanoides, Tilia cordata, Fagus sylvatica.* The age of forest: 70 – 80 years, relative stand density: 0.9 – 1.0, stand volume: 380 – 440 m^3 ha^{-1} (Gorshenin 1972).

The study was performed in three experimental sections of the permanent study area: section SC: a two-stage uniform shelterwood felling was carried out (first cut in 1962–1963, the second one in 1967–1968); section CC: clearcutting was carried out in 1962–1963,and the control section C: no felling of the forest was conducted.

In section SC, the forest stand was based on natural regeneration of Scots pine (*Pinus sylvestris* L.), common oak (*Quercus robur* L.), hornbeam (*Carpinus betulus* L.) and other species. In section CC following timber cutting in 1962, a forest plantation was established according to the scheme 50% of Scots pine, 50% common oak. Two year old seedlings of pine and oak were planted in rows. The row spacing was 2 m, the plant spacing was 0.5 m. Hornbeam and other species were regenerated naturally. Forest inventory characteristics of the forest stands in the sections are presented in Table 1.

The share of tree species was calculated according to basal area. Canopy density was estimated as the ratio of the area of horizontal projections tree crowns (excluding the area of overlap) to the total area of the stand.

As can be seen from Table 1, 53 – 56 year old highly productiveforest stands got established in the experimental sections SC and CC dominatedby Scots pine, witha significant share of common oak, and mixture of hornbeam and other species.

The artificially regenerated forest stand, in comparison to naturally regenerated, is characterised by a markedly higher productivity of Scots pine, common oak and common hornbeam, as well as significantly greater volume of wood. The control section C has preserved a highly productive stand 120 – 130 years of age which is dominated by pine. However, its share in the stand has been gradually decreasing as pine trees of more than a hundred year old are often affected by plant diseases resulting in pine decline.

Auxiliary species in the sections of the permanent study area also participate in the formation of litter. Their participation in the litter-fall of dead organic matter can be quite significant. Thus, according to N. Remezov's research (1953), the undergrowth of hazel (*Corylus avellana* L.) increased the weight of litter by 0.9 tons per hectare and thickets of yellow acacia (*Caragana arborescens* Zam.) – up to 4 tons per hectare.

In the control section C, where the total stand canopy density is 0.80 – 0.85 and the age of forest stand is more than 100 years, the undergrowth is well developed. Its density is 0.4; the composition is dominated by common hazel, the height of bushes reaching 6 – 8 (10) m. Common in the section are also bird cherry tree (*Padus avium* Mill.) and rowan tree (*Sorbus aucuparia* L.), with occasional spindle tree warty (*Euonymus verrucosa* Scop.) and haw tree (*Crataegus monogyna* Jacq.).

In the experimental sections of the permanent study area, in contrast to the control section, the undergrowth began to emerge relatively recently and yet it is underdeveloped.

Table 1. Forest inventory indices of the forest stands in the sections of the permanent study area, 2015.

Section	Stand composition	Share [%]	Age [years]	Average D [cm]	Average H [m]	Canopy density	Volume [m^3 ha^{-1}]
C	*Pinus sylvestris*	60	124	45.0	32.9	0.80–0.85	589
	Quercus robur	30	134	40.6	28.0		
	Carpinus betulus	10	85	12.2	12.5		
	Fagus sylvatica	Individual trees					
	Tilia cordata						
	Acer platanoides						
SC	*Pinus sylvestris*	80	53	28.4	23.0	0.85–0.90	359
	Quercus robur	10	53	14.9	17.1		
	Carpinus betulus	10	38	4.3	5.2		
	Fagus sylvatica	Individual trees					
	Acer pseudoplatanus						
	Acer platanoides						
	Picea abies						
CC	*Pinus sylvestris*	60	56	32.3	26.5	0.90–0.95	454
	Quercus robur	20	56	30.6	25.4		
	Carpinus betulus	20	53	16.0	15.3		
	Fagus sylvatica	Individual trees					
	Tilia cordata						

In section SC, whose stand was regenerated naturally, the canopy density of tree species is 0.85 – 0.90. The undergrowth is sparse, its canopy density being 0.1 – 0.2. Its composition is dominated by common hazel (the height of shrubs is 1 – 5 m) with occasional rowan trees, bird cherry tree and buckthorn alder (*Frangula alnus* Mill.).

Stand canopy density in section CC is 0.9 – 0.95. The undergrowth is almost absent, there are only a few instances of common hazel (the height being up to 1m) and spindle tree warty (the height is 0.5 m).

To determine forest inventory indices of the sections' stands, sample plots (size of plot – 1 ha) were established according to the common forest inventory technique (Sokolova 1984). The stock of the tree species was determined by using the guidelines of works (Shvydenko 1987; Nikitin 1984). The age of the trees was estimated by using the increment cores of wood technique, adjusted to the height of the cores extraction.

To study the annual dynamics of litter-fall, litter collectors (traps) were used of size 1 × 1 m installed in geometric order in each section in 12-fold repetition. Litter collectors were the crates with a side height of 15 cm and a mesh (4 × 4 mm) down. The top edge of skirting litter collectors located at a height of 0.6 m. above the ground. The working area of each litter collectors was 1 m^2. Separate samples of raw litter-fall collected from litter collectors on each section were combined into one (mixed) sample.Mass of litter-fall was calculated from mixed sample (12 m^2) per hectare. The litter from the collectors was taken on the last day of each month (for the December-March period – total in March). For maintaining equidistant distance we divided sum of litter-fall in December – March proportionally to each month in the analyzed period. In the laboratory, the litter was divided into fractions: 1 – needles of Scots pine (Fig. 2); 2 – common oak leaves (Fig. 3); 3 – leaves of the other (associate) species (Fig. 4); 4 – twigs (Fig. 5); 5 – bark (Fig. 6); 6 – cones of Scots pine; 7 – acorns of common oak; 8 – seeds of other species; 9 – acorn cups, winged seeds; 10 – lichens, mosses. The litter fractions were oven-dried. For each analyzed fractions according to the sections (Fig. 1 – 6), we calculated the following statistical indicators: Average, Standard deviation, Minimum, Maximum, and Median.

3. Results and discussion

The analysis of the field materials showed that an accumulated amount of litter-fall was larger in the middle-aged stands than in the mature ones in the hornbeam-oak-pine stands of the Lviv Roztoche within a year period (Table 2).

Comparable litter production (up to 7 tons per hectar) in mixed oak stands was also marked by Gursky (1952); Kovalevsky (1952); Gorshenin & Shvidenko (1977); Nakonechny (1978) and Ostapchuk (2012) in other forest areas. According to Bondar (2007), the annual mass of litter in pine-oak stands of fresh fairly fertile site type of Central Polissia of Ukraine is about 5.2 tons per hectare. In young oak stands in the Czech Republic fell around 4 tons of dry mass per hectare (Novak et al. 2014) and in young pine stands also about 4 tons per hectare (Novak et al. 2015).

The litter-fall in the stands is a continuous process, but its intensity changes depending on the months of the year. In general, according to Gorshenin & Shvidenko (1977), the autumn litter-fallofdead organic matter amounts to 68 – 72%, winter and spring: 20 – 23%, and in summer: 6 – 9%.

As it can be seen from Table 2, two peaks can be observed in the annual dynamics of litter-fall in hornbeam-oak-pine forest stands in Roztoche: the highest is in October (in section C the litter-fall was 38.1% of all the litter, in section SC: 26.1%, in CC: 36.9%) and one lower peak was observed in May(12.9%; 14.4%; 16.1% and 10.6%; 9.8%; 15.4%, respectively, of the annual litter – see Table 2, Fig. 1). Very similar finding was reported also by Monitoring of ICP Forests plots in spruce, beech, fir forest stand in central Carpatian (Pavlenda & Pajtík & Priwitzer et al. 2012).

On the whole, during the autumn months, section C had 61.3% of the annual litter, section SC: 53.6%, CC: 54.1%; during the winter and spring months in section C fell 25.7% of the litter,SC: 28.1%, CC had 33.9%; during the summer months in section C fell 13.0% of the litter, SC: 18.3%, and CC: up to 12.0%.

The least amount of litter was seen in April (in section C: 2.2%, SC: 3.9%, CC: 2.4%). Small amount of litter was observed in July (section C: 2.9%, SC: 5.5%, CC: 4.2%), in August (section CO: 5.4%,SC: 5.3%, CC: 3.0%) and in November (section C: 7.6%, SC: 7.0%, CC: 7.3% – see Fig. 1).

The analysis of the fractional composition of the litter revealed the following regularities. The largest share of litter accounts for the needles and leaves: in section C: 64.3%, SC: 54.8%, CC: 61.3% (Table 3). Next, in order of decreasing, fractions are arranged as follows: twigs (section C: 12.8%, SC: 21.3%, CC: 17.3%), cones (section C: 11.2%, SC: 14.5%, CC: 11.8%), bark (section C: 8.5%, SC: 9.2%, CC: 7.6%), acorn cups, winged seeds (section C: 1.2%, SC: 0.1%, CC: 0.4%), seeds of other species (sec-

Table 2. Monthly and annual mass of litter in the sections of the permanent study area, kg ha^{-1}.

Section	2013					2014							Total for the year
	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	
C	310.3	900.2	2210.0	440.9	187.13	187.13	187.13	187.13	126.4	612.5	277.8	167.4	5794.0
SC	319.3	1228.9	1568.7	423.1	215,45	215,45	215,45	215,45	236.4	586.1	451.9	327.8	6004.0
CC	196.5	654.0	2428.2	482.0	264.73	264.73	264.73	264.73	157.0	1015.9	320.6	275.0	6588.1

tion C: 1.7%, SC: 0.1%, CC: 1.6%), lichens and mosses (section C: 0.24%, SC: 0.03%, CC: 0.04%), acorns of common oak (section C: 0.07%, SC: 0.02%, CC: 0.02%).

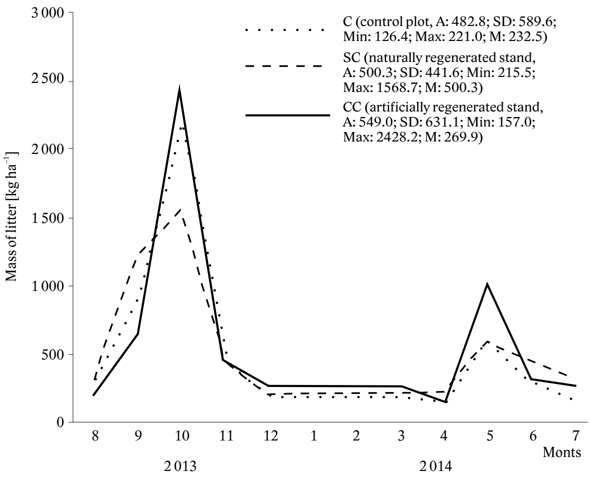

Fig. 1. Annual dynamics of the mass of litter in the sections of the permanent study area. (A: Average, SD: Standard deviation, Min: Minimum, Max: Maximum, M: median).

Similar data are shown in the works by Remezov (1953), Pogrebnyak (1968) and Gorshenin & Shvidenko (1977). In particular, Kremenetska (2000) indicates that in the green belt of Kiev in pine-oak stands with domination of oak, the fraction of needles and leaves is 54 – 79% and with domination of pine is 44 – 64%; a significant proportion falls also on the fraction of twigs (31 – 34%).

It should be noted that the studies also shows that the mass of certain fractions of litter is significantly dependent on the composition of forest stands. Thus, in section SC, most clearly dominated by pine, the proportion of needles in the litter-fall is the highest among all of the sections. Accordingly, section C is distinguished for the highest proportion of oak leaves, while section CC has the largest proportion of leaves of associate species (Table 3).

Table 3. Annual mass of the litter fractions in the sections of the permanent study area, kg ha^{-1}.

Litter fractions	Sections					
	C		SC		CC	
	[kg ha^{-1}]	[%]	[kg ha^{-1}]	[%]	[kg ha^{-1}]	[%]
Needles of Scots pine	1505.8	25,99	2089.9	36,07	1831.6	31,61
Leaves of common oak	1111.3	19,18	750.3	12,95	732.3	12,64
Leaves of other species	1105.9	19,09	447.5	7,72	1472.7	25,42
Twigs	742.9	12,82	1278.4	22,06	1136.9	19,62
Bark	492.2	8,49	551.1	9,51	502.3	8,67
Pine cones	651.4	11,24	869.5	15,01	777.0	13,41
Common oak acorns	3.9	0,07	1.0	0,02	1.6	0,03
Seeds of other species	98.8	1,71	8.0	0,14	102.1	1,76
Acorn cups, winged seeds	68.0	1,17	6.7	0,12	29.0	0,50
Lichens, mosses	13.8	0,24	1.6	0,03	2.6	0,04

The annual dynamics of individual fractions of litter in the stands is due to the specific functioning of respective bodies of the trees (Figs. 2 – 6).

Thus, the maximum fall of pine needles in the mature stands (section C) is observed in September (35.1%), while in the middle-aged stands (sections SC and CC) – in September and October (29.1% and 36.0%, respectively) – Fig. 2. The least amount of needles falls off in April (in section C: 1.5%, SC: 1.0%, CC: 1.1%), followed by a slight increase in May – August. The needles in the artificially regenerated stand last longer than in mature stand and naturally regenerated stand.

The annual dynamics of the mass of leaf litter of common oak and the mass of leaf litter of associate species are almost identical (Fig. 3 and 4). The greatest amount of common oak leaves in all sections falls off in October (in section C: 85.4% of all oak leaf litter, SC: 81.8%, CC: 83.1%) and minimum – in April (section C: 0.1%, SC: 0.2%, CC: 0.05%.

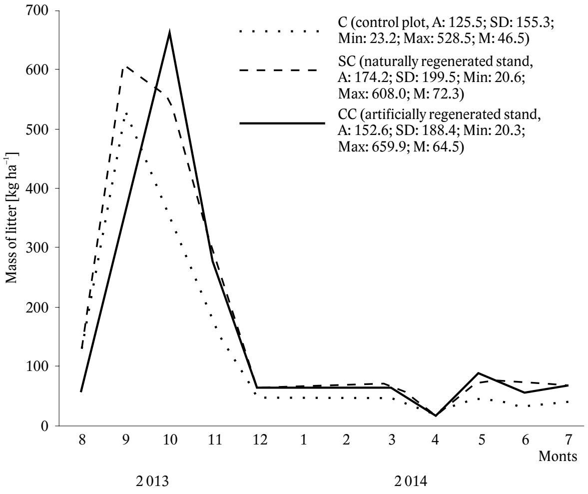

Fig. 2. Annual dynamics of the mass of needle litter in the sections of the permanent study area (A: Average, SD: Standard deviation, Min: Minimum, Max: Maximum, M: median).

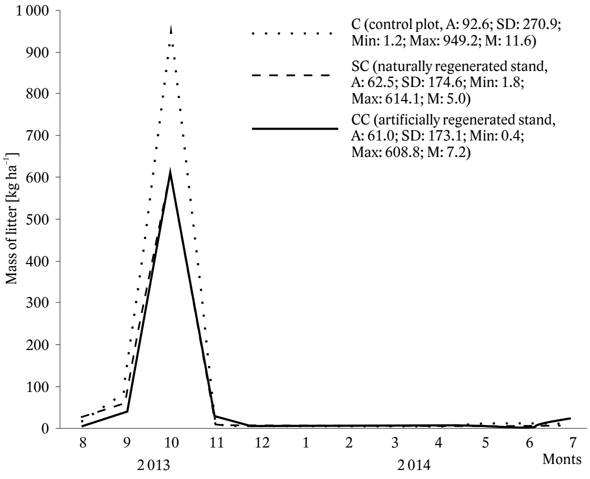

Fig. 3. Annual dynamics of the mass of common oak litter in the sections of the permanent study area (A: Average, SD: Standard deviation, Min: Minimum, Max: Maximum, M: median).

In the annual dynamics of the mass of leaf litter of associate species, in addition to the maximumin October (in section C: 67.2% of the annual litter, SC: 78.4%, CC: 71.8%), there was a slight increase in May (in section C: 11.2%, SC: 5.5%, CC: 9.4%). The second maximum is associated with the damage of young leaves, in particular of hornbeam, by insect pests.

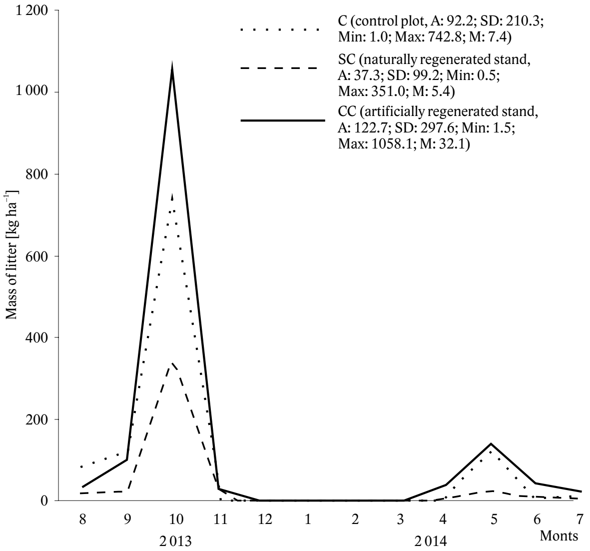

Fig. 4. Annual dynamics of the mass of associated woody species leaf litter in the sections of the permanent study area area (A: Average, SD: Standard deviation, Min: Minimum, Max: Maximum, M: median).

Annual dynamics of twig fall is quite different from the dynamics of the falling of needles and leaves. In the annual dynamics of the mass of the twig litter, the same maximum for all sections was only observed in winter (December – March: in section C: 34.8% of the annual litter, SC: 21.7%, CC: 42.4%). In addition, one more maximum was observed in sections C and CC in May, and in section SC in September (Fig. 5). These peaks could be due to local wind action.

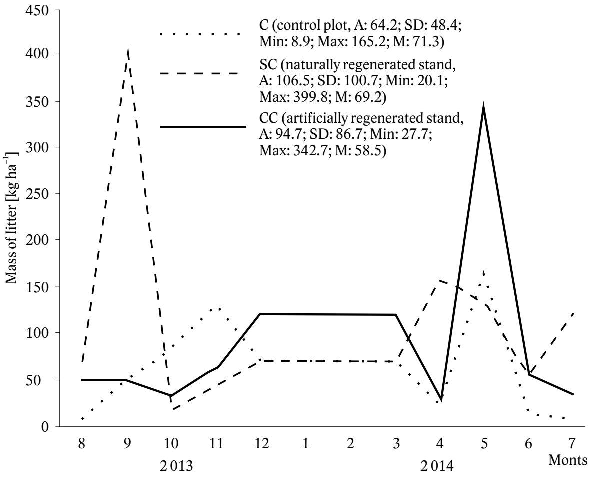

Fig. 5. Annual dynamics of the mass of twig litter in the sections of the permanent study area (A: Average, SD: Standard deviation, Min: Minimum, Max: Maximum, M: median).

In the annual dynamics of the mass of bark litter in all of the sections, there was observed one significant maximum in winter months (section C: 33.3% of the annual litter, SC: 34.3%, CC: 31.4 %) and two small peaks: in September (section C: 12.4%, SC: 11.4%, CC: 10.9%)and in May (section C: 11.4%, SC: 11.1%, CC: 15.2 %); in October, April and June, minimums were observed (Fig. 6).

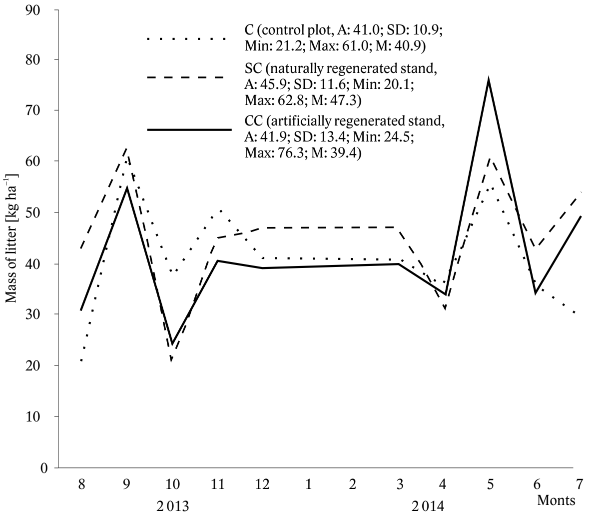

Fig. 6. Annual dynamics of the mass of bark litter in the sections of the permanent study area (A: Average, SD: Standard deviation, Min: Minimum, Max: Maximum, M: median).

The maximum of cone falling in all of the sections was observed in May. In sections SC, where the proportion of pine in the growing stock is the largest, the most significant cone falling occurred in June.

The fall of acorns of common oak was recorded only in August and September (there was hardly any crop). The bulk of seeds of other species was falling from September to April of the following year.

The litter-fall of lichens and mosses in all of the sections reached its maximum in December – March. Acorn cups were falling mainly in October – March.

Based on cumulative value of litter-fall in each section (Table 3) and statistical indicators (Figs. 2 – 6) we can confirm the difference between mature and middle age stands and as well as between artificially and naturally regenerated stands. Total mass of litter-fall is the highest in artificially regenerated stand (6588 kg ha^{-1}), then in naturally regenerated stand (6004 kg ha^{-1}) and the lowest mass of litter-fall is in the mature stand (5794 kg ha^{-1}). Similar situation is in case of needles (Fig. 2) and twigs (Fig. 5). On the contrary, at common oak leaves (Fig. 3) the highest mass of litter-fall is by mature stand. The highest differences between artificially and naturally regenerated stands are in case of total mass of litter-fall (Fig. 1) and in mass of associated woody species leaves (Fig. 4). Mass of litter-fall is higher in artificially regenerated stand. Slight differences with a higher proportion of litter-fall in naturally regenerated stand is in needle´s fractions, common oak leaves, twigs and barks. Mass of litter-fall varies considerably during the year as is confirmed by high standard deviation by each fraction and section.

The dynamic of litter-fall plays a significant role in carbon and nutrient cycle. The total annual litter-fall was according to forest type in the range of 5794 – 6588 kg ha^{-1} y^{-1}. This finding is in agreement with Pavlenda & Pajtík & Priwitzer et al. (2012) finding. Increased litter-fall(up to 7000 kg ha^{-1} y^{-1}) were reported by Gursky (1952), Kovalevsky (1952), Gorshenin, Shvidenko, (1977), Nakonechny (1978) and Ostapchuk (2012) in other forest areas. According to Bondar (2007), the annual mass of litter in pine-oak stands of fresh fairly fertile site type of Central Polissia of Ukraine is about 5200 kg ha^{-1} y^{-1}, whereas for pine in Finland it ranged from 1325 to 3402 kg ha^{-1} y^{-1}, what is caused by colder climate (Ukonmaanaho et al. 2008). There are even higher annual above ground litter production up to 11000 kg ha^{-1} y^{-1} in temperate deciduous forest (Gobat et al. 2004). This higher production of litter is caused by higher precipitation and warmer climate.

4. Conclusion

The formation of litter in the hornbeam-oak-pine stands in the Lviv Roztoche region occurs throughout the year.

In the annual dynamics of litter-fall mass in the hornbeam-oak-pine stands, two peaks can be observed: the highest one in October (mainly due to the falling of leaves and pine needles cast) and in May (mainly due to the falling of cones, twigs, pine needles, damaged young leaves of associate species). There were observed third peak during the winter months in the case of twig´s and bark´s fractions. This results correspond with findings in other part of temperate forest zones.

Based on the our results we can confirm hypotheses that in in the hornbeam-oak-pine stands of the Lviv Roztoche region are differences by litter-fall according to age of the stand and form of forest stand regeneration. In the middle-aged hornbeam-oak-pine stands, despite the lower growing stock, the annual mass of litter is larger than in mature stands. The annual litter mass in the artificial middle-aged hornbeam-oak-pine forest stands is greater than in the naturally regenerated stand. This results are not valid for all fraction of litter-fall. There is higher mass of litter-fall in mature stand in case of common oak leaves fraction. Similar slight differences with a higher proportion of litter-fall in naturally regenerated stand is in needle´s, common oak leaves, twig´s and bark´s fraction.

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ORIGINAL PAPER

Long-term changes in atmospheric depositions in Slovakia

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Abstract
The aim of this paper was to analyse temporal changes in chemism of atmospheric deposition in Slovakia. Two kinds of deposition, bulk and throughfall were considered and analysed for the period of 1996–2010. Data acquired from permanent monitoring plots (PMP) of Level II were used for this purpose. These plots were established as a part of the ICP Forests Programme. The changes in the composition of deposition were identified for the spruce and beech plots. The results were compared among three spruce plots, two beech plots and one mixed spruce-beech-fir plot. Precipitation pH was higher on the beech than on the spruce plots and during the spotted period increased on both spruce and beech plots. Depositions of cations decreased significantly on the spruce and beech plots in bulk deposition for all elements except for calcium. The significant decline of sulphur and ammonium nitrogen was found on both spruce and beech plots, but the highest decrease of sulphur deposition was found in throughfall precipitation ($R^2 = 0.75$). The amount of nitrate nitrogen did not change during the study period.

Key words: temporal change of deposition; permanent monitoring plots; spruce; beech

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1. Introduction

In the early eighties of the last century, there has been observed the rapid deterioration of the European forest state which led in 1985 to the establishment of an International Cooperative Program for Monitoring and Evaluating the Impact of Air Pollution on Forests (ICP Forests). Plots of ICP Forests cover the whole territory of Europe. Monitoring of the forests vitality in Slovakia started in 1987 (Račko 1986, 1987) when there were established 111 permanent monitoring plots (PMP) of Level I in a grid of 16 × 16 km in accordance with manual of ICP Forests and the project "Partial Monitoring System of Forests".

The extensive large-scale monitoring of forest state on PMP of Level I has been characterised by low-intensity, so in 1994, according to Regulation No. 1091/94, the intensive monitoring was additionally implemented. It included widespread research surveys (crowns condition, atmospheric deposition, foliar analysis, soil, soil solution, air quality, meteorology, phenology, vegetation, ozone injury and litterfall). Intensive monitoring plots (Level II) in Slovakia has been on gradually based since 1995 in the most important forest communities with main forest tree species Turkey oak (*Quercus cerris* [L.] Karst), Sessile oak (*Quercus petraea* [L.]), European beech (*Fagus sylvatica* [L.]) and Norway spruce (*Picea abies* [L.]). Number of PMP of Level II has changed over the years due to objective reasons (calamities, harvesting, a cost of data collection). Only the data from spruce plots (*Picea abies* [L.] Karst.) and beech plots (*Fagus sylvatica* [L.]) on PMP of Level II, which were established in the 90s, were evaluated in our study. Temporal trends in the chemical composition of depositions in the period of 1996–2010 were investigated.

2. Material and methods

2.1. Study areas

PMP Level II are unevenly distributed across the territory of Slovakia to cover main tree species and the most important site condition (geology, soil, and climate). According to the methodology of ICP Forests, they were established outside the sites with intense immission load (Pavlenda et al. 2011, 2012). Basic information about the PMPs selected for the study is presented in Table 1. (Pavlenda et al. 2012).

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Table 1. Description of permanent monitoring plots of Level II in Slovakia.

	Plot	Year establishment	Altitude [m a. s.l.]	Aspect	Type of soil	Tree species	Age [year]	Tree species [%]	Avg. prec [mm]	Avg. temp. [°C]
PMP 203	Lomnistá dolina	1995	1250	SE	Skeletic Umbrisol	Spruce, Beech Maple	72	94%, 4%, 2%	1438	3.6
PMP 204	Poľana – Hukavský Grúň	1991	850	NE	Andic Cambisol	Beech, Spruce, Fir, Ash, Maple	90–120	45%, 42%, 6%, 5%, 2%	886	5.4
PMP 206	Turová	1997	575	E	Eutric Cambisol	Beech, Oak	70	99%, 1%	853	6.9
PMP 207	T. Lomnica	1998	1150	SE	Dystric Hyperskeletic Leptosol	Spruce, Larch, Pine, Fir,	60–140	50%, 45%, 3%, 2%	1207	3.8
PMP 208	Svetlice	1999	570	W	Haplic Cambisol	Beech, Larch, Oak, Pine	53	78%, 16%, 4%, 2%	994	6.3
PMP 209	Grónik	1998	875	W	Albic Podzol	Spruce	94	1	1129	4.9

2.2. Data collection and data analyses

The data from the deposition of PMP of Level II in program ICP Forests were collected and processed according to the Manual ICP Forests "Part XIV. Sampling and Analysis of Deposition, Manuals on Methods and Criteria for Harmonised Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests", issued by the UN/ECE ICP Forests Programme Co-ordinating Centre in Hamburg (Clarke et al. 2010). Samples were taken in regular two-week intervals throughout the year (Pavlenda et al. 2011, 2012). Samplers for the collection of rainfall were located in respective forests under the canopy (throughfall – THR) and on the stands nearby the throughfall collectors without forest trees (bulk). The average sample of each collection has been formed by proportional mixing of samples from 3 collectors from the open area and 10 collectors from the throughfall stand, in order to capture the variability of the environment. The chemical analyzes were carried out in Central CHemical Laboratory of National Forest Centre according to appropriate methods ISO and STN for water quality: pH in water (STN EN ISO 10523), ammonium nitrogen by indophenol method in water (STN ISO 7150-1), sulphur and nitrate anions by liquid chromatography (STN EN ISO 10304-2), inorganic elements by ICP-AES (STN EN ISO 22036). The parameters were determined on the calibrated instrument pH on the pH-meter inoLab WTW 2, ammonium on PHARO Spectrometer 300, SO_4^{2-} and NO_3^- by Liquid chromatographic on instrument DIONEX IC CS-1000 and the elements Na, Ca, Mg, K by the atomic emission spectrometry AES-ICP- LECO. The results of specified parameters were in mg l^{-1}. This data based on total rainfall for the measurement intervals (14 days) in the observed area were converted into the deposition in kg ha^{-1} according to equation [1].

$$D_x = (C_x .\, M) / 100 \qquad [1]$$

D_x – deposition for following period, x – parameter in kg ha^{-1}, C_x – concentration of the element in mg l^{-1}, M – rainfall in mm.

Depositions in the measurement intervals (14 days) were evaluated in the program "Statistica" ANOVA, linear regression, where pH development in throughfall and bulk deposition (below the canopy and stands in an open area) were quantified. The data were processed separately for spruce, beech, and mixed stands. The differences between woody plants were evaluated by ANOVA and the trends by linear regression using the least square method.

3. Results

During the reporting period, the increase of pH has been seen in both the bulk and the throughfall deposition (Fig. 1 – 2). This fact is confirmed by the highest pH in 2010 on both beech stands (bulk and throughfall) and by the lowest pH in the throughfall depositions on the spruce stands in 1996. While the pH value is almost identical in both types of precipitations on beech areas, the pH on the spruce plots in the throughfall and bulk precipitation is different. It was recorded a higher pH up to 0.5 in the bulk precipitation than in throughfall on these stands.

The development of annual variability showed some differences between plots with different species composition and between two types of precipitation. At the beginning of the monitoring of deposition, the intra-annual variability of the tested parameters was higher, which was caused by methodology, as well as the number of evaluated data. In the first few years, the number of samples throughout year was considerably lower than 24. Data from beech plots had the comparable annual variability of the bulk and the throughfall deposition. The lowest annual variability was recorded in throughfall deposition on the spruce stands.

Table 2 shows the significance of the temporal trends in sulphur, nitrogen compounds and base cations in bulk and throughfall deposition. Statistically significant (95% confidence) trends are highlighted in bold. Statistically significant decrease ($P \leq 0.05$) was observed for both forest types in the most evaluated parameters.

The trends of elements contents are reflected the changes of precipitation composition. The different trends between precipitations are caused by enriching the throughfall samples. However the throughfall deposition includes also the other elements which are coming from assimilation organs or from dry deposition on the foliage.

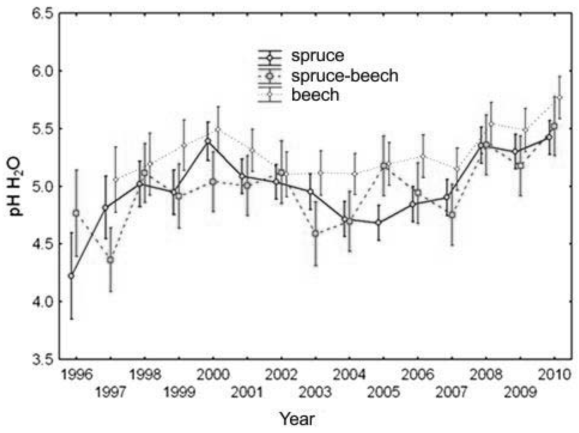

Fig. 1. Average value of pH in bulk deposition of PMP Level II.

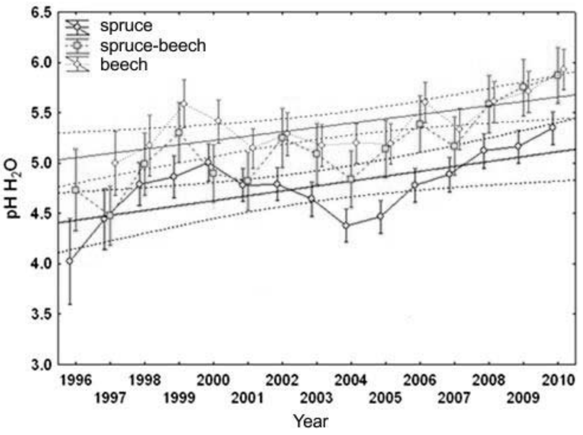

Fig. 2. Average value of pH in throughfall deposition of PMP Level II.

Table 2. Trends of annual deposition of basic cations, sulphur and nitrogen in the period 1996–2010 evaluated by linear regression.

Elements		Spruce PMP				Beech PMP			
		b_0	b_1	R^2	P-value	b_0	b_1	R^2	P-value
Ca	Bulk	269	−0.13	0.19	0.11	235	−0.11	0.20	0.09
	THR	500	−0.25	**0.27**	**0.05**	95	−0.04	0.02	0.63
Mg	Bulk	129	−0.06	**0.37**	**0.02**	79	−0.04	**0.32**	**0.03**
	THR	113	−0.06	0.21	0.08	32	−0.02	0.06	0.34
K	Bulk	846	−0.42	**0.53**	**0.00**	646	−0.32	**0.43**	**0.01**
	THR	-354	0.18	0.09	0.29	358	−0.17	0.07	0.30
Na	Bulk	269	−0.13	**0.64**	0.00	219	−0.11	**0.63**	**0.00**
	THR	187	−0.09	**0.35**	0.02	98	−0.05	**0.23**	**0.00**
S-SO4 2	Bulk	830	−0.41	**0.63**	0.00	781	−0.39	**0.57**	**0.00**
	THR	1173	−0.58	**0.75**	0.00	898	−0.44	**0.70**	**0.00**
N-NO3 -	Bulk	135	−0.07	0.16	0.14	111	−0.05	0.23	6.00
	THR	128	−0.06	0.18	0.10	72	−0.03	0.05	0.37
N-NH4 +	Bulk	606	−0.30	**0.61**	**0.00**	655	−0.32	**0.50**	**0.00**
	THR	756	−0.37	**0.42**	**0.00**	667	−0.33	**0.58**	**0.00**

Note: Bulk – open area, THR – throughfall. Statistically significant results P ≤ 0.05 are highlighted. PMP – permanent monitoring plots.

4. Discussion

4.1. The pH development in depositions

The precipitation is the main factor affecting the quality of the environment (Thalman et al. 2002). Their composition is a result of many processes and chemical reactions associated with natural phenomena and emission of pollutants (Walna & Kurzyca 2006). If there are sufficient amounts of cations in the air, sulphide and nitrate anions are neutralized by the formation of salt. However, in the case of the excess of anion the strong acids (sulphuric and nitric) are formed which, as precipitation fall down, may cause acidification. The precipitation water has the natural acidity of pH = 5.65, whereby as the critical value for vegetation is considered pH below 3.5 (Kunca 2007). The acidity of rain is influenced by local sources of pollution from nearby chemical factories, as well as cross-border transmission.

The pH 5.65, which is considered as the natural value of precipitation, was reached only in the samples under the canopy of beech and in the mixed species stands since 2009. Most of the annual average pH values were below the value of natural acidity. Thus, these precipitations could be considered as acidic. At the open area, which reflected the characteristics of the atmosphere, including secondary pollution, a rain pH did not reach this value on any of the monitored plots. On the contrary, these values were achieved in the throughfall deposition, but this deposition was influenced by capturing of atmospheric pollution, as well as the leaching and washing of different components from the surface of assimilation organs (Pavlenda et al. 2011). Parker (1983) suggested that throughfall precipitation in coniferous forests usually have a lower pH than deposition in open area, which is mainly due to the acidic organic acids washout from the needles. This was also confirmed by our results.

H^+ depositions, which represented acidity of rainfall, are higher in the mountains and increases with the amount of rainfall (Walna & Kurzyca 2007). Our results also support this finding. H^+ deposition on the spruce plots, which were located at higher altitude (820 – 1150), with average precipitation of 1254 mm, was higher than the H^+ deposition on beech plots (altitude 570 meters) with the average rainfall of 909 mm.

The increase of pH value for both types of precipitation and at all stands was evident during the reporting period.

4.2. The development of basic cations and sulfur and nitrogen compounds

The contents of alkaline cations in deposition are influenced by natural sources e.g. wind erosion of dry soil, volcanic eruptions and biological mobilization (pollen) and in the coastal areas by sea sprays (Gorham 1994). They are affected also by the anthropogenic sources from the agricultural soil tillage (plowing, liming, planting and harvesting), burning of biomass, traffic on unpaved roads, from construction and demolition of buildings and roads, but also from the burning of oil and coal with the formation of fly ash (Draaijers et al. 1997). The alkaline cations play an important role in the chemical process involving acidification (Hedin et al. 1994). Their neutralizing capacity is significant, whereby in central and north-western Europe the deposition of alkaline cations usually neutralized less than 25% of potential acid deposition (De Vries 1994). The basic cations Mg^{2+}, Ca^{2+} and K^+ are important nourishment for forest ecosystems (Gorham 1994). The deposition of active basic cations can improve the nutritional status of the ecosystem (De Vries 1994). The influence of basic cations on forest ecosystem is positive, but in recent decades their amounts are reduced (Ferm & Hultberg 1999) as a result of the reduction of emissions from fuel combustion and industrial processes. Although our results showed no statistically significant changes in the deposition of calcium, except for the spruce throughfall, the changes of the other basic cations were proved significant. The sodium element had the largest decrease for the both forest types and depositions. The statistically significant decrease of the magnesium and potassium was detected only in bulk precipitation (Table 2).

According to Walna & Kurzyca (2007), rigid structure representation cations may indicate a stabilization of emission sources. Thöni (2008) did not find a reduction in the deposition of the elements Na, Mg, Ca and K but in Slovakia, the statistically significant changes were determined. These depositions in the past in Slovakia were affected by the situation in neighboring countries, where high values in the "Black Triangle" were recorded as a result of intense industrial activity (Draaijers et al. 1997). So the statistically significant decrease may be due to the reduction of industrial activity.

As in the most European countries, also in Slovakia, the high sulphur depositions gradually decreased. Atmospheric sulphur compounds usually include sulphur dioxide, hydrogen sulphide, mercaptans and sulphates which come from human activity, volcanic emissions and from waterlogged soils. Sulphur dioxide originates mainly from industry and thermal power plants as the result of the combustion of fossil fuels. Nitrogen oxides (NOx and NO_2) are also the result of the combustion of coal, oil, gasoline (Asman et al. 1998). In the past, high levels of these compounds were detected in the so-called "Black Triangle", the area between Germany, the Czech Republic, and Poland, but also in Ukraine (Van Leeuwen et al. 1995). Statistically significant decrease in the sulphur content was determined for both types of precipitation and for the both beech and spruce forest types. The most significant decrease was found for sulphur deposition in throughfall on the spruce stands ($R^2 = 0.75$). This is probably the result of the abandonment as well as the modernization of industrial enterprises emitting significant amounts of sulphur oxides in the countries of Eastern Europe. It was also the reduced sulphfur content in fuels and coal fired power stations to be fitted with filters depicting sulphur (Thöni et al. 2008). However, the downward trend in sulphur deposition between 1998–2010 was found in the most areas of Europe confirmed as statistically significant mainly thanks to the applied measures (Lorenz & Becher 2012). The beneficial effect of reducing sulphur depositions on the growth of European silver fir (Elling et al. 2009; Bošeľa et al. 2014; Büntgen et al. 2014) as well as Norway spruce (Kroupová 2002; Kolář et al. 2015).

On the contrary the development of nitrogen components was not so clear. Although statistically significant decrease of ammonia nitrogen was identified on the both forest types, the changes of nitrate nitrogen were not detected. The total nitrogen in the atmosphere is mainly in the form of nitrate and ammonia nitrogen. While the ammonium nitrogen is formed in particular as the result of agriculture, nitrate nitrogen comes from NO_x emissions from vehicle, industrial and heating plants (Van Leeuwen et al. 1995). Increasing the number of animals (Behera et al. 2013), as well as the intensification of plant cultivation brings further increase of ammonium nitrogen emissions. Cape et al. (2004) suggested that the concentration of NO_x and NH_4^+ found near the road is proportional to the density of traffic. Ammonia nitrogen is the primary alkaline gas in the atmosphere, and it is therefore important for determining the total acidity of precipitation (Shukla & Sharma 2010; Behera et al. 2013). Statistically significant decrease in ammonia nitrogen on the monitored plots might have been caused by decline in the agricultural production in Slovakia since the 90s.

No trends in nitrogen deposition were found also in the Czech Republic (Hunová et al. 2014) and also the evaluation of data from all European ICP Forests plots Level II confirmed no significant changes in the development of nitrate deposition. The effect of the increasing traffic and also long-range transfer may cause permanently high deposition of this parameter.

5. Conclusion

Although there was a significant reduction of pollutants since the early nineties of the 20th century, the forest ecosystems continue to be influenced by anthropogenic activities. Depositions of sulphur on the territory of Europe are lower but they are still high in the area of the continental shelf of the North Sea to Central and Middle East Europe (Belgium, Netherlands, Denmark, Germany, Czech Republic, Poland and Slovakia). Depositions of sulphur which are considered as a part of the acid deposition still affects the forest and aquatic ecosystems and threat to the environment everywhere. pH precipitation has improved, namely to increase its value, but this is still considered acidic.

The forests in Slovakia are situated in the region that is constantly threatened by a high environmental impact from industry and transport. The higher sulphur depositions were recorded in the industrial areas and the increased nitrogen depositions are mainly in the areas with a dense transport network and intensive agriculture.

Since the 90s there has been a significant reduction in industrial emissions, particularly sulphur dioxide, as a result of the cessation of production with an environmental burden and the modernization of production processes, which was also confirmed by our data. However, currently, there are new factors affecting the forest ecosystems, in particular, climate change, the impact of various abiotic, biotic and anthropogenic factors, and the current atmospheric pollution caused by all types of transport, industry and agriculture producing emissions of nitrogen oxides and associated with elevated concentrations of ground-level ozone.

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ORIGINAL PAPER

The effects of Alginite fertilization on selected tree species seedlings performance on afforested agricultural lands

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Abstract

Afforestation of marginal agricultural lands is an important issue in the land use changes running in Europe at present. The aim of the presented study is the documentation of effects of site improving material Alginite three years after afforestation of agricultural land in the locality with unfavourable hydrophysical regime. The impact was evaluated on growth parameters (height increment, mortality and foliar nutrient content) of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), Scots pine (*Pinus sylvestris* L.) and a mixture of English oak (*Quercus robur* L.), red oak (*Quercus rubra* L.) and Norway maple (*Acer platanoides* L.) seedlings on former agricultural land in central Bohemia, Czech Republic. The research plot consists of 36 square sub-plots, each sub-plot is 400 m^2 in size. Each sub-plot consists of 400 individuals, except Douglas-fir with 200 individuals. The following doses of Alginite were applied: control (variant A without Alginite), 0.5 kg of Alginite (B) and 1.5 kg of Alginite (C) on both conifers and broadleaves. The results showed that Alginite application had greater positive effect on height growth of seedlings than mortality, especially variant C. In most of the cases height increments were significantly positively affected ($p < 0.05$) by both variants of Alginite application only in the third year after planting. Alginite applications were also connected with differences in the foliar nutrient content, especially with higher magnesium and phosphorus values. The highest differences among Alginite variants were observed for Norway maple and English oak, while the lowest for red oak and Scots pine within all monitored parameters.

Key words: afforestation; soil improvement; fertiliser; plantation growth; mortality

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1. Introduction

Changes of the land use are continuously running in the Europe for centuries (Skaloš et al. 2012). From a historical perspective, the population of Central Europe has been engaged in reforestation of agricultural land for at least two centuries (Špulák & Kacálek 2011). This trend reversed tendencies common in the previous period, causing deforestation for the purpose of obtaining fuel, construction materials, but also for gaining the land suitable for agricultural use (Kaplan et al. 2009; Williams 2000), throughout the whole European continent (Rowney 2015). Although some evidence on the reforestation of non-forest lands are dated in the 16th century (Kacálek & Bartoš 2002; Špulák 2006), the largest expansion of afforestation of agricultural land was not until after the Second World War (Kacálek & Bartoš 2002), especially in the border regions after the confiscation of grounds originally belonging to the German population (Špulák & Kacálek 2011; Vacek et al. 2016). In the sixties of the 20th century afforestation of non-forest land reached up to 6,000 hectares per year, later on annually around 1,000 hectares (Černý et al. 1995). Another phase of afforestation and forest expansion comes in the 1990s and is still under way (Špulák & Kacálek 2011). Nowadays (from 2010 to 2014) forest area in the Czech Republic increased by 2,250 ha $year^{-1}$ (MZe 2015).

Large areas of agricultural land suitable for afforestation are not found only in Eastern Europe (Henebry 2009) and in some parts of Western Europe (Anthelem et al. 2001), but currently also in the Czech Republic. More exact estimates are depending on the used criteria, for example Podrázský & Štěpaník (2002) have reported between 50,000 to 500,000 hectares. In the area of the European Union there is cca 12 to 16 million ha of land to be excluded from agricultural production and thus suitable for afforestation from ecological as well as economic reasons (Campbell et al. 2008). It is therefore important to pay a great attention to this issue.

The most frequently used tree species in the newly established forest stands was Norway spruce (*Picea abies* [L.] Karst.), but also other specimen such as European larch (*Larix decidua* Mill.), black alder (*Alnus glutinosa* L. Gaertn.), European ash (*Fraxinus excelsior* L.) and Scots pine (*Pinus sylvestris* L.) (Hatlapatková et al. 2006; Šindelář & Frýdl 2006; Vacek et al. 2015, 2016). Intro-

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**Corresponding author. Lukáš Linhart, e-mail: linhartl@fld.czu.cz* duced tree species such as Douglas fir (*Pseudotsuga menziesii* Mirbat.) or red oak (*Quercus rubra* L.) have been recently gaining attention (Gruber & Nick 2000; Miltner & Kupka 2016). Those are also used in afforestation of former agricultural land.

The most problematic stage in the establishment and development of forest stands, particularly in extreme climatic and habitat conditions, is undoubtedly the phase of actual planting. Survival rate and initial growth of established stands determines further development of plantations (Kupka et al. 2015). Failures in reforestation are often affected by unfavourable soil conditions. However, forest species have various mechanisms allowing successful growth under unfavorable habitat conditions (Vacek & Hejcman 2012; Vacek et al. 2012). On the other hand, there is thus many practices designed to facilitate reforestations used in forestry, categorized as chemical or biological amelioration (Podrázský 1994, 2006a, b; Podrázský et al. 2003; Kacálek et al. 2009; Balcar et al. 2011; Kuneš et al. 2011). These interventions may involve the application of lime, pulverized basic rocks (Kuneš et al. 2009) or special slowly soluble fertilizers (Kuneš et al. 2004). Furthermore, a number of deciduous trees has beneficial effect on the state of forest soils in mountain conditions (Podrázský et al. 2004).

One of the important factors ensuring successful reforestation and decent survival rate of young trees is undoubtedly soil moisture in the upper horizon of the soil profile. Moisture deficiency in the soil negatively affects root system. This problem may be partially mitigated by adding fossil materials such as Alginite (Kupka et al. 2015), which, besides, have the function of enhancing water uptake in the root area of the seedlings.

Alginite is an organic sediment representing the oil shale category, which was formed 3–4 million years ago during volcanic changes (Kulich et al. 2001; Kadar et al. 2015). This gray to dark gray rock is rich in organic matter and contains 5 to 50%, in some deposits even 90% of organic matter (Szabó 2004). Alginite was created in aquatic environment of algae and therefore performs a high content of elements such as phosphorus, potas sium, calcium and magnesium (Gömöryová et al. 2009). Vass et al. (1997, 1998) formerly described the use of Alginite in forestry. The effect on seedlings in the first year after afforestation of agricultural land was assessed by Tužinský et al. (2015) and Kupka et al. (2015).

This study is focused on the afforestation of non-forest land in areas less favourable for forest tree species and documents the effects of Alginite fertilization on plantations survival rate (mortality) and growth (height increment) of Scots pine (*Pinus sylvestris* L.), English oak (*Quercus robur* L.), red oak (*Quercus rubra* L.), Norway maple (*Acer platanoides* L.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) three years after planting on agricultural land. The aim was also to assess the effect of different Alginite doses on nutrition concentrations in the assimilation apparatus of particular tree species.

2. Material and methods

2.1. Description of the study area

The effects and use of Alginite as supporting material for forest stands establishment on non-forest land was assessed at a relatively dry area near the Hovorčovice village north of Prague (Natural Forest Area/PLO 17 Polabí) in the Czech Republic. The site is located at GPS coordinates N50°13.95' E14°25.58', and provisionally named "U Lomu". It is a former agricultural land on warm and moderately dry sites with an average annual temperature of 8–9 °C. The average annual precipitation is 500–600 mm and the expectation of dry vegetation season is 20–30%. Higher temperatures and low precipitation in vegetation season are notably limiting factors on site (Tužinský et al. 2015). The research area is exposed to the west with modal eubasic to mesobasic cambisol on slate soil-forming substrate. The soil is deep to moderately deep with medium particle size distribution and good water storage capacity.

The research plot has a total area of 14,400 m^2 and consists of 36 sub-plots designed 20 × 20 m. All sub-plots were established using dug-hole method in the spring of 2013 in the 1 m by 1 m spacing (400 pieces per plot). The whole research plot was fenced and no weed trimming was applied. Selected tree species were following: Scots pine (*Pinus sylvestris*), and a line mix of English oak (*Quercus robur*), red oak (*Quercus rubra*) and Norway maple (*Acer platanoides*). Furthermore, Douglas-fir (*Pseudotsuga menziesii*) planting stock were planted in the 1 m × 2 m spacing (200 trees per plot). Scots pine and Douglas-fir seedlings were two years old, all broadleaves were three years old while all seedlings used were bare rooted. Besides the control variant without any application of Alginite fertilizer (variant A), two variants with the application of 0.5 kg (B) and 1.5 kg of Alginite (C) per planting point were planted. Alginite used in the study had following content of macroelements: Ca 15 528 mg/kg, Mg 1 841 mg/kg, P 42,9 mg/kg, K 196 mg/kg and N total content was 0.207%. All the variations (3 tree species choices by 3 variant choices) were established in 4 replications.

2.2. Sample processing

Tree heights were measured every autumn in the years 2013, 2014 and 2015 using height measuring instruments while mortality of individuals was also registered. Due to this fact the average height increments were calculated. In 2015, foliage samples (leaves or needles) were taken choosing 50 randomly selected trees (uniform distribution of random numbers by RNG/Excel) in each sub-plot in August from deciduous and coniferous species, respectively. Three composite samples were taken in each sub-plot for each tree species and for each variant.

The analysis of assimilation apparatus was realized in the Tomáš laboratory, resident in VÚLHM Opočno according to standard methodologies (Zbíral 2001). The concentration of macroelements (N, P, K, Ca, Mg) in the dry matter of foliage was contrasted with the classification limits according to Bergmann (1993).

The analyses were processed in the Statistica 12 software (StatSoft, Tulsa). All data were at first log transformed in order to meet the assumption of normal distribution (tested by Kolmogorov-Smirnov test). The differences between height increments of tree species were tested by one-way analysis of variance (ANOVA). Significant differences were consequently tested by post-hoc comparison Tukey's HSD tests. Unconstrained principal component analysis (PCA) in the CANOCO for Windows 4.5 program (Ter Braak & Šmilauer 2002) was used to analyse relationships among number of plants, mortality, mean height, height increment, nutrient content in the assimilation apparatus, tree species and variants of Alginite application. Data were centred and standardized during the analysis. The results of the PCA analysis were visualized in the form of an ordination diagram constructed by the CanoDraw program (Ter Braak & Šmilauer 2002).

3. Results

3.1. Plantation mortality

The values of seedlings mortality for individual tree species are listed in Table 1 below. The Alginite fertilization effect was most significantly exhibited immediately after planting, therefore already in 2013. Both smaller and larger doses had mostly positive impact on plants during the whole three-year period for Scots pine. For deciduous trees and Douglas fir, the application acted negatively in the first year, positive impact was found for English oak and Maple only in the B variant of Alginite application. In 2014 the situation was different for each tree species. Clearly positive reaction was shown by Red oak for both doses of Alginite. Douglas fir and English oak had lowest mortality in control variant A and Norway maple reacted positively to variant C. In 2015 the reaction was also mostly negative as in the first year after planting.

3.2. Seedlings height increment

For pine the plants significantly reacted to applications until second year after planting in smaller dose variant, but the reaction was negative (Table 2). In 2015 the results were significantly positive for both doses of Alginite application ($p < 0.05$). The differences in Douglas fir increment reactions were statistically significant in each year of measurements. The reaction was negative in both variants of Alginite application, the highest increment was measured in control variant A.

All deciduous trees had the same trend of reaction in the first year after planting (Table 2). Statistically significant differences were registered for the C variant where the increment was lower than in the control A variant. For Red Oak and Norway maple we also recorded statistically significant negative reaction in B variant. In 2014 the situation was different. Statistically significant positive reaction was documented for Red oak and English oak trees in C variant of Alginite fertilization. Douglas fir reacted positively in both doses of Alginite. Statistically significantly lower increment was measured for Scotch pine in C variant and also for Norway maple in B variant. In general the trend of increment in 2014 was ambiguous. On the other hand, in 2015 a majority of planted trees showed the same reaction. The only exception was Douglas fir with smaller increment for B and C variant. All other tree species had statistically significantly higher increments in the C variant of Alginite fertilization, Scots pine reacted positively for both B and C variants (Table 2).

3.3. Nutrients concentration in assimilation apparatus

There were no statistically significant differences ($p > 0.05$) for any of the values. The nitrogen concentration was higher only in the English oak growing on both Alginite doses. Furthermore, only Scots pine growing on

Table 1. Evaluation of mortality in individual tree species reflecting Alginite applications.

Tree species	Variants of Alginite	Number of trees planted – spring 2013	2013	2014 [%]	2015
Pine	A	1600	26.5	8.7	0.9
Pine	B	1600	23.9	3.3	0.4
Pine	C	1200	24.5	1.8	0.8
Oak	A	562	5.5	6.4	4.8
Oak	B	578	4.0	9.9	5.0
Oak	C	722	7.9	9.8	5.4
Maple	A	478	2.9	9.8	1.9
Maple	B	522	1.9	10.0	3.3
Maple	C	680	12.2	4.6	3.8
Red oak	A	560	20.5	53.6	7.9
Red oak	B	500	24.6	39.8	11.0
Red oak	C	598	32.6	35.5	7.7
Douglas fir	A	800	3.4	1.4	0.9
Douglas fir	B	800	5.1	5.3	1.9
Douglas fir	C	800	7.6	2.9	1.9

Table 2. The development of height increments after Alginite application in single years.

Tree species	Variant	Height 2012	±SE 2012	P value 2012	Mean incr 2013	±SE 2013	P value 2013	Mean incr 2014	±SE 2014	P value 2014	Mean incr 2015	±SE 2015	P value 2015
Pine	A	25.2 a	0.156		15.9 a	0.196		24.3 a	0.248		30.5 a	0.255	
Pine	B	**24.3 b**	0.158	<0.001	15.4 a	0.186	0.152	24.6 a	0.230	0.003	**33.1 b**	0.239	<0.001
Pine	C	**26.6 c**	0.172		15.5 a	0.225		**23.0 b**	0.265		**32.3b**	0.275	
Red oak	A	**59.2 b**	1.157		35.9 a	1.060		3.5 a	1.925		6.6 a	0.953	
Red oak	B	**57.1 b**	0.998	<0.001	**18.5 b**	1.375	<0.001	5.1 a	1.325	0.002	6.4 a	0.983	0.036
Red oak	C	51.3 a	0.999		**10.8 c**	1.181		**10.7 b**	0.945		**9.7 b**	1.004	
Oak	A	27.9 a	0.304		11.5 a	0.337		**6.6 ab**	0.317		7.1 a	0.380	
Oak	B	27.1 a	0.449	<0.001	11.0 a	0.329	<0.001	5.8 a	0.320	0.039	6.1 a	0.388	<0.001
Oak	C	**34.1 b**	0.566		**9.0 b**	0.299		**7.2 b**	0.271		**9.4 b**	0.347	
Douglas fir	A	25.8 a	0.226		7.3 a	0.115		12.6 a	0.249		22.9 a	0.313	
Douglas fir	B	**27.9 b**	0.243	<0.001	**6.7 b**	0.185	<0.001	**13.6 b**	0.337	0.039	**18.4 b**	0.326	<0.001
Douglas fir	C	26.2 a	0.235		**6.1 c**	0.099		**13.1 ab**	0.258		**19.4 b**	0.356	
Maple	A	51.9 a	0.569		17.5 a	0.586		4.5 a	0.518		4.9 a	0.536	
Maple	B	52.7 a	0.466	<0.114	**12.6 b**	0.593	<0.001	**2.7 b**	0.505	<0.001	3.9 a	0.491	<0.001
Maple	C	51.3 a	0.537		**9.6 c**	0.533		5.5 a	0.389		**6.9 b**	0.476	

Note: Different letters indicate the significant differences from the control plots without Alginite application with probability $p < 0.05$; ±SE standard error of the mean increment.

C variant showed positive response. For other species Alginite did not affect plants in nitrogen concentrations.

The most interesting results were found in phosphorus concentrations. The best results were performed by English oak and Norway maple on B and C variants. In addition, the Alginite application acted positively in red oak and Douglas fir but only for variant B, i.e. with smaller amount of fertilizer. Scots pine did not react to the stimulator and phosphorus values were even in all variants.

Diverse responses to Alginite were found in terms of potassium concentration. Only Douglas fir responded positively to the lower dose of Alginite. English oak and Scots pine were the only tree species showing positive reaction to the higher dose, i.e. 1.5 kg of Alginite. For red oak in both B and C variants the concentrations were smaller than control, Norway maple potassium concentration were smaller only in B variant.

The least positive concentrations were detected for calcium. In this element only red oak responded positively on both variants. Furthermore, the positive effect of larger Alginite dose was found in Scots pine. For other planted tree species the concentration on both variants was smaller than control.

In contrast, for magnesium the situation was reverse. The concentration of this element was higher in Alginite treated variants compared to the control variant A. The most positive reaction was found in both oaks where the concentration of magnesium was greater in both B and C variants. Maple responded positively only to 0.5 kg Alginite application. For Scots pine and Douglas fir only C variant with 1.5 kg of Alginite showed positive results.

3.4. Relationships among seedling parameters, nutrient content and variants of Alginite application

Results of the PCA analysis are presented in the form of the ordination diagram in Figure 1. The first ordination axis explained 41.1%, the first two axes together 69.3% and the first four axes together explained 96.8% variability in the data. The first axis x represented seedlings content of calcium and magnesium in the assimilation apparatus. The second axis y represented seedlings content of nitrogen and potassium in the assimilation apparatus. Height increment in 2014 and 2015 was positively correlated with content of nitrogen and mortality in the first year after planting, while these parameters were negatively correlated with potassium. Alginite application had a negative effect on mortality in the first year, but after rooting of seedlings Alginite had a positive significant impact on height growth in following years. Opposite height increment in 2013 had negative relationship with mortality in following two years. Height of seedling in 2013 was positively correlated with content of calcium and magnesium, while these parameters

Table 3. Nutrient content in the assimilation apparatus of particular tree species in variants and recommended values according to Bergmann.

Tree species	Variant of Alginite	N [%]	±SE	P [%]	±SE	K [%]	±SE	Ca [%]	±SE	Mg [%]	±SE
Oak	A	1.75	0.1	0.17	0.01	0.57	0.02	2.25	0.08	0.24	0.02
Oak	B	**1.97**	0.1	**0.2**	0.01	0.57	0.02	2.22	0.08	**0.28**	0.02
Oak	C	**1.81**	0.1	**0.18**	0.01	**0.58**	0.02	2.08	0.08	**0.25**	0.02
Red oak	A	1.55	0.07	0.16	0.02	0.65	0.06	1.93	0.15	0.21	0.01
Red oak	B	1.49	0.07	**0.17**	0.02	0.58	0.06	**1.95**	0.15	**0.23**	0.01
Red oak	C	1.34	0.07	0.15	0.02	0.62	0.06	**1.97**	0.15	**0.23**	0.01
Oak Bergmann	—	2–3	—	0.15–0.3	—	1–1.5	—	0.3–1.5	—	0.15–0.3	—
Maple	A	1.59	0.09	0.29	0.05	0.67	0.04	2.3	0.15	0.26	0.03
Maple	B	1.46	0.09	**0.35**	0.05	0.67	0.04	2.28	0.15	**0.27**	0.03
Maple	C	1.55	0.09	**0.31**	0.05	0.65	0.04	2.12	0.15	0.26	0.03
Maple Bergmann	—	1.7–2.2	—	0.15–0.25	—	1–1.5	—	0.3–1.5	—	0.15–0.3	—
Pine	A	1.66	0.03	0.14	0.04	0.59	0.01	0.34	0.01	0.11	0.01
Pine	B	1.63	0.03	0.14	0.04	0.59	0.01	0.33	0.01	0.11	0.01
Pine	C	**1.69**	0.03	0.14	0.04	**0.6**	0.01	**0.35**	0.01	**0.12**	0.01
Pine Bergmann	—	1.4–1.7	—	0.14–0.3	—	0.4–0.8	—	0.25–0.6	—	0.1–0.2	—
Douglas fir	A	1.29	0.04	0.13	0.03	0.66	0.02	0.38	0.01	0.08	0.01
Douglas fir	B	1.11	0.04	**0.14**	0.03	**0.67**	0.02	0.33	0.01	0.08	0.01
Douglas fir	C	1.12	0.04	0.13	0.03	0.65	0.02	0.35	0.01	**0.09**	0.01
D. fir Bergmann	—	1.1–1.7	—	0.12–0.30	—	0.6–1.1	—	0.2–0.6	—	0.1–0.25	—

Note: The higher nutrient contents in variants with Alginite compared to control plots (without fertilizer) are highlighted. Values according to Bergmann describe the first content value as a threshold of sufficiency, the second value as a threshold of excess; ±SE standard error of the mean.

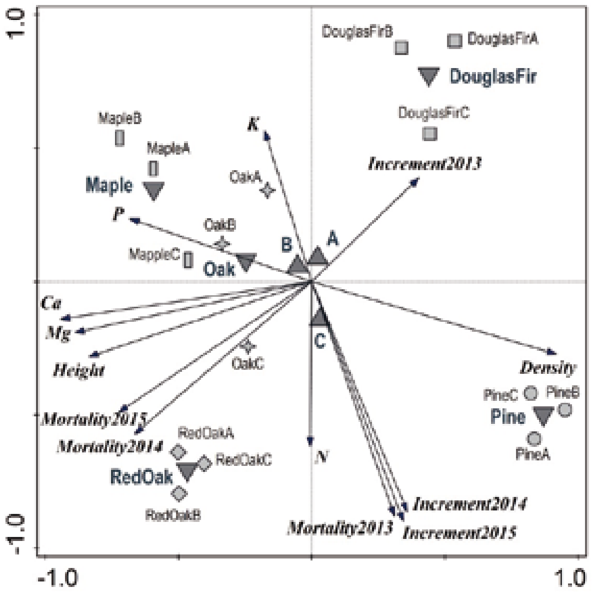

Fig. 1. Ordination diagram showing results of PCA analysis of relationships number of seedlings at planting (*Density*), heights at planting (*Height*), tree mortality (*Mortality*) and height increments (*Increment*) in 2013, 2014 and 2015 and nutrient content in the assimilation apparatus (*N*, *K*, *Ca*, *P*, *Mg*), tree species (*Maple*, *Douglas Fir*, *Oak*, *Red Oak*, *Pine*) and variants of Alginite application (*A*, *B*, *C*); Small codes: ●,♦, ■, ✦, ▌ indicate tree species with variants of Alginite application; Large codes: ▲,▼ indicate tree species or variants of Alginite application.

were negatively correlated with number of seedlings. The contribution of mean increment in 2013 was relatively small. The Alginite application (variants A, B, C) showed low significance to mutual relationships among seedling mortality, mean increment and nutrient content in the assimilation apparatus compared to great differences among tree species. Differences of variants of Alginite application were remarkable especially for English oak and maple as marks of each record are relatively distant from one another whereas marks for Red oak and pine are fairly close together in the diagram. Comparing variants of tree species with different Alginite application there were differences among one another, where variants with broadleaves with higher mortality and content of mostly nutrients (Ca, Mg and P) occupied the left part of the diagram, while higher height increment of seedlings one year after planting and density were typical for coniferous (right part). Overall Alginite application had positive higher effect on height growth of seedlings than mortality. Differences between variant A (without Alginite) and B (0.5 kg Alginite) were smaller compared to variant C 1.5 kg Alginite), while the C variant had the greatest effect on height growth.

4. Discussion

Reduction of trees mortality in the first year immediately after planting is one of the reasons why fertilizers are used in forestry. There are already publications focusing on plant mortality causes on forest land (Barbeito et al. 2012) and therefore raises the question of optimal ways of supporting newly planted trees. Those are for instance nutrient loaded seedlings (Scott et al. 2016), water retaining polymers in tree nursery substrates (Navroski et al. 2016) or different fertilization approaches (Huotari et al. 2008; Pärn et al. 2009; Ferreiro-Dominguez et al. 2011; Yang et al. 2016). Support for planting of forest trees on agricultural land with unbalanced conditions is often necessary (Kupka et al. 2015) and it becomes increasingly important with regard to further expected afforestation of agricultural land (Hatlapatková & Podrázský 2011). Positive impact of Alginite on the seedling survival in the first year after plantation on this site were confirmed and published (Tužinský et al. 2015) and a similar attempt in "U Hnojiště", approximately 3 km away from the locality "U Lomu" (Kupka et al. 2015) also showed positive effects. Definitely positive results in mortality through the three years were only recorded on pine plots, especially in 2014. In this year we can cogitate a positive impact of Alginite water absorbing capability, while the spring (Apri l– June) months were dry (Czech Hydrometeorological Institute Prague Kbely) which might have resulted in high mortality in A variant without Alginite application. Other tree species showed rather indifferent response to fertilization via mortality.

The height increment of seedlings, i.e. their growth, is another factor reflecting the response to the fertilizer application. In the past, the effect of fertilizers on different kinds of trees using wood ash or ash obtained from peat was tested (Huotari et al. 2008; Kikamägi et al. 2014; Pärn et al. 2009). These works investigate development of the seedlings height during the first 3 years after planting; a positive influence of fertilizing by the ashes, however, was studied only on forest land. Sewage sludge is another fertilizer. These studies evaluated sparsely wooded sites on agricultural land, where forestry and pasture were combined. Evaluating the impact of sewage sludge in combination with adding nitrogen confirmed the increased height increment in red oak seedlings during the first four years after planting (Ferreiro-Dominguez et al. 2011). Positive effect of nitrogen on height increment of seedlings in 2014 and 2015 follows also from results of PCA analysis. Furthermore Alginite application had a negative effect on mortality in the first year after planting, but in following years Alginite had a positive significant impact on height growth, probably due to rooting of seedlings through used fertiliser. Another paper, which compared the use of sewage sludge in comparison with the control and the area fertilized with mineral fertilizers (by 500 kg to 8% N – 24% P_2O_5 – 16% K_2O per hectare) also confirmed the positive effect of sewage sludge on the height of seedlings (Rigueira-Rodríguez et al. 2010). On the other hand, the use of sewage sludge in combination with lime has not been confirmed as a positively functioning agent in the height of the seedlings (Mosquera-Losada et al. 2012). Alginite influence with positive results in height increment has only been evaluated one year after planting (Kupka et al. 2015; Tužinský et al. 2015). The three-year planting evaluation showed a positive trend in height increment overall. In the first year the results were somewhat negative, but this might be caused by slow growth of the root system. The second year after planting was heterogeneous throughout tree species while mostly broadleaves reacted positively. The explanation could be different root system growth rapidity. In the last year of measurements the effect of Alginite application was positive for almost all tree species. Due to these results we can suspect positive Alginite influence on agricultural land plantations. Only Douglas fir reaction was negative. Positive results are comparable with the results of sewage sludge (Ferreiro-Dominguez et al. 2011; Rigueira-Rodriguez et al. 2010).

One of the main factors that influence the growth of forest trees is the nutrient content in assimilation organs (Šrámek et al. 2009; Truparová & Kulhavý 2011; Vacek et al. 2009). None of the variants with different Alginite applications showed statistical significance in the nutrient content in dry matter of the assimilation apparatus. Only slightly higher values were found for each of the measured nutrients, with the highest for P and Mg, in at least one of the species. Those were always recorded in one of the variants with Alginite application. This indicates a positive effect of Alginite fertilization on forest plants for both P and Mg have a major role in growth and formation of seedlings (Materna 1963; Vacek et al. 2006). Those contents might also reach higher values after a longer period of growth. Furthermore, a trend of higher concentrations of elements in deciduous trees has been observed (Hagen-Thorn et al. 2004; Šrámek et al. 2009), most strikingly in magnesium. The actual supply of elements in the dry matter of the assimilation apparatus on afforested agricultural land according to Bergmann (1993) showed values approaching, and often exceeding the threshold of excess. In all deciduous trees, lack of nitrogen and potassium was found, which can be caused by the nature of the soil or the soil type and local conditions overall.

5. Conclusions

The results showed ambiguous trend of Alginite utilization on mortality of seedlings, positive effect was discovered only for Scots pine in the whole measured period, other planted trees reacted mostly negative for both doses of Alginite. The positive reaction was recorded in the height increment of most tree species in the third year after planting. One of the reasons could be a slow roots growth through used fertiliser. Agricultural land afforestation is of growing importance and we need to pay more attention to improving the soil environment and support the growth of stands. Alginite application is a way to effectively support plantations of specific tree species, and therefore, more research should be devoted to this topic in the coming years.

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