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ORIGINAL PAPER

Evaluation of winter food quality and its variability for red deer in forest environment: overwintering enclosures vs. free-ranging areas

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Abstract
Populations of European ungulates have grown substantially over recent decades, resulting in considerable environmental and socio-economic impacts. Availability and quality of natural and supplemental food sources are among the main factors driving their population dynamics. Detailed knowledge of food quality of management-targeted species is therefore of primary importance for their successful management. The main aim of this study was to evaluate winter food quality and its variability for an important ungulate species in the Czech Republic - i.e. red deer, using faecal indices (faecal nitrogen, faecal acid detergent fibre, faecal neutral detergent fibre) and near infrared reflectance spectroscopy. We compared food quality for red deer and its possible differences between overwintering enclosures (i.e. fenced areas where red deer spend harsh winter conditions) and neighbouring unfenced free-ranging areas within two study areas. The results obtained showed that winter food quality and its variability for red deer are of different quality and variability in the overwintering enclosure and neighbouring free-ranging area. The observed differences in concentrations and amounts of variation of faecal indices are most probably related to animal densities at individual study areas. Wildlife managers should therefore keep animals in overwintering enclosures at moderate densities and to provide high quality forage to all individuals in order to balance nutrition of both the individuals inside and outside the enclosures. Nevertheless, further studies are needed in order to provide deeper knowledge on red deer food quality and its variability in space and time.

Key words: deer diet; nutrition; near infrared reflectance spectroscopy; nitrogen; fibre

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1. Introduction

Numbers of free-ranging ungulates have been recently increasing throughout the whole Europe (Apollonio et al. 2010). These overabundant ungulate populations may have significant impacts on the structure and functioning of their environment, resulting in considerable economic losses in agriculture and forestry (Weisberg & Bugmann 2003; Côté 2004; Massei & Genov 2004). Food quality and availability are among the main factors determining condition, survival and reproductive success of free-ranging ungulates, as well as one of the main driving forces influencing their distribution and habitat selection (Pettorelli et al. 2003; Parker et al. 2009; Van Beest et al. 2010). Accordingly, detailed information on food quality for large ungulates is essential for their efficient management.

Red deer (*Cervus elaphus*) feed opportunistically on mixed diet of grass and concentrate food items such as browse, forbs and fruits (e.g. Gebert & Verheyden-Tixier 2001; Krojerová-Prokešová et al. 2010). Food quality (i.e. in terms of the content of nutrients, digestible energy and digestibility-reducing compounds) is of particular importance to red deer (Robbins 1993; Van Soest 1994). They do not simply consume any plant species they encounter, but demonstrate preferences for plant species containing higher amounts of nitrogen and digestible energy and lower amounts of digestibility-reducing substances, such as fibre and secondary metabolites (e.g. Robbins 1993; Forsyth et al. 2005; Iason 2005).

Direct measurements of food quality for herbivorous ungulates can be both time-consuming and expensive (Leslie et al. 2008). An alternative approach is to measure a nutritional characteristics of faeces that bear a relationship to the quality of ingested diet (Holechek et al. 1982a; Leslie & Starkey 1985). Faecal material offers a convenient, non-invasive method as it is readily available and easy to obtain. There are several faecal constituents demonstrating the relationship with food quality of herbivorous ungulates (Belovsky 1981; Robbins 1993). Among the most widely applied faecal indices of food quality are faecal nitrogen (FN), faecal acid detergent fibre (FADF), and faecal neutral detergent fibre (FNDF; Leslie et al. 2008; Dixon & Coates 2009). Despite its broad application, the use of FN as an indicator of food quality for ungulates remains controversial (see review by Leslie et al. 2008). The digestibility of the diet affects the FN levels as the bacterial fermentation activity as well as turnover increases with higher digestibility (Robbins 1993). This results in a positive linear relationship between digestibility and FN (Holechek et al. 1982b). Since nitrogen content shows a positive linear relationship with digestibility in plants, FN also correlates with dietary nitrogen, which is one of the most important parameters of food quality for herbivorous ungulates (e.g. Robbins 1993; Leslie & Starkey 1985; Hodgman et al. 1996). However, woody plant species contain secondary

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metabolites which are known to bind with plant proteins and gastrointestinal enzymes during chewing and digestive processes. These complexes are not digestible at rumen pH and are excreted in the faeces, thereby inflating concentrations of FN (Robbins 1993; Palo & Robbins 1991). Nevertheless, it has been suggested that under natural conditions, where free-ranging herbivores can make their own choice of what plant species they will consume, a relatively consistent correlation exists between FN and dietary nitrogen (Palo & Robbins 1991).

Regarding the fibre fractions in faeces, NDF consists predominantly of hemicellulose, cellulose and lignin (Van Soest et al. 1991) and it has been demonstrated that increasing levels of NDF in diet reduce voluntary food intake (Van Soest 1994). A subset of NDF is ADF, which represents lignin, cellulose and cutin – i.e. the least digestible compounds for most herbivores (Van Soest et al. 1991). As content of ADF in diet increases, digestibility as well as available energy decreases (Van Soest 1994). Red deer are known to show higher preferences for plant species containing lower levels of fibre (Forsyth et al. 2005). Adequate levels of fibre in diet are however required to maintain normal rumen function (Van Soest 1994).

Plant nutrients and thus quality of food consumed by herbivorous ungulates are highly variable in space and time (e.g. Palo & Robbins 1991; Crawley 1997; Holá 2012). To efficiently evaluate variation in food quality, however, requires large number of samples and the wet-chemistry methods used to measure FN, FADF, and FNDF in faeces frequently become very time-consuming and expensive. Near infrared reflectance spectroscopy (NIRS) provides a useful tool to overcome these drawbacks since it allows rapid, low-cost, chemical-free, and non-destructive analyses of a large number of samples (Foley et al. 1998). NIRS has been widely used in wildlife nutrition research over the past four decades and numerous studies have used NIRS to measure food quality through faecal indices in herbivorous ungulates (Kamler et al. 2004; Dixon & Coates 2009; Showers et al. 2006).

In recent decades, the use of fenced overwintering enclosures for free-ranging ungulates is a common management practice in many central European countries, including the Czech Republic. The main purpose of these enclosures is to reduce damage to forest stands and to assist animal survival over harsh winter conditions. Enclosures are 10 – 50 ha and animals are usually kept inside for about a half-year (i.e. from the beginning of December until the beginning of growing season; Putman & Staines 2004; Pepin et al. 2006). Supplementary feeding is a major food source for animals kept inside the enclosures. Therefore, temporarily confining the animals into a restricted fenced area may be reflected in their feeding habits and quality of food consumed. Considering the importance of food quality for herbivorous ungulates, it is essential to evaluate the quality of foods consumed inside the enclosures in comparison to foods consumed outside them.

Our purpose here was thus to evaluate winter food quality and its variability for red deer using faecal indices (i.e. FN, FADF, FNDF) and NIRS. We compared food quality for red deer and its possible differences between overwintering enclosures (i.e. fenced areas where red deer spend harsh winter conditions) and neighbouring unfenced free-ranging areas within two study areas in the Czech Republic. We selected winter since this time period is of particular importance for red deer. Plants available in winter are usually less digestible and have lower amounts of necessary nutrients (Van Soest 1994). Severe winter conditions and related reduction in food quality are thus among the main factors influencing survival and reproduction success of red deer populations (Christianson & Creel 2007).

2. Materials and Methods

2.1. Study areas

Faecal samples of red deer were collected during winter 2013 in two study areas in the Czech Republic: (i) military training area Hradiště (Karlovy Vary region; hereinafter MTA Hradiště), and (ii) military training area Boletice (South Bohemia region; hereinafter MTA Boletice; Fig. 1). The climatic conditions of study areas is describe in the Table 1.

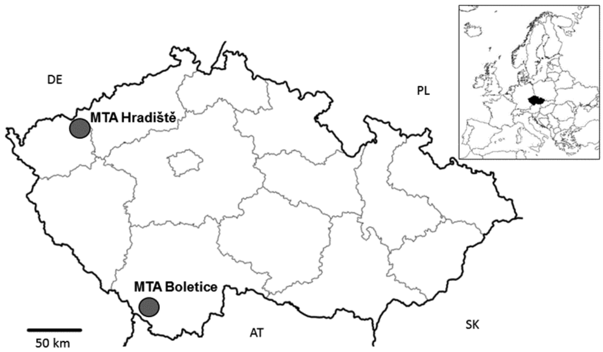

Fig. 1. Location of the study areas (indicated by grey circles) within Europe and the Czech Republic.

Table 1. Climatic conditions during winter 2013.

		January	February	March	April
Average monthly temperature [°C]	MTA Boletice	−4.2	−5.1	−3.9	4.2
	MTA Doupov	−2.8	−3.5	−2.7	6.8
Duration of snow cower [day]	MTA Boletice	28	28	25	8
	MTA Doupov	21	20	17	6

The MTA Hradiště (50°16´ N, 13°7´ E) is situated in the Doupovské hory Mountains and has a total acreage of 331 km^2. Forests cover 41% of the area, agricultural land 8%, other land cover types 51%, and water surfaces 0.2%. Deciduous forests with Norway spruce (*Picea abies*), European larch (*Larix decidua*), and pine (*Pinus sylvestris, Pinus nigra*) cover 71%. Broad-leaved forests with beech (*Fagus sylvatica*), sycamore maple (*Acer pseudoplatanus*), and ash (*Fraxinus excelsior*) cover 29%. The predominant forest type is herb-rich beech forest. The other forest types are ravine forests, alluvial forests, oak-hornbeam forests, and thermophilous oak forests (Vojta & Kopecký 2006).

The MTA Boletice (48°49´ N, 4°13´ E) has a total acreage of 219 km^2. Forests cover 60% of the area, agricultural land 10%, and shrubs and natural open areas 30%. Spruce forests with Norway spruce (*Picea abies*) and rowan (*Sorbus aucuparia*) are the dominating cover. Flowering beech forests and acidophilus beech forest mostly with European beech (*Fagus sylvatica*) and sycamore maple (*Acer pseudoplatanus*), and fir forests with silver fir (*Abies alba*) are found at altitudes between 600 and 1000 m a.s.l. Large complexes of semi natural treeless areas occur at lower altitudes.

Regarding the overwintering enclosures in our study areas in 2013, the enclosure in the MTA Hradiště had a total acreage of 12 ha with 280 individuals of red deer (90%), and sika deer (10%; *Cervus nippon*), and the enclosure in the MTA Boletice had 8 ha with 35 individuals of red deer. Supplemental feed (i.e. corn and meadow hay) was regularly provided to free-ranging ungulates, including red deer, in the overwintering enclosures and neighbouring free-ranging areas in both study areas from November to May.

2.2. Sampling and chemical analyses

We randomly collected fresh red deer faeces from fenced overwintering enclosures and neighbouring unfenced areas within each study area during winter 2013 (n = 149 in MTA Hradiště, n = 161 in MTA Boletice). All faecal samples were oven-dried to constant weight at 50 °C and subsequently ground to pass 1 mm sieve.

A subset of faecal samples (i.e. calibration (n = 100), further used for NIRS interpolation of chemical constituents in the remaining samples, was assayed by standard chemical methods to determine the exact concentrations of FN, FADF, and FNDF. Total FN content was determined using an automated C/N analyser TruSpec (LECO Corporation, USA) after oxygen combustion in an oven at 950 °C. Total FADF and FNDF concentrations were determined by standard methods of the Association of Official Analytical Chemists (AOAC 1984). The results of the chemical assays were then used to calibrate NIRS as described by Foley (1998). All faecal samples were scanned from1 100 to 2 500 nm using a Thermo Nicolet NEXUS 670 scanning spectrophotometer and an OMNIC 7.4 software (Thermo Scientific™, USA). The spectrum of each sample was the average of 32 successive scans at a resolution of 4 cm^{-1}. Each spectrum was recorded as the logarithm of the reciprocal of reflectance (log 1/R).

Prior to calibrations, the scatter correction of standard normal variate (SNV) and detrend was applied to the spectral data, along with a number of possible combinations of derivative (1,2), gap (4,10), and smoothing (4,10; Barnes et al. 1989). The calibrations were performed by partial least square (PLS) regressions with internal cross-validation (Shenk & Westerhaus 1991). Outliers were detected by using the residual sample variance plot after the PLS regression. The predictive ability of the PLS equations was evaluated on the basis of coefficient of determination (R^2) of the linear regression of predicted against measured values, the root mean square errors of calibration (RMSEC), the root mean square errors of cross-validation (RMSECV), and the ratio of performance deviation (RPD), which is the ratio of the standard deviation of the reference values and the root mean square errors of prediction (RMSEP). Good predictions are regarded as having an $R^2 > 0.81$ and an RPD > 2. Predictions having $0.66 < R^2 < 0.80$ and 1.5 < RPD < 2 are considered to be approximate and predictions having $R^2 < 0.65$ and an RPD < 1.5 are considered to be poor (Shepherd & Walsh 2007).

Statistical analysis

The Kendall´s tau τ correlation coefficients were calculated in order to evaluate whether there was any relationships among FN, FADF, and FNDF in individual study areas.

The amounts of individual faecal indices of food quality within and outside the overwintering enclosures in individual study areas were compared by Student´s t-tests or Wilcoxon signed-rank test depending on the normality of the data.

To quantify the degree of variation in food quality in overwintering enclosures and neighbouring free-ranging areas, the coefficients of variation (i.e. CV, standard error divided by mean) for concentrations of FN, FADF, and FNDF were estimated. Significance was tested at $\alpha = 0.05$ level. All statistical analyses were performed with the R software, version 3.1.1 (R Development Core Team, 2014).

3. Results

Overall, a total of 310 red deer faecal samples, including 149 from the MTA Hradiště and 161 from the MTA Boletice, was analysed for concentrations of FN, FADF, and FNDF.

The developed calibration models (derived from the absorbance spectra of faeces) confirmed the high potential of near infrared reflectance spectroscopy for analysing a large number of samples and accurate determination of major faecal indices of food quality for red deer (Table 2).

Table 2. Developed calibration models. Predictive power of partial least square regression with cross-validation for modelling the relationship between spectral characteristics of faecal samples of red deer and concentrations of faecal nitrogen (FN), faecal acid detergent fibre (FADF), and faecal neutral detergent fibre (FNDF).

Constituent	N	R^2	RMSEC	RMSECV	RPD
N	100	0.99	0.03	0.18	2.8
ADF	100	0.98	1.21	4.42	2.9
NDF	100	0.99	0.58	3.55	2.4

Note: N = number of samples used for calibration; R^2 = the degree of correlation between the predicted values and the actual measured values; RMSEC = root mean square error of calibration; RMSECV = root mean square error of cross-validation; RPD = ratio of standard deviation of laboratory reference values and the root mean square error of prediction; RPD ≥ 2 indicates good models.

Concentrations of FN, FADF and FNDF showed the basic values in red deer feaces collected within and outside the overwintering enclosures in individual study areas (Table 3).

Table 3. Concentrations of FN, FADF, and FNDF in red deer faeces. The mean (±SD), minimum, and maximum values of faecal nitrogen (FN), faecal acid detergent fibre (FADF), and faecal neutral detergent fibre (FNDF) in red deer faeces collected from fenced overwintering enclosures and neighbouring unfenced areas within two study areas (MTA Hradiště and MTA Boletice) during winter 2013.

	enclosure				Free-ranging area			
FN	μ±SD	n	Min	Max	μ±SD	n	Min	Max
MTA Hradiště	2.17 ± 0.34	107	1.50	2.88	1.88 ± 0.19	42	1.34	2.28
MTA Boletice	2.21 ± 0.31	79	1.66	3.04	2.27 ± 0.31	82	1.75	3.26
FADF	μ±SD	n	Min	Max	μ±SD	n	Min	Max
MTA Hradiště	44.24 ± 5.13	107	28.10	55.40	47.84 ± 4.22	42	37.10	56.20
MTA Boletice	41.67 ± 4.02	79	33.70	52.30	45.78 ± 3.15	82	36.20	55.00
FNDF	μ±SD	n	Min	Max	μ±SD	n	Min	Max
MTA Hradiště	56.61 ± 5.62	107	38.80	73.80	60.710 ± 3.76	42	52.40	68.00
MTA Boletice	61.48 ± 7.67	79	48.10	75.00	60.80 ± 4.50	82	51.20	71.30

Note: μ – mean, SD – standard deviation; n – number of collected faeces. All values expressed as % dry matter.

The Kendall´s tau τ correlation coefficient showed significant negative relationship between FN and FADF ($\tau_{MTA\ HRADIŠTĚ} = -0.40$, $p < 0.5$; $\tau_{MTA\ BOLETICE} = -0.12$, $p < 0.5$), as well as FNDF ($\tau_{MTA\ HRADIŠTĚ} = -0.65$, $p < 0.5$; $\tau_{MTA\ BOLETICE} = -0.78$, $p < 0.5$) in both study areas. The relationships between FADF and FNDF were positive ($\tau_{MTA\ HRADIŠTĚ} = 0.67$, $p < 0.5$; $\tau_{MTA\ BOLETICE} = 0.16$, $p < 0.5$).

Regarding the differences in individual faecal indices between overwintering enclosure and outside it in the MTA Hradiště, the FN contents were higher in the enclosure compared to the neighbouring area (Wilcox.t.: Z=-4.582; p<0.0001, Fig. 2). The levels of FADF and FNDF showed the opposite trend, with higher levels found in the free-ranging areas compared to the enclosure (ADF: Wilcox. t.: Z=4.040; p<0.0001, Fig. 3; NDF: Student. t-test.: t=4.337; p<0.0001, Fig. 4).

Turning now to the MTA Boletice, the amounts of FN showed a different trend in comparison to MTA Hradiště. The FN levels in the MTA Boletice were similar in the overwintering enclosure and in neighbouring free-ranging area (Wilcox. t.: Z = −0.955; p < 0.3394, Fig. 5). Similarly the concentrations of FADF and FNDF were comparable in the overwintering enclosure and outside it (*ADF*: Wilcox. t.: Z = −0.544; p < 0.5861, Fig. 6; *NDF*: Wilcox. t.: Z = −0.8928; p < 0.3720, Fig. 7).

The amounts of variation in faecal indices of red deer food quality showed interesting patterns in individual study areas. In the MTA Hradiště, the amount of variation was higher in the overwintering enclosure compared to free-ranging area for all studied faecal indices. In the MTA Boletice, on the other hand, the amounts of variation were comparable between the overwintering enclosure and outside it (Table 4).

Table 4. The amounts of variation in faecal indices. Coefficients of variation [%] for faecal indices of food quality for red deer in overwintering enclosures and neighbouring free-ranging areas in MTA Hradiště and MTA Boletice.

	MTA Hradiště		MTA Boletice	
	enclosure	Free-ranging area	enclosure	Free-ranging area
FN	16	10	14	14
FADF	12	9	7	6
FNDF	10	6	8	7

Coefficient of variation (%) was estimated as the ratio of the standard deviation to the mean.

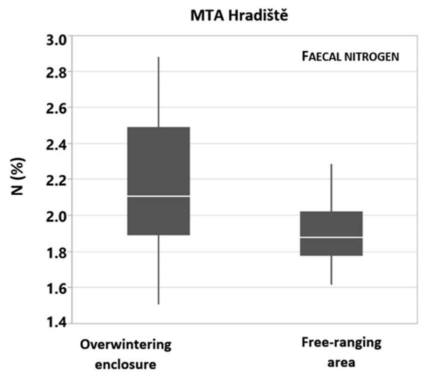

Fig. 2. Volume of nitrogen. Box and whisker plots showing the median, minimum, maximum, upper and lower quartile for the concentrations of *faecal nitrogen* in red deer faeces collected in the overwintering fenced enclosures and neighbouring free-ranging areas in the MTA Hradiště.

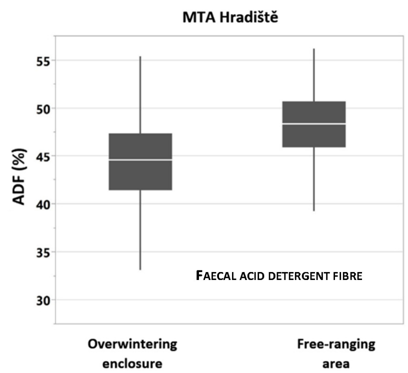

Fig. 3. Volume of ADF. Box and whisker plots showing the median, minimum, maximum, upper and lower quartile for the concentrations of *faecal acid detergent fibre* in red deer faeces collected in the overwintering fenced enclosures and neighbouring free-ranging areas in the MTA Hradiště.

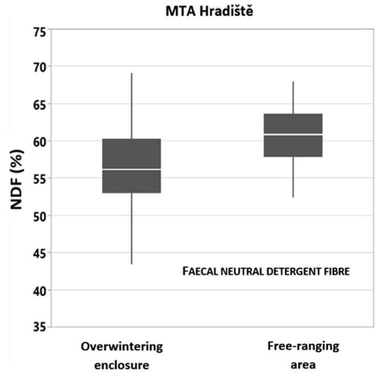

Fig. 4. Volume of NDF. Box and whisker plots showing the median, minimum, maximum, upper and lower quartile for the concentrations of *faecal neutral detergent fibre* in red deer faeces collected in the overwintering fenced enclosures and neighbouring free-ranging areas in the MTA Hradiště.

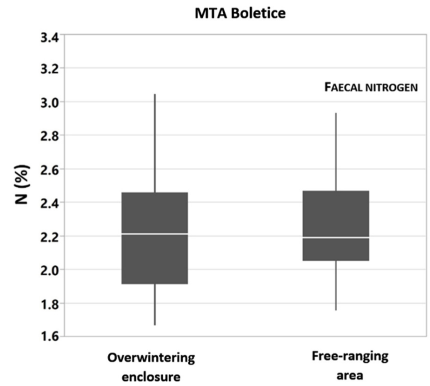

Fig. 5. Volume of nitrogen. Box and whisker plots showing the median, minimum, maximum, upper and lower quartile for the concentrations of *faecal nitrogen* in red deer faeces collected in the overwintering fenced enclosures and neighbouring free-ranging areas in the MTA Boletice.

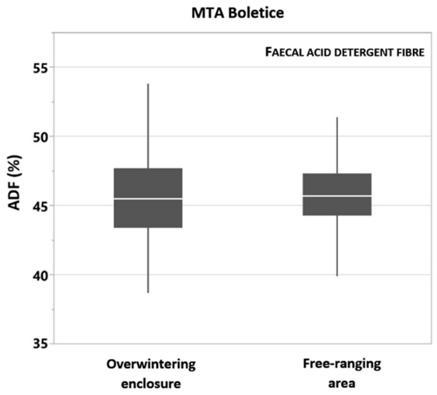

Fig. 6. Volume of ADF. Box and whisker plots showing the median, minimum, maximum, upper and lower quartile for the concentrations of *faecal acid detergent fibre* in red deer faeces collected in the overwintering fenced enclosures and neighbouring free-ranging areas in the MTA Boletice.

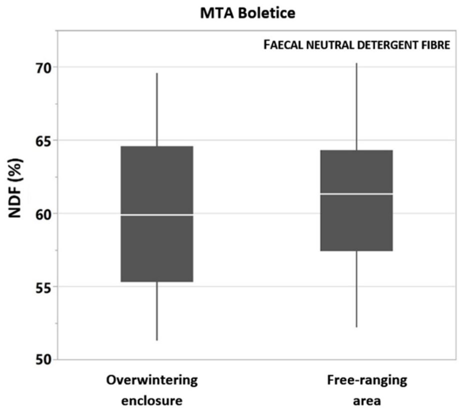

Fig. 7. Volume of NDF. Box and whisker plots showing the median, minimum, maximum, upper and lower quartile for the concentrations of *faecal neutral detergent fibre* in red deer faeces collected in the overwintering fenced enclosures and neighbouring free-ranging areas in the MTA Hradiště.

4. Discussion

The use of FN as a proxy for food quality of herbivorous ungulates is based on the fact, that there is a positive relationship between dietary N and FN (e.g. Leslie & Starkey 1985; Hodgman et al. 1996). Nevertheless, it cannot always be assumed that dietary N is directly reflected in the faeces, particularly due to possible effects of secondary metabolites (e.g. Palo & Robbins 1991; Leslie et al. 2008). Therefore, conclusions based only on the FN levels should be strengthened by the use of multiple nutritional indices, such as fibre fractions in faeces (FADF and FNDF). These indices should be more sensitive to fluctuations in food quality than FN, especially when diets contain high amounts of secondary metabolites such as tannins (Hodgman et al. 1996; Leslie et al. 2008). As expected, our results showed a strong negative relationships between FN and FADF, as well as FNDF. This is due to the FN levels being lower if the diet contains more indigestible compounds, such as fibre components, since FN is associated with indigestible fibre (Van Soest 1994).

Our analyses showed that in the MTA Hradiště, the FN concentrations were higher in the overwintering enclosures compared to neighbouring free-ranging areas. The FADF and FNDF levels showed the opposite trends. On the other hand, the food quality indices were similar in the overwintering enclosure and outside it in the MTA Boletice. The observed differences in concentrations of faecal indices at individual study areas are most probably related to animal densities. The density of animals was significantly higher in the overwintering enclosure in the MTA Hradiště (i.e. animal density ranged from 22 to 24 individualsper ha) in comparison to the enclosure in the MTA Boletice, where the animal density was lower (i.e. 4 to 5 individuals per ha). Therefore, at high densities, there may be less plant species of higher quality for red deer as a consequence of over-browsing, thus favouring the growth of woody plant species which are less palatable for red deer (Suzuki et al. 2008). Such plant species have higher concentrations of tannins which are able to bind to plant proteins in the digestive tract of ruminants and thus reduce the levels of digestible protein and increase the excretion of FN (Palo & Robbins 1991; Robbins 1993). This could explain the higher FN values observed in the overwintering enclosure in the MTA Hradiště. Similarly Carpio et al. (2015) have found the highest FN values in areas with the highest red deer densities and tannin concentrations in faeces. On the other hand, other studies focusing on ungulate diets have observed a negative relationship between FN and population density, for example Sams et al. (1998) for white-tailed deer (*Odocoileus virginianus*), and Asada & Ochiai (1999) for sika deer (*Cervus nippon*). These authors have argued that as population density increases, competition for high quality plant species is higher and consequently the high quality plant species are rapidly depleted and the consumed food is of lower quality resulting in decreased FN levels (Sams et al. 1998; Asada & Ochiai 1999).

Another possible explanation for the observed trends in faecal indices in the MTA Hradiště could be the fact that the red deer in the overwintering enclosure were to a larger extent dependent on supplemental foods provided by hunters, which is of better nutritional value and more palatable than winter plant species available outside the enclosure. As reported by Carpio et al. (2015), a positive relationship was found between FN and dietary N in plants on hunting estates with a supplemental food supply, whereas no relationship was observed in the absence of supplementary feeding.

The different degrees of variation in food quality observed in this study may be again attributed to the differences in animal density. Increased population densities may lead to intensified competition for food resources and thus only highly socially ranked individuals are more successful at obtaining foods of high quality (Clutton-Brock & Albon 1985; Putman & Staines 2004). The higher amounts of variation in food quality observed in the enclosure in the MTA Hradiště could hence be attributed to the differential access to high quality foods related to social rank (e.g. Appleby 1980; Thouless 1990). In the MTA Boletice, on the other hand, the amounts of variation were similar in the enclosure and outside it, most probably due to adequate population densities in the area and not intense competition for food resources.

To sum up, the results obtained suggest that the red deer food is of different quality and variability in the overwintering enclosure and neighbouring free-ranging area most probably due to high population density. Therefore, it is necessary to keep animals in overwintering enclosures at moderate densities and to provide high quality forage to all individuals in order to balance nutrition of both the individuals inside and outside the enclosures. Moreover, the analyses confirmed the high potential of NIRS for analysing large numbers of samples necessary for monitoring purposes of red deer diets. However, further studies are needed in order to provide deeper knowledge on red deer food quality and its variability in space and time. The further studies should aim to evaluate the differences in each sex and age classes especially.

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ORIGINAL PAPER

Spatial considerations of an area restriction model for identifying harvest blocks at commercial forest plantations

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Abstract

In the past few decades, ecological and environmental issues have dominated the forest industry worldwide, but economic aspects have been much less studied in this dynamic period. However, a sustainable and efficient forest biomass supply is critical for socio-economic development in many regions, particularly in rural areas. Nature protection efforts have contributed to reduced harvesting quotas, which have resulted in an imbalance of the environmental functions of the forests and forest management, particularly wood supply.

Considering the size and distribution of forest production management units and the forest stands that compose those units, there is a clear need for improved decision-making tools that help forest managers in planning harvest sequences. The optimization of harvest scheduling should consider economic and spatial factors, which may reduce production costs by increasing the logistic efficiency. Moreover, incorporating maximum harvesting opening size constraints into planning can help preserve biodiversity.

This article presents a new spatial harvest scheduling model based on the integer programming method; it was developed using real data from a forest production unit located in the northern part of the southeast region of Brazil. The goal of the proposed scheduling approach is to maximize the net present value and concentrate the harvesting locations in each period. In spite of the fact that the object of the study is plantation forest under management different to common conditions in Europe or North America, the model is flexible and can be used in management of forest in Central Europe.

Keywords: Eucalyptus; plantation management; spatial harvest scheduling; harvest-flow constraints

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1. Introduction

The importance of exact mathematical methods in decision-making processes is indisputable, especially in forest management, which is faced with very complex scenarios due to the spatial and temporal aspects of decision models with many sources of uncertainty. Furthermore, forest managers often have to find a balance between goals of multiple participants (owner, public society, nature protection organizations, etc.) in most cases.

According to Baskent & Keles (2005), forest planning can be defined as the organization of the various activities to be undertaken over time in a forest to meet the objectives of the project, while also ensuring long-term sustainability of forest resources and the steady flow of wood products. Buongiorno & Gilles (2003) recognized that the strategic planning of wood production involves managing large forested areas, and many operations and people; often different aspects of the production process compete for the same resources, which makes the allocation of this resources a complex task. Thus, to achieve a satisfactory return on investment, it is necessary to implement a detailed forest management plan efficiently allocating production factors to achieve the established objectives. According to Falcão & Borges (2003), management models that consider the geographical locations of forest activities contribute to avoid segregation across levels of strategic and operational planning. They can also provide necessary information to address problems related to the transport of forest products and / or the spatial arrangement of cultural operations.

A key aspect of spatial forest planning is the combination of optimal harvest scheduling with the spatial dispersion of harvesting units; variations in either of these factors involve not only environmental impacts, but also consideration of operational logistics. Scheduling of forest harvesting involves identifying a series of areas to be cut to ensure maximum profit for the landowner and guarantee a balance in the harvested amount of wood or area over a defined period. However, more traditional forest planning methods did not consider spatial dispersion of harvesting units, so it is difficult to evaluate the tradeoffs of a harvest plan in terms of logistical and environmental impacts versus financial goals.

By introducing spatial variables in forest planning problems, it is possible to find an optimal solution between economic, environmental, and logistical objectives within the constraints provided. According to Öhman & Eriksson (2010), including spatial parameters in strategic planning of forest harvesting increases its complexity. One reason for the increased complexity is that to represent the aggregation of management units into the models, integer variables need to be

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introduced to specify the type of management regime that will be applied to each unit; in addition, specific information about adjacent units also needs to be considered, not solely for each isolated harvest unit.

In traditional unit restriction models (URM), harvest clusters are formed *a priori* by the forest planner (Murray 1999). This approach is often used in countries where laws limit the size and/or shape of harvest units (Kašpar et al. 2016). Underestimation of objective function values is one of the major disadvantages of URM (Richards & Gunn 2000). However, Hokans (1983) and Lockwood & Moore (1993) proposed a modelling approach to create harvest clusters during the optimization process; this approach is referred as the area restriction model (ARM). One of the possible exact integer programming formulations is called the *Path formulation*, originally proposed by McDill et al. (2002), which is based on enumerating all feasible clusters that cannot be harvested as a whole and which are minimal. Each of these clusters is a continuous group of stands with total area exceeding the limit size and does not contain any cluster with area exceeding the limit size. So, it is necessary to remove only one of the stands, in such a cluster, before it becomes feasible (Crowe et al. 2003), that is, if |C|[1] is the cardinality of cluster C then at most |C| – 1 of them can be harvested simultaneously. We consider that two sands are adjacent if the boundary that they share is not a discrete set of points.

Harvesting units sparsely dispersed in a forest management area have lower environmental impacts because they present fewer problems related to erosion after harvesting and they promote wildlife protection. However, this dispersion may cause logistical problems in the harvesting and transport of the timber, thus increasing production costs. So, in reality, environmental and economic goals often conflict with one another; we attempt to find a compromise between them by using a maximum distance constraint and creating clusters of harvest units.

The complexity of spatial forest planning requires mathematical models and techniques within decision support systems that consider adjacency restrictions. The Decision support system (DSS) Optimal, developed for Central Europe forest management conditions, has been presented in several previous papers (Marušák & Kašpar 2015; Marušák et al. 2015; Vopěnka et al. 2015). The DSS Optimal is a powerful tool used in the Czech Republic for harvest scheduling. Because DSS Optimal uses Java SDK for ArcGIS desktop extensions, it is easily modified to include different spatial constraints.

The goal of this paper is to present a basic harvest scheduling model in the context of plantation management conditions in Brazil. We also present results of analyses based on alternative initial conditions. The model has been implemented into an updated version of DSS Optimal tool applied in countries of Central Europe. The newly developed DSS tool was used to analyze the alternative harvest scheduling scenarios.

2. Material and methods

2.1. Model

A very simple area restriction harvest scheduling binary programing model was created for the purpose of our case study. The model is presented in Equations 1–7:

$$\text{Maximize} \sum_{i=1}^{N} \sum_{p=1}^{P} c_{ip} x_{ip} \quad [1]$$

subject to:

$$\sum_{p=1}^{P} x_{ip} \leq 1 \;\; \forall i=1,\ldots,I \quad [2]$$

$$\mathrm{x_{ip}} + x_{jp} - 2z_{ijp} \geq 0 \quad [3]$$

Maximum distance constraints:

$$d_{ij} z_{ijp} \leq D \; \forall \; z_{ijp} \quad [4]$$

Harvest volume-flow constraints:

$$(1-\propto) \sum_{i=1}^{N} v_i x_{i(p-1)} \leq T \leq (1+\propto) \sum_{i=1}^{N} v_i x_{i(p-1)} \;\; \forall \; p = 1, \ldots, P \quad [5]$$

Maximum opening size constraints:

$$\sum_{i \in C} x_{ip} \leq |C| - 1 \; \forall \; C \in \Im \quad [6]$$

$$x_{ip} \in \{0,1\} \; \forall \; p = 1, \ldots, P; i = 1, \ldots, N$$
$$z_{ijp} \in \{0,1\} \; \forall \; p = 1, \ldots, P; i,j = 1, \ldots, N, i < j \quad [7]$$

The objective function [1] maximizes the net present value (NPV) from all harvested forest stands, $i = 1, \ldots, N$, and from all planned years, $p = 1, \ldots, P$, while the c_{ip} parameter expresses the NPV from harvested wood in Euro (€), and x_{ip}, for $i = 1, \ldots, N$ and $p = 1, \ldots, P$, is the decision variable that takes value 1 if stand is harvested in period p and 0 otherwise. The first constraint, equation 2, ensures that each unit is harvested only once during the planning horizon. Equations 3 and 4 ensure the distance between selected stands, d_{ij}, calculated as a Euclidean distance between centroids of stands i and j, is less than parameter D, the maximum distance allowed between those stands. The z_{ijp}, for $p = 1, \ldots, P$; $i, j = 1, \ldots N$, $i < j$, are decision variables taking value 1 if both stands i and j are harvested in period p and 0 otherwise. Equation 5 ensures an annual balanced harvest volume throughout the planning horizon. A harvest volume is allowed to vary by $\propto$(%) from one period to the next. The T variable is a new general variable that defines the potential harvest level for each year, and v_i is the absolute value of the wood volume of stand i. The constraint (6) are known as the path constraints, impose area limit in the opening areas. These constraints prohibit to harvest too large clusters, that is, clusters whose area exceed the imposed area limit. The set $\Im$ consists of all possible minimal infeasible clusters, that is, all possible clusters that cannot be harvested as a whole and are mini-

[1] |C| denotes the cardinality of set C, that is the number of elements of set C.

mal. They assure that from each cluster C in set $\Im$ we can harvest at the same period at most $|C|| - 1$ stands, being $|C|$ the cardinality of set C, that is, it is necessary to remove only one stand from the set C before it becomes feasible. Finally, the constraints (7) impose that all variables are binary.

2.2. Case study

We used spatial and numerical data from a timber farm in north of the southeast region of Brazil for this study. The farm belongs to a private entity, thus we do not specify the location or the name of the farm. The total area is 2412 hectares and the number of forest stands is 105 (N) were their areas ranging from 1.07 hectares to 24.50 hectares with average value equal to 22.97 hectares. The location of this timber farm is presented in Fig. 1. The timber farm is on the border of two geographical regions - Cerrado and Mata Atlântica. There is a prevailing tropical climate, which influence the eucalyptus production of 30 – 40 m^3/hectare/year.

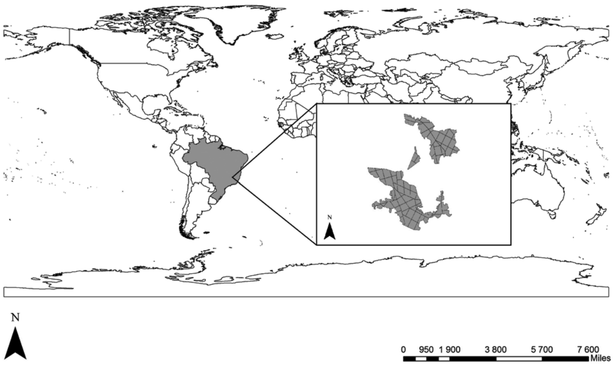

Fig. 1. The location of the timber farm in Brazil.

Exlusively, *Eucalyptus urophylla* S.T. Blake, is planted at the timber farm while the wood would be used for commercial purposes, such as construction, power generation, furniture making, charcoal, pulp and paper production. Stands are harvested when the MAI (Mean Annual Increment) curve crosses the CAI (Current Annual Increment) curve; for *E. urophylla*, this occurs between 6 and 8 years of age. Stands younger than 5 years old cannot be harvested, and stands older than 8 years old are prioritized for harvesting. Age, site index, and stand volume data for all stands in each year were available.

We used several combinations of the following parameters to conduct the analysis, including: D=2.5 km, 5 km, and 10 km; $\propto$ = 5%, 10%, and 15%; and, C was tested at 25 ha, 50 ha, and 75 ha) were analyzed. The different combinations of these alternative parameters were compared against the results of a null scenario that used no maximum distance between harvested stands in a given year (D), no limits on the percentage of volume harvested from year-to-year ($\propto$), and no opening size constraints (C)

The total NPV of the 5-year planning horizon (P) was calculated for each scenario. The price of harvested wood, harvest costs, and silviculture costs are included in the NPV calculation; all monetary values are presented in Euro (€). The real prices of wood at the timber farm as well asreal Brazil interest rate of 14% were used for all analyses. The effects of different management conditions and input parameters on total NPV were evaluated.

3. Results

The final results of are presented in Tables 1 – 5. The objective function values (total NPV) of the different alternatives are presented in Tables 1 – 4, which display scenarios with no maximum opening constraints, 75-ha maximum opening constraints; 50-ha maximum opening constraints, and 25-ha maximum opening constraints. A comparison of the objective functions of all scenarios relative to the null scenario is presented in Table 5.

The highest potential objective function value, € 21,783,770, was found in the no maximum opening size, maximum distance, and harvest volume flow constraint scenario (Table 1). All other alternatives´ objective function values were lower (Tables 1 –4), which simply means that constraints on any of these factors limit the objective function value.

Maximum opening constraints and harvest volume flow constraints had the smallest effect on objective function values; the maximum distance constraints had the greatest impact on NPV. However, the constraints also displayed a synergistic effect; the maximum distance constraints most negatively decreased the objective function values when the maximum opening constraint was 25 ha.

As it can be seen in tables 1 to 4, the objective function value coincide without considering constraints about the maximum distance and considering 10 km as the maximum distance. It means that without constraint in the distance between the opening areas we get already a solution where the distance between them are less or equal than 10 km. Furthermore, in that solution the distance between some of the opening areas are greater than 5 km and so, with D = 5 km, the objective value decreases.

Table 1. NPVs (expressed in Euro) with no maximum opening size constraints using alternative harvest volume flow and maximum distance constraints in an area restriction harvest scheduling binary programing model.

Harvest volume-flow constraints	Maximum distance constraints no	D = 10 km	D = 5 km	D = 2,5 km
no	€ 21,783,770	€ 21,783,770	€ 21,611,032	€ 20,312,147
$\propto$ = 15%	€ 21,709,180	€ 21,709,180	€ 21,524,723	€ 20,218,849
$\propto$ = 10%	€ 21,688,842	€ 21,688,842	€ 21,495,634	€ 20,096,002
$\propto$ = 5%	€ 21,662,521	€ 21,662,521	€ 21,472,272	€ 19,997,284

Table 2. NPVs (expressed in Euro) with 75-ha maximum opening size constraints using alternative harvest volume flow and maximum distance constraints in an area restriction harvest scheduling binary programing model.

Harvest volume-flow constraints	Maximum distance constraints no	D = 10 km	D = 5 km	D = 2.5 km
no	€ 21,775,739	€ 21,775,739	€ 21,333,623	€ 19,500,606
$\propto$ = 15%	€ 21,698,958	€ 21,698,958	€ 21,224,200	€ 19,230,089
$\propto$ = 10%	€ 21,674,122	€ 21,674,122	€ 21,190,465	€ 19,171,129
$\propto$ = 5%	€ 21,647,094	€ 21,647,094	€ 21,155,801	€ 18,934,139

Table 3. NPVs (expressed in Euro) with 50-ha maximum opening size constraints using alternative harvest volume flow and maximum distance constraints in an area restriction harvest scheduling binary programing model.

Harvested volume-flow constraints	Maximum distance constraints no	*D* = 10 km	*D* = 5 km	*D* = 2.5 km
no	€ 21,619,031	€ 21,619,031	€ 18,890,391	€ 14,564,865
∝ = 15%	€ 21,570,390	€ 21,570,390	€ 18,882,110	€ 14,557,164
∝ = 10%	€ 21,559,932	€ 21,559,932	€ 18,865,260	€ 14,544,095
∝ = 5%	€ 21,546,020	€ 21,546,123	€ 18,819,400	€ 14,520,904

Table 4. NPVs (expressed in Euro) with 25-ha maximum opening size constraints using alternative harvest volume flow and maximum distance constraints in an area restriction harvest scheduling binary programing model.

Harvested volume-flow constraints	Maximum distance constraints no	*D* = 10 km	*D* = 5 km	*D* = 2.5 km
no	€ 21,743,614	€ 21,466,606	€ 16,980,118	€ 12,539,383
∝ = 15%	€ 21,433,964	€ 21,433,964	€ 16,934,360	€ 12,520,616
∝ = 10%	€ 21,421,127	€ 21,421,127	€ 16,907,691	€ 12,520,616
∝ = 5%	€ 21,405,127	€ 21,405,127	€ 16,819,627	€ 12,480,796

The relative differences (%) in the NPV for all alternatives compared to the scenario without a maximum opening size, maximum distance constraint, and harvested volume-flow constraint (€ 21,783,770) are presented in Table 5. The values were divided into four groups to identify stronger effects on NPV, which confirms the previously discussed importance of each constraint. The range between 99% – 100% is green; 91% – 98% is yellow; 81% – 90% is orange and less than 80% is red. Moreover, this type of results´ presentation can be very helpful in decision process since the simplicity of data presentation.

Table 5. The relative differences (%) in the objective functions for all alternatives compared to the scenario without a maximum opening size, maximum distance constraint, and harvested volume-flow constraint: A) no maximum opening size constraint; B) 75-ha maximum opening size constraint; C) 50-ha maximum opening size constraint and D) 25-ha maximum opening size constraint.

Harvest volume-flow constraints	A) no	A) 10 km	A) 5 km	A) 2.5 km	B) no	B) 10 km	B) 5 km	B) 2.5 km
no	100%	100%	99%	93%	100%	100%	98%	90%
∝ = 15%	100%	100%	99%	93%	100%	100%	97%	88%
∝ = 10%	100%	100%	99%	92%	99%	99%	97%	88%
∝ = 5%	99%	99%	99%	92%	99%	99%	97%	87%

Harvest volume-flow constraints	C) no	C) 10 km	C) 5 km	C) 2.5 km	D) no	D) 10 km	D) 5 km	D) 2.5 km
no	99%	99%	87%	67%	98%	99%	78%	58%
∝ = 15%	99%	99%	87%	67%	98%	98%	78%	57%
∝ = 10%	99%	99%	87%	67%	98%	98%	78%	57%
∝ = 5%	99%	99%	86%	67%	98%	98%	77%	57%

The spatial distribution of harvested stands from the scenario examining 25-ha maximum opening size constraint, 5% harvest volume flow constraint, and 2.5 km maximum distance constraint is displayed in Fig. 1. The harvested stands within each year of the planning horizon are generally close to one other, which could potentially help minimize transportation costs. The maximum opening constraint did not allow for harvested stands to occur in large contiguous areas. In this case, as the area of forest stands are big when compared with the maximum opening area, the obtained opening areas doesn't contain many forest stands.

The spatial distribution of harvested stands from the scenario with no maximum opening size constraint, no harvest volume flow constraint, and no maximum distance constraint is displayed in Fig. 3. Compared to Fig. 2, no maximum opening size constraints and maximum distance constraints created large contiguous harvested areas in years 1 and 2, but over the rest of the planning horizon the harvested stands are more dispersed throughout the management area, which would potentially result in much higher transportation costs. In this solution all the forest is harvested during the planning horizon which could compromise the forest sustainability due the fact that the planning horizon has 5 years and the species considered should be harvested around 7 years of age. That situation doesn't occurs in the solution presented in Fig. 2. Depending on the goal of the forest managers they could follow one of the proposed planning management. Refer that Table 5 is good to see the relations between percentages of harvest flow and maximum distance.

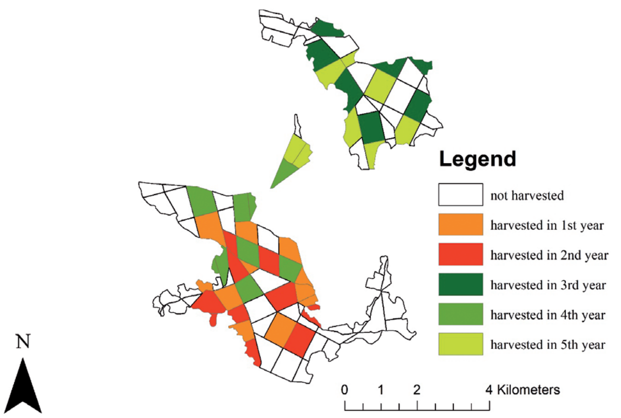

Fig. 2. The resulted spatial distribution of harvested stands by alternative 25 hectares maximum opening constraints, 5% harvested volume-flow constraints and 2.5 kilometers maximum distance constraints.

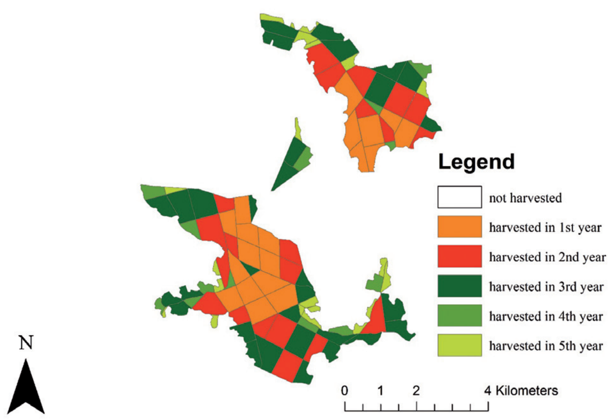

Fig. 3. The resulted spatial distribution of harvested stands by alternative without maximum opening constraints, harvested volume-flow constraints and kilometers maximum distance constraints.

4. Disccusion

This paper presents the effects of two different spatial constraint types, maximum distance and maximum opening size, used in a harvest scheduling area restriction model. Maximum distance constraints encourage the creation of clustered spatial harvest blocks, which helps minimize associated transportation costs (economic aspect), and maximum opening size constraints limit the size of clear cuts (environmental aspect). The harvest volume flow constraints are inherent parts of any harvest scheduling model and contribute to both economic and environmental aspects of harvest planning.

Many researchers have examined the economic aspects of different management approaches (for example, Tiernan & Nieuwenhuis 2005 or Emmingham et al. 2002). In coincidence with other studies (see for example, Crowe et al. 2003), positive influence of maximum opening size on NPV was confirmed in our study. In addition to this, negative impact constraints on NPV is evident in this study, similar to the findings of Borges et al. (2015). The use of ARM in managed forests of central Europe is problematic because of the shape of harvest units´ legaly limitations (Kašpar et al. 2016). However, as Richards & Gunn (2000) demonstrated, URM are also subject to harvest units´ legaly limitations, which could underestimate NPV. Murray & Weintraub (2001) estimated the difference could be as high as 16.5%. On the other hand, if NPV was the only constraint in the planning process, clear cut sizes would likely present environmental problems (e.g., erosion, wind damage). The size and shape of clear cuts is important in managing risk of wind damage (Zeng et al. 2004, 2009).

It is required to include orientation of harvest units in the model to reduce the effect of climatic conditions (wind) at the edge of the stand (Konôpka & Konôpka 2008). Many other conditions should be incorporated into the model if it is to be willingly adopted in Central Europe. For instance, the shelterwood management system is an increasingly used silvicultural prescription in Central Europe and there are few papers that deal with spatial harvest scheduling under shelterwood management systems (see for example Marušák & Kašpar (2015)). Another important difference between plantation and managed forests in Central Europe is the length of crop rotation periods. The rotation of managed forests in Central Europe is over 100 years in most cases, compared to only a period of 6 to 8 years, as presented in this study. The longer the rotation period, managers will have to contend with greater risk and uncertainty related to forest growth and also concerns about long-term health and stability of forest stands (Pasalodos-Tato et al. 2013). Stand characteristics play an important role in lowering the risk of windthrow events (Lohmander & Helles 1987). Nevertheless the principle of the presented model is fully flexible to use in different spatial conditions by slight modification, which take into account specific management conditions. It makes the model utilizable in Central Europe region but also in other management systems which are using optimization techniques. Following this the model can be used to analyze the currently used clear cut size, shape, and adjacency constraints in managed forests of Central Europe.

The maximum distance constraints played an important role in the economic aspects of the model. Unfortunately, this approach did not consider forest roads and associated routes, so the creation of harvest blocks is only hypothetical and does not include the high capital costs of forest road building (Bruce et al. 2011). It would be necessary to use an extended type of model that includes minimizing transportation infrastructure construction costs and more detailed information about transportation costs (see for example Palma, Nelson (2013)). Nevertheless, as a general rule, the total harvest costs increase and productivity decreases with increased transportation distances (Spinelli et al. 2004). It is evident that concentrating harvesting activities will produce lower transportation infrastructure construction costs. However, this method can offer a spatial analysis of alternative harvest scenarios, or in areas without developed road networks, such as the timber farm presented in this case study. Maximum opening size had a lesser effect than the maximum distance constraints on NPV. No maximum opening size constraints produced similar NPV compared to the most restrictive maximum opening size constraint (25 ha).

It is necessary to mention that presented results are valid for specific spatial configuration of these forest stands, the assumed timber prices and interest rates, and the rapid growth of E. urophylla. However, based on the previous experience of the authors, one can assume that the general trends of our results will be similar even if other input data and proposed models were used in different management conditions.

5. Conclusions

Our study examined the question of whether considering different spatial aspects (economic and environmental) in forest harvest scheduling would have a significant influence on the total NPV of timber, one of the primary goals of every forest manager.

We presented different alternative constraints and concluded that including maximum opening size area limitation (environmental aspect) will reduce total NPV, but not to the same degree as the maximum distance limitation (economic aspect). Nevertheless, it is evident that the greater number of management goals included in harvest planning (presented as constraints), the more complex the harvest scheduling problem becomes, and that exact mathematical methods and computer tools are needed to find the optimum balance of the desired goals.

Since the presented model is flexible, it could be used also for plantation management in Central Europe. Its implementation in a variety of managed forests is specifically possible by the means of changed model´s parameters (length of period, tree species, growth function etc.). The resulted values will be different in case of lower interest rate (0.5 – 2% usually used in Central Europe), however, the general relationships will remain the same.

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ORIGINAL PAPER

Structural analysis of the drivers and barriers to forest management in the Slovak regions of Podpoľanie and Kysuce

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Abstract

The paper presents an application of structural analysis in search of key drivers and barriers of forest management in two Slovak regions: Podpoľanie and Kysuce. A comparison with factors identified in selected European regions is also presented. First, various relevant factors affecting forest management were selected for both regions. The selections draw on the pool of primary data (structured in-person interviews) and secondary data (qualitative analysis of national and European documents). Second, factors were grouped according to the STEEP categories (Society, Technology, Economy, Ecology, and Policy). Subsequently, factors were rigorously assessed by the regional stakeholders in participatory workshops, and their answers were analysed by structural analysis with the help of Parmenides EIDOS™ software. The results show that in both Slovak regions political, economic, and ecological factors dominated over social and technological factors. The comparison with selected European regions revealed that in the Slovak and other European regions, the Policy category dominated due to having the highest number of factors and their overall impact on forest management. In contrast, the least important societal domain was Technology in both the Slovak and other European regions. However, while stakeholders across the selected European regions perceived the Society domain as significant, stakeholders in both Slovak regions perceived the Economy and Ecology domains as more significant.

Key words: STEEP categories; regional stakeholders; participatory approach; forest management

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1. Introduction

To address the challenges of diverse demands for ecosystem services in a future Europe requires a better knowledge of the drivers and barriers that forest management faces across various regions. These drivers and barriers influence the decisions made by forest owners, managers, and other stakeholders, which result in various approaches to forest management and the allocation of various ecosystem services (Brodrechtová et al. 2016). Knowledge of key influences and their interplay is crucial, as they play an important role in establishing consistent narratives and models for future developments in forest management in Europe (Sotirov et al. 2014). For instance, while almost a quarter of its area is either under EU and/or national nature conservation, in terms of forest management aims the provisioning services remain still crucial (Sotirov & Deuffic 2015; Brodrechtová et al. 2016). In this respect, a deeper understanding of forest management's key drivers and barriers can help eliminate existing discrepancies between social perspectives and demands that are reflected in incoherent policy aims, inconsistent instruments, and management approaches for the conservation and sustainable management of forests across Europe (e.g. Volz 2006; Adams & Jeanrenaud 2008; Adams 2009; Arnouts & Arts 2009; Winkel et al. 2009). Moreover, as the implications of various drivers and barriers directly influence different forest management strategies, more emphasis should be placed on local context next to national and European levels (Sotirov et al. 2014; Sotirov & Deuffic 2015; Brodrechtová et al. 2016).

So far, these challenges of various drivers and barriers of forest management from the local perspective have not been addressed in European research (Sotirov & Deuffic 2015). The attempt has been done within an interdisciplinary INTEGRAL project[1]. Drawing on various schools of thought (e.g., the Advocacy Coalition Framework adapted after Sabatier & Weible 2007, the Policy Arrangement Approach adapted after Arts et al. 2006) or on politicized Institutional Analysis and Development Framework (Ostrom 2005, 2007; Clement 2010) in the case of Slovakia (Brodrechtová et al. 2016), a broad set of ecological, social, economic, technological, and political factors across local, national, and European levels has been derived. Although all these factors might be important to forest management in the future, it has not been clear which factors are the key drivers and barriers to forest management. The goal of this study is therefore twofold: first, to look at selected Slovak regions and to identify the key factors and main societal domains affecting forest management in these regions; and second, to compare the results with factors identified in selected regions across Europe that are invol-

[1] INTEGRAL project – Future oriented integrated management of European forest landscapes – FP-7 project.

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ved in the INTEGRAL project. The selected European regions differ in their basic biophysical conditions and socio-economic circumstances related to forest management and conservation (Table 1).

The views of forest managers, owners, and other stakeholders from each region in Slovakia as well as across Europe are grasped via participatory workshops and with the use of the future-oriented research method called structural analysis. The workshops are used as they enable to test scientific knowledge against the practical knowledge of forest managers, owners, and other stakeholders. Moreover, public participation in sustainable forestry may help to develop better informed and more widely accepted forest management outcomes (Sarvašová 2014). The structural analysis is method that can be applied within participatory workshops as it produces visible results in a time-span of a few hours. This method simulates the decision processes of policymakers, other actors, or consumers in choosing among alternatives. It allows studying relationships in order to identify the influential and dependent domain drivers, and it also enables domain participants to find a method to share ideas, and to express their views and thinking about a specific problem (Glenn & Gordon 2005).

In this study, the systematic analysis is demonstrated in the Slovak regions of Podpoľanie and Kysuce. The results are compared with factors identified in other European regions (Table 1). The differences and similarities found in the social, cultural, economic, and ecological contexts of forest management in Europe can generally support development of coherent policy, economic frameworks, and consistent policy instruments.

2. Material and Methods

2.1. Characteristics of INTEGRAL regions

The INTEGRAL project study was conducted in 20 regions in 10 European countries (Table 1). Diversity among all the concerned areas derives not only from differences among

Table 1. INTEGRAL study regions (Betuch et al. 2015).

No.	Region	Country	Acreage (1000 ha)	Basic characteristics
1	Teteven	Bulgaria	70	Mountainous rural area with predominance of beech forests. Dispersed rural settlements and traditional land use. Issues: wood production, biodiversity, clean water, tourism and recreation.
2	Yundola		5	Wooded landscape with 90 % forest cover, managed by University of Forestry in Sofia. Rich physiographic and biological diversity, broad spectrum of vegetation and natural sightseeing, richness of mushrooms and herbs.
3	Pontenx	France	102	Important rural landscape with 66% forest cover primarily of maritime pine. One of the largest cultivated and privately owned (92%) region in Europe. Issues: wood production, water regulation, biodiversity, recreation, hunting.
4	Munich South	Germany	60	City-near forest landscape with 72% forest cover. Urban conurbation with a high economic, ecologic and recreational value. Important recreational area for urban population. Traditional forest use is in conflict with strong demand for recreational services as well as drinking water protection.
5	Upper Palatinate		300	Rural area with 53% forest cover. Predominance of small private forest owner (60%) and state of Bavaria (26%). Arising conflicts of the "new" forest biomass utilisation (mostly energy) with traditional forest products and conservation issues.
6	Newmarket	Ireland	75	Rural, agricultural area with 17% forest cover. State forests predominance. Conflicting objectives of timber production and biodiversity conservation. Issues: wood, fuelwood, biodiversity, clean water, soil erosion.
7	Western Peatlands		211	Areas of peatlands, afforested in 1950s–1960s, many considered to be 'in the wrong place' with wrong objectives and systems. Important in terms of water quality, biodiversity and landscapes.
8	Asiago	Italy	47	High share of public (municipal) property. Asiago Plateau is a well-known tourist destination. Issues: wood production, recreational activities, biodiversity.
9	Etna		25	North-western area of Mount Etna with 20% forest cover. High fragmentation of forest ownership. Active forest management is marginal and related mainly to public forests. Biodiversity conservation and recreation are of primary concern within the Natural Park area.
10	Molise		42	Mountain region with forest and rural environment. About 40% of state forests, the remaining forests are private with high fragmentation problems. Biodiversity is not considered in active forest management. Issues: wood production, non-wood forest products.
11	Suvalkija	Lithuania	66	Region with coniferous-deciduous forests. State forests predominance. Commercial use of forests dominates with only small portion of protected areas.
12	Žemaitija		38	Medium productive mixed spruce forests on relatively unproductive agricultural land, abandoned agricultural lands, could be afforested. Predominance of private forests. Management restrictions due to the presence of National park.
13	South-East Veluwe	Netherlands	8	Conservation of natural and cultural history is the main objective while timber production is important especially for the estates. The high recreational pressure and the effects of (over) grazing are the main management concerns currently.
14	Chamusca	Portugal	75	The rural region with forests and scrublands. The main species are cork oak, eucalyptus and pines. Issues: sustainable product supply, wildfires, certification, collaboration, climate change (drought).
15	Vale do Sousa		16	Region with high productive potential for *Eucalyptus globulus* and *Pinus pinaster*. Irregular topography, high number of small private owners with forest estates about 1.5 ha. Issues: sustainable timber supply and revenues, wildfires, collaborative forest management.
16	Leiria National Forest		11	The region with largest and oldest national forests representing the state forest management system. Targeted mostly for timber production and conservation or recreation. Issues: sustainable timber supply, wind protection and recreation.
17	Kysuce	Slovakia	98	Agricultural-woodland highland territory. High fragmented forest ownership structure with large proportion of non-state owners and unsettled ownership. Coniferous spruce forests affected by intensive and widespread necrosis accompanied by an incidental felling.
18	Podpoľanie		21	Agricultural-forest highland landscape with varying land-uses. Dispersed rural settlements and traditional land use. A large part of the region under the nature protection. Very productive forests and rich biodiversity. State forests predominance.
19	Helgeå	Sweden	152	Heavily forested region with private ownership predomination. Conflicting interests: timber production and biodiversity conservation, rural development and urbanization.
20	Vilhelmina		850	Rural area with a low population density. Boreal forest is to a great extend used for timber, bio-fuel and reindeer herding. Conflicting interests: timber production and biodiversity conservation, timber production and reindeer herding.

countries, but also within national conditions. Applying a uniform methodology in different regions of Europe allowed us to capture differences or similarities in the social, cultural, economic and environmental contexts of an integrated forest management in Europe.

2.2. Characteristics of Podpoľanie and Kysuce regions

The Podpoľanie and Kysuce regions are agricultural–woodland landscapes with more than 50% of forest cover and typical for their long tradition of agricultural and forestry use. Despite these similarities, the ownership structure and current state of the forests are remarkably different in these two areas. While in Podpoľanie state forest ownership dominates, a very fragmented ownership structure is typical for Kysuce, with the ownership of large acreages of forested land unsettled due to an unfinished restitution process. Besides this, the forest stands in Podpoľanie are relatively stable, productive, and healthy, while the health of spruce forests in Kysuce in the last decades has declined (e.g. Konôpka 2004; Kulla 2009; Hlásny et al. 2010), resulting in a high proportion of incidental felling.

Podpoľanie region

The Podpoľanie region is located in the central part of Slovakia, within Banská Bystrica Region and District Detva. The area is agricultural-forest land, with forests in the north and mainly agricultural areas in the south. Beech, fir-beech, and spruce forests are typical for the very productive upper part of the forest area, in contrast to the lower part where the Carpathian oak-hornbeam forests prevail. The northern part of the region is predominantly under nature protection, belonging to the Poľana Protected Landscape Area. The area is dominated by the massif of Poľana Mt., which is the highest extinct volcano in Central Europe; the entire mountain is part of the Carpathian arc. In a relatively small area mountain thermophile species of plants and animals also are present; thus, the region is known for its diversity and richness of flora and fauna. Moreover, the Podpoľanie region has a specific cultural landscape characterized by dispersed rural settlements and traditional land use by small private owners (Mojses & Petrovič 2013; Bezák & Mitchley 2014). Ownership of the forest land is split between the state (84.7%) and non-state entities (e.g. communal, private, and church owners), so State Enterprise Forests of the Slovak Republic is the strongest forestry subject in the region (Tuček et al. 2015).

Kysuce region

The Kysuce region is located in north-western Slovakia, bordering the Czech Republic in the west and Poland in the north. It belongs to the Žilina Region and completely covers two districts: Čadca and Kysucké Nové Mesto. The region is agricultural, with forests in the north and at higher altitudes (about 56%), and agricultural land mostly in the lower hollow basin and furrows separated by hills. Forest land ownership in the Kysuce region is characterized by very high fragmentation: state forest owners (19.5%), disputed ownership managed by state forest enterprise (33.9%), and non-state forest owners including private, communal, municipal, and church owners (46.3%) (Tuček et al. 2015). Almost half of the case study area is part of the Kysuce Protected Landscape Area covering the northeast and northwest parts of the territory. Tree species composition in the region has been significantly changed from the past. Spruce was previously considered a very economical fast-growing tree species; therefore, spruce monocultures have been commonly established in the region. In recent years, however, the region has been affected by intensive and widespread necrosis of spruce stands (Sitková et al. 2010; Bošeľa et al. 2014), which also interferes with protected and valuable ecosystems within the Kysuce Protected Landscape Area. The cause of mortality is the critical health condition of spruce stands, caused by complex of abiotic, anthropogenic, and biotic harmful factors with the dominant effect of honey fungus (*Armillaria*) and an aggressive species of bark beetles (Hlásny & Sitková 2010). These factors are the cause of frequent calamities, so the Kysuce region belongs to the regions with the highest volume of incidental felling in Slovakia (e.g. in 2010 incidental felling represented 97% of total felling in Čadca District and 100% in Kysucké Nové Mesto District) (Vakula 2011).

2.3. Data collection

2.3.1 Primary and secondary data collection

Within the INTEGRAL project the various drivers and barriers were analysed at (i) local level of study regions, (ii) national and (iii) European level. Identification of various determinants of forest management in different regions was based on primary data (structured in-person interviews) and secondary data (output of qualitative analysis of national and European documents).

In Slovakia primary data were obtained via 50 in-person interviews with forest owners, managers from the Podpoľanie and Kysuce regions, and other relevant actors at the sub-national and national levels (Brodrechtová et al. 2016). The output of this research phase was the identification of subset of 22 drivers and barriers of forest management decision-making on regional level. More precisely, biophysical conditions and attributes of the community, including the politico-economic context, institutions, and discourses, were among the significant drivers affecting forest owners and managers, and their interactions and decisions concerning forest management in the Podpoľanie and Kysuce regions.

Analysis of secondary data in the form of desktop research was conducted parallel to the primary data collection. First, an extensive review of existing national documents (e.g. strategic and prognostic documents related to forestry, nature protection, and the rural economy) was conducted. This resulted in the isolation of subset of 28 drivers and barriers, including bio-physical conditions and attributes of the community, politico-economic contexts, and institutions that can potentially determine decisions concerning forest management in Slovakia. Second, European Union (EU) documents (e.g. regulations and directives concerning forestry, nature protection, and energy) were subsequently systematically scrutinized, which resulted in the identification of subset of 35 potential drivers and barriers of forest management (Riemer, 2013). These factors concerning attributes of the community, including demographic and technology development, politico-economic context, institutions, and discourses provided a wide overview of possible barriers and drivers of forest management in Europe.

2.3.2 Selection of relevant factors

The total set of 85 local, national, and EU drivers and barriers of forest management decision making as an outcome of broad diagnostic analysis represented a base for further investigation. More detailed analysis of the forest management factors with the help of structural analysis resulted in a required reduction to 15 – 25 relevant factors for each region (Schüll 2013).

Reduction to 15 – 25 relevant factors was completed at a workshop attended by 10 experts from Technical University and National Forest Centre, both in Zvolen, Slovakia. From the list of 85 factors, every expert chose 20 factors considered relevant for the further development of forest management decision making in the Podpoľanie and Kysuce regions. Subsequently, the experts ranked every chosen factor from most important to least important. Finally, the factors were evaluated by the frequency analysis, taking into account the frequency and ranking of the factors. The findings of the analysis were set at 20 relevant factors for each region. The factors were afterwards thematically grouped according to the STEEP categories (Table 2). STEEP is an acronym for societal fields 'society', 'technology', 'economy', 'ecology' and 'politics'. The allocation of factors to these categories helped to identify a possibly unbalanced selection.

2.4. Data analysis

2.4.1 Participatory workshops

To determine key drivers and barriers to future forest management, a structural analysis was applied. The basic idea behind the analysis was to isolate and assess the relative mutual influences of the key factors affecting forest management. Each factor was assessed according to its influence on the other factors included in the analysis and also according to how strongly it was affected by the other factors (Glenn & Gordon 2009). In order to grasp the view of regional stakeholders in Podpoľanie and Kysuce, and to decrease subjectivity in factors assessment, the structural analysis was carried out via participatory workshops. In each region, seven regional stakeholders participated (from 15 invited in Podpoľanie and from 11 invited in Kysuce) at a half-day workshop (Table 3).

2.4.2 Conducting structural analysis

The task of the workshop participants was to assess the relationship among 20 relevant factors that will significantly influence forest management in their regions. First, these factors were structured into STEEP categories and explained to participants. Each factor was introduced individually, with discussion about why it was considered a factor that will influence future forest management. Second, each participant received the *structural analysis matrix* worksheet printed in A3 format (Fig. 1). This matrix consisted of 20 relevant factors listed in columns and rows. Finally, the participants answered two questions for each pair of factors: (1) *How strongly does one factor affect the other one?* and (2) *To what extent can the development of one factor be explained*

Table 2. 20 relevant drivers and barriers of forest management for Podpoľanie and Kysuce regions.

Level of evaluation / STEEP category	Macro level	Meso level	Micro level
Society		SOC1 Demography development SOC3 Public opinion	SOC2 Qualified workforce SOC4 Codes of conduct
Technology		TEC1 Innovation and technology TEC2 Wood processing industry	
Economy	ECN2 Timber market ECN3 Bioenergy market	ECN4 Tourism	ECN1 Forest owners economic situation ECN5 Forest management Costs
Ecology	ECO3 Climate change		ECO1 State and structure of forest ECO2 Abiotic and biotic harmful factors ECO4 Non-wood ecosystem Services
Politics	POL1 Environmental policy and legislation POL2 Forest policy and legislation POL3 Rural Development policy	POL5 Subsidies and compensations	POL4 Forest ownership Structure

Table 3. Basic characteristics of workshop participants in Podpoľanie and Kysuce regions.

	Podpoľanie region								Kysuce region							
		Position		Education		Age				Position		Education		Age		
	Actors	D	M	H	S	40+	50+	60+	Actors	D	M	H	S	40+	50+	60+
State forest managers	1	1		1			1		1		1	1		1		
Private forest owners	1	1		1		1			2		2	1	1	2		
District government	1		1	1		1			2	1	1	2		1		1
State nature protection	1	1		1		1			—							
National Forest Centre	1		1	1		1			1		1	1		1		
Slovak association of wood processors	1		1	1		1			—							
Non-state forest owner association	1		1	1				1	1		1	1			1	
Total	7								7							

Abreviations: D – Director/Chairman; M – Manager; H – Higher; S – Secondary.

by the development of the other factor? (Schüll, 2013). In order to avoid a negative group effect, everyone filled out the printed *structural analysis matrix* worksheet individually. The participants were given sufficient time to carefully consider their responses.

An evaluation of individual factors' influence in the structural matrix was measured on a Likert scale where 0 = no influence, 1 = weak influence, 2 = medium influence, and 3 = strong influence. Subsequently, an arithmetical average of values for each matrix cell was calculated. While the resulting *structural analysis matrix* reflected the view of all participants, the opinion of each participant was weighted equally and not influenced by collective thought. Furthermore, the sums of rows and columns in the *structural analysis matrix* represented metrics for the level of mutual relationships among the considered factors. While the "row sum" represented the Active value (AV) of a factor and indicated how strongly that factor affects other factors, the "column sum" of a factor represented the Passive value (PV) of a factor and indicated how strongly that factor is influenced by other factors. In this way, every factor was evaluated according to the relationship between its Active and its Passive values (Fig. 1).

2.4.3 Conducting structural analysis with the help of Parmenides EIDOS™

The structural analysis applied via participatory workshops was carried out with the help of the program Parmenides EIDOS™ software, which is usually used in decision-making processes and strategic decisions. Its analytical and visualization functions help experts to identify key elements, especially in complicated and complex processes that require a multidisciplinary approach (Navrátil et al. 2014). Moreover, the Active and Passive values of the factors could be displayed by means of the Active/Passive Map. More precisely, the Parmenides EIDOS™*'s* program module *Situation Analysis* allows all assessed factors to be displayed in coordinate axes using the individual Active and Passive values as their x- and y-coordinates (Fig. 2). In the map four groups of factors are distinguished (Schüll 2013): (i) **active** or influent factors (with high AV and low PV) located in the upper left quadrant, (ii) **dynamic** or critical factors (with high AV and high PV) located in the upper right quadrant, (iii) **excluded** or lazy factors (with low both AV and PV) located in the lower left quadrant, and (iv) **passive** or depending factors (with low AV and high PV) located in the lower right quadrant.

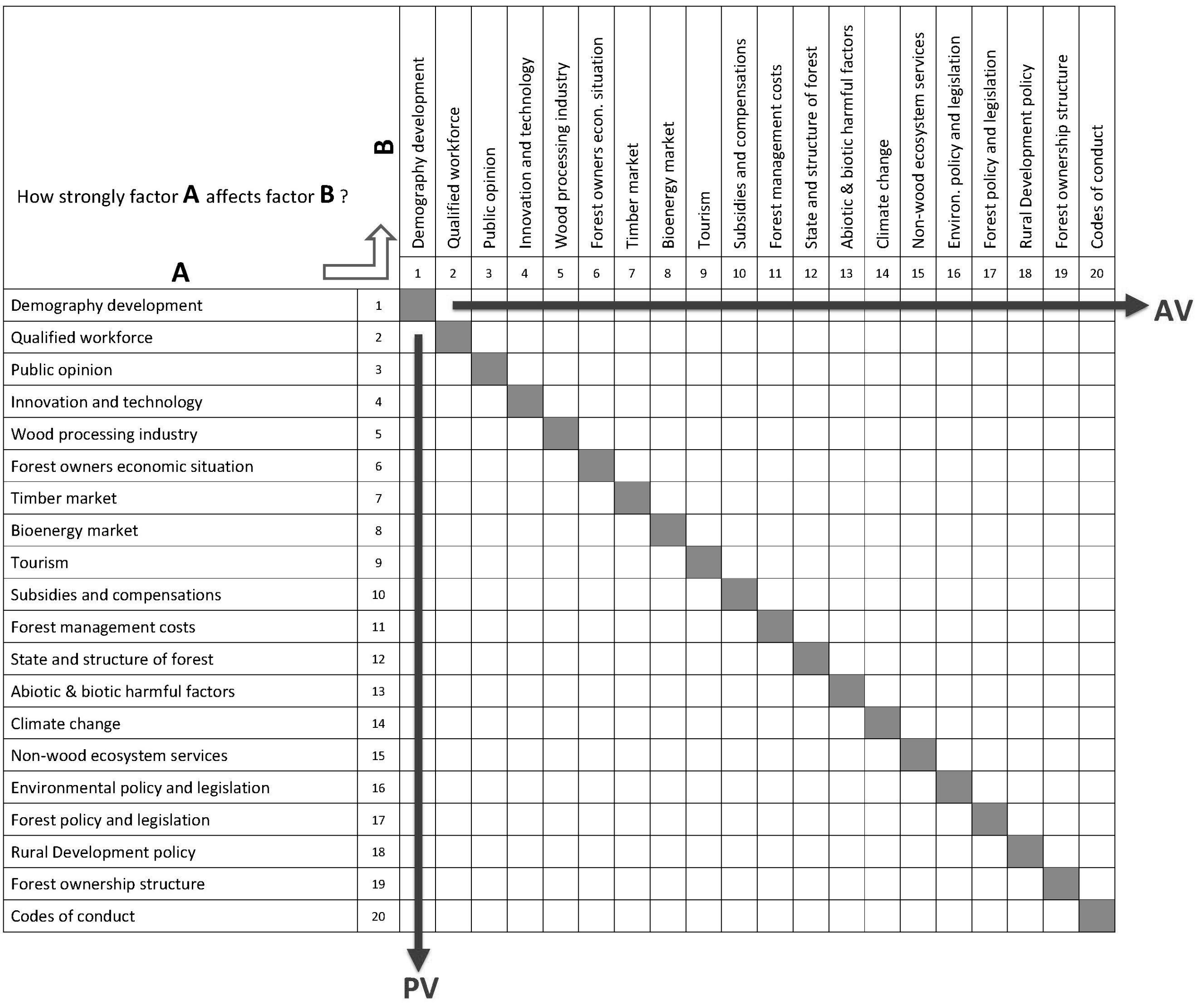

Fig. 1. *Structural analysis matrix* with 20 relevant factors used in participatory workshops.

For instance, **active** factors influence future forest development more than they are influenced by other factors (i.e., they are very influential and have a low dependency). These factors are hard to steer and control given their low PV. Dynamic factors are very influential and at the same time very dependent; thus, any action on them has consequences on the other assessed factors. Since excluded factors have little influence and, at the same time, little dependence, they are rather isolated from the rest of the assessed factors. Passive factors are influenced more strongly than they influence other factors. They are also sensitive to the development of other especially dynamic factors. In summary, the higher the position of a factor on the map, the stronger it affects the other factors. In contrast, the right-most position means that the factor is heavily affected by the other factors. Consequently, factors with high AV are factors of special importance. While the active factors can probably serve as major key drivers or barriers for the future development of forest management, dynamic factors should receive special attention, because they are more likely to change and more likely to be changed (Schüll 2013).

2.4.4 Selection of key factors

The results of the structural analysis realized within the participatory workshops were twofold: (i) key factors were isolated according to Active and Passive values, and (ii) key factors were isolated according to Active/Passive maps. The Active and Passive values were used to compare key factors from Slovak regions with factors in other INTEGRAL regions. However, the final selection of key factors in the Podpoľanie and Kysuce regions was based on Active/Passive maps and subsequent discussion with stakeholders in participatory workshops. Distribution of factors in individual quadrants of maps was presented to stakeholders at the end of the workshops. The following discussions resulted in final identification of key drivers and barriers for forest management in the Podpoľanie and Kysuce regions.

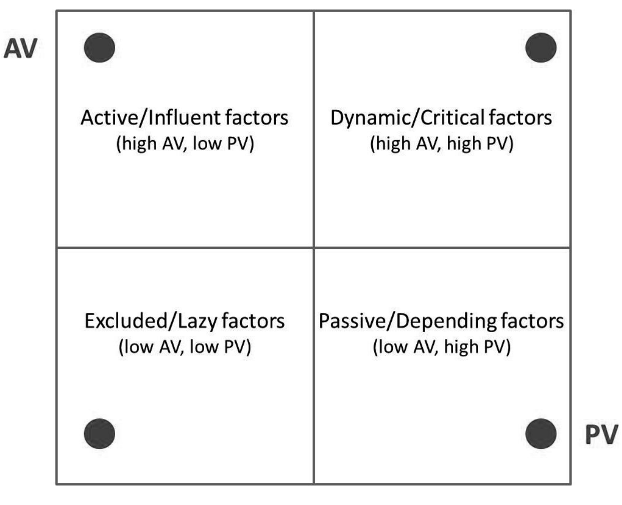

Fig 2. Distribution of factors in Active/Passive map.

2.4.5 Comparison of results within project INTEGRAL

Resulting Active and Passive values of factors from the Podpoľanie and Kysuce regions were compared with Active and Passive values of factors identified in other INTEGRAL regions. In order to ensure the comparability of results, Active and Passive values from the Podpoľanie and Kysuce regions were modified. First, as not all regions used the same Likert scale for their structural analysis (some used 0 – 3; some used 0 – 10), the results were adjusted to a consistent scale ranging from 0 to 10. Second, since the structural analysis across the INTEGRAL regions also differed by the number of involved factors, adjusted active and passive values of each factor were calculated using the following formulas:

$$AVad = \left[\frac{\sum_1^n AV}{(n-1)}\right] \times 10$$

$$PVad = \left[\frac{\sum_1^n PV}{(n-1)}\right] \times 10$$

(Av_{ad} – adjusted Active value and PV_{ad} – adjusted Passive value). The range of the scale used and the number of factors involved across INTEGRAL regions ensured comparability of the results (Hinterseer et al. 2014).

2.4.6 Analysis of factors according to STEEP categories

The factors were also assessed by their frequencies within the STEEP categories. This gave a picture of the importance of individual societal domains for the development of forest management. However, the frequencies do not give any information about the overall influence of each STEEP category. Therefore, in both the Podpoľanie and Kysuce regions, the Global Active values for each STEEP category were calculated by adding the Active values of the individual factors. Subsequently, the results of Slovak regions were compared with the factors isolated in other INTEGRAL regions. Again, the adjusted Active values were used to ensure comparability.

3. Results and discussion

3.1. Active and Passive values – Podpoľanie and Kysuce regions

In the Podpoľanie region (Table 4), the highest Active values were assigned to two policy factors (*Subsidies and compensations, Forest policy and legislation),* followed by the economic factor (*Forest owners' economic situation*). The factors with the highest Passive values, and therefore the factors most affected by other assessed factors, were *Forest owners' economic situation*, *State and structure of forest,* and *Forest management costs*.

In the Kysuce region (Table 5), the regional stakeholders assigned the highest Active values to ecological factors (*Climate change*, *Abiotic and biotic harmful factors*, *State and* *structure of forest)* and economic factors *(Subsidies and compensations)*. The factor that had the highest Passive value was *Forest owners' economic situation* followed by the *Forest management costs* and *Timber market*.

While the most influential factors with high Active values in the Podpoľanie region were mainly political, in the Kysuce region, the most influential factors with high Active values were mainly ecological. This could be attributed to the regional stakeholders' perception of unfavourable health conditions of the Kysuce forests. Additionally, in both regions the factors *Subsidies and compensations* and *Forest policy and legislation* were among the top-ranked influential factors.

Table 4. Active and passive values of factors in Podpoľanie region.

Podpoľanie region							
Rank	Code	Factor	Total AV	Rank	Code	Factor	Total PV
1	POL5	Subsidies and compensations	6.32	1	ECN1	Forest owners' economic situation	6.95
2	POL2	Forest policy and legislation	6.23	2	ECO1	State and structure of forest	6.60
3	ECN1	Forest owners' econ. situation	5.95	3	ECN5	Forest management costs	6.49
4	POL4	Forest ownership structure	5.88	4	ECN3	Bioenergy market	6.09
5	POL3	Rural Development policy	5.75	5	ECN2	Timber market	5.88
6	ECN2	Timber market	5.63	6	POL5	Subsidies and compensations	5.77
7	ECO1	State and structure of forest	5.51	7	TEC2	Wood processing industry	5.72
8	SOC4	Codes of conduct	5.49	8	ECO4	Non-wood ecosystem services	5.58
9	ECN5	Forest management costs	5.47	9	POL3	Rural Development policy	5.49
10	ECN3	Bioenergy market	5.23	10	TEC1	Innovation and technology	5.32
11	ECO3	Climate change	5.19	11	POL2	Forest policy and legislation	5.19
12	ECO2	Abiotic and biotic harmful factors	5.11	12	ECN4	Tourism	5.04
13	ECO4	Non-wood ecosystem services	4.74	13	SOC3	Public opinion	4.74
14	TEC1	Innovation and technology	4.58	14	POL1	Environ. policy and legislation	4.74
15	POL1	Environ. policy and legislation	4.54	15	ECO2	Abiotic and biotic harmful factors	4.51
16	TEC2	Wood processing industry	4.28	16	SOC4	Codes of conduct	4.37
17	SOC1	Demography development	3.81	17	SOC2	Qualified workforce	3.46
18	ECN4	Tourism	3.68	18	POL4	Forest ownership structure	3.35
19	SOC2	Qualified workforce	3.67	19	ECO3	Climate change	2.60
20	SOC3	Public opinion	2.89	20	SOC1	Demography development	2.14

Table 5. Active and passive values of factors in Kysuce region.

Kysuce case region							
Rank	Code	Factor	Total AV	Rank	Code	Factor	Total PV
1	ECO3	Climate change	6.32	1	ECN1	Forest owners' economic situation	7.37
2	ECO2	Abiotic and biotic harmful factors	6.18	2	ECN5	Forest management costs	6.91
3	POL5	Subsidies and compensations	6.11	3	ECN2	Timber market	6.63
4	ECO1	State and structure of forest	6.11	4	ECO1	State and structure of forest	6.14
5	POL2	Forest policy and legislation	5.86	5	ECN3	Bioenergy market	5.96
6	ECN5	Forest management costs	5.75	6	TEC1	Innovation and technology	5.89
7	SOC2	Qualified workforce	5.75	7	POL3	Rural Development policy	5.79
8	ECN1	Forest owners' econ. situation	5.65	8	POL5	Subsidies and compensations	5.72
9	ECN2	Timber market	5.54	9	TEC2	Wood processing industry	5.72
10	POL1	Environ. policy and legislation	5.54	10	POL2	Forest policy and legislation	5.51
11	POL4	Forest ownership structure	5.47	11	SOC2	Qualified workforce	5.47
12	TEC1	Innovation and technology	5.44	12	ECN4	Tourism	5.40
13	TEC2	Wood processing industry	5.26	13	SOC3	Public opinion	5.33
14	POL3	Rural Development policy	5.19	14	POL1	Environ. policy and legislation	5.09
15	SOC1	Demography development	5.02	15	ECO2	Abiotic and biotic harmful factors	5.05
16	SOC3	Public opinion	4.67	16	ECO4	Non-wood ecosystem services	4.91
17	ECN3	Bioenergy market	4.53	17	POL4	Forest ownership structure	4.81
18	ECN4	Tourism	4.42	18	SOC4	Codes of conduct	4.21
19	ECO4	Non-wood ecosystem services	4.35	19	ECO3	Climate change	2.91
20	SOC4	Codes of conduct	4.21	20	SOC1	Demography development	2.53

Table 6. Active and passive values of factors from other INTEGRAL regions (Hinterseer et al. 2014).

INTEGRAL regions					
Rank	Factor	Total AV	Rank	Factor	Total PV
1	Policies, laws and regulations	104.42	1	Policies, laws and regulations	91.17
2	Ownership structure	88.24	2	Timber market	73.23
3	Timber market	79.16	3	Ownership structure	68.70
4	Population	60.48	4	Bioenergy market	53.91
5	Bioenergy market	55.03	5	Subsidies	49.96
6	Climate change	54.27	6	Owner`s norms, values & objectives	49.72
7	Subsidies	48.51	7	Management plans	48.77
8	Non-wood ecosystem services	48.50	8	Non-wood ecosystem services	44.12
9	Management plans	46.88	9	Owner`s economic situation	44.12
10	Owner`s norms, values & objectives	40.96	10	Population	42.07
11	Owner`s economic situation	38.38	11	Public opinion	40.16
12	Forest calamities	36.31	12	Timber processing industry	39.21
13	Public opinion	36.14	13	Forest structure	38.72
14	Timber processing industry	35.34	14	Climate change	36.33
15	Forest structure	34.26	15	Rural Development (Plans/Activities)	36.31
16	Rural Development (Plans/Activities)	34.11	16	Technology	34.24
17	Technology	31.34	17	Forest road network	32.59
18	Forest services and functions	29.06	18	Type of silviculture	31.11
19	Forestry paradigms	27.43	19	Forest services and functions	29.91
20	Certification	25.79	20	Management costs	26.70

Comparison of the Passive values in Podpoľanie and Kysuce revealed that the top five influenced factors (*Forest owners' economic situation*, *Forest management costs, State and structure of forest*, *Timber market,* and *Bioenergy market*) were similar. According to their Active and Passive values, six factors (*Forest owners' economic situation, Subsidies and compensations, State and structure of forest, Forest management costs, Timber market,* and *Forest policy and legislation)* were therefore identified as key factors for future forest management of both the Podpoľanie and Kysuce regions.

3.2. Active and passive values – other INTEGRAL regions

Comparison across INTEGRAL regions (Table 6) revealed that *Policies; laws and regulations*; *Timber market*; *Ownership structure*; *Bioenergy market*; *Subsidies;* and *Owner`s norms, values, and objectives* were important for future forest management. Moreover, the first three factors have both the highest active and passive values, considerably higher than other factors. Accordingly, based on the perception of regional stakeholders across Europe, the *Policies, laws and regulations*, *Timber market,* and *Ownership structure* factors were crucial for future forest management in Europe.

If compared to the Slovak regions, the *Policies, laws and regulations*, *Timber market,* and *Subsidies* factors were universal for both Slovak and other European regions. However, for stakeholders from the Podpoľanie and Kysuce regions, *State and structure of forest*, *Forest management costs,* and *Forest owners' economic situation* were also important factors.

3.3. Evaluation of factors according to STEEP categories

In terms of frequency of factors within STEEP categories in the Podpoľanie and Kysuce regions, the *Policy* category had the highest number of factors (Table 7). Comparison across INTEGRAL regions showed similar results. There was a considerable gap between *Policy* and other categories such as *Economy*, *Society* and *Ecology*. Across all INTEGRAL regions, the *Technology* category was far behind all other categories.

Table 7. Frequency of factors grouped by STEEP categories.

STEEP category	Frequency: Podpoľanie and Kysuce regions	Frequency: INTEGRAL regions
Society	4	85
Technology	2	46
Economy	4	88
Ecology	4	71
Policy	5	102

In both Slovak regions, the ranking of STEEP categories according to Global Active values showed similar findings in the number of factors in each category (Table 8). Specifically, in Podpoľanie and Kysuce, the *Policy* category had not only the highest frequency of identified key factors, but it also had the highest overall impact. The Global Active values of the *Economy*, *Ecology,* and *Society* categories indicated differences in their relevance despite the same number of factors. In both regions, the *Technology* category had the least impact, with a huge gap between it and other categories in ranking. In sum, according to the Global Active values the STEEP categories *Policy*, *Economy,* and *Ecology* were considered societal domains with the highest importance for future forest management in the regions of Podpoľanie and Kysuce.

From the European perspective, the comparison of STEEP categories by Global Active values revealed both similarities and differences with the Slovak regions. The *Policy* category was ranked the highest, whereas *Technology* had the lowest ranking (Table 8). In contrast, in the Slovak regions the *Economy* category was the second most important; in INTEGRAL regions the second most important category was *Society*. Thus, there were apparent dissimilarities between stakeholders' perceptions of societal factors in Slovak and in other European regions involved in INTEGRAL.

Table 8. STEEP categories and their Global Active values.

Podpoľanie region			Kysuce region			*INTEGRAL regions		
Rank	STEEP Category	Global AV	Rank	STEEP Category	Global AV	Rank	STEEP category	Global AV
1.	Policy	28.72	1.	Policy	28.18	1.	Policy	426.86
2.	Economy	25.96	2.	Economy	25.89	2.	Society	344.72
3.	Ecology	20.54	3.	Ecology	22.95	3.	Economy	319.28
4.	Society	15.86	4.	Society	19.65	4.	Ecology	241.95
5.	Technology	8.86	5.	Technology	10.7	5.	Technology	163.29

* Hinterseer et al. 2014.

3.4. Active/Passive maps – Podpoľanie and Kysuce

Active/Passive Maps were used for easier and transparent visualization of the results during participatory workshops and subsequent discussion of findings with regional stakeholders. The resulting distribution of factors in maps showed at a glance how strongly each factor acted on all other factors and how strongly it was affected by other factors (Fig. 3).

In Podpoľanie the distribution of factors and their concentration in the right upper quadrant demonstrates their dynamics as well as their strong connection among each other. Policy factors *Subsidies and compensations* (POL5), *Forest policy and legislation* (POL2), and *Rural development policy* (POL3) clearly formed the group of most **dynamic** factors. Similarly, the majority of economic and ecological factors were dynamic factors. Factors located in the upper left corner, *Ownership structure* (POL1), *Climate change* (ECO3), and *Demography development* (SOC15), were determined to be **active;** thus, they were very influential and uncontrollable factors. *Public opinion* (SOC3) fell into the lower right quadrant as the only **passive** factor. No one factor was determined to be an **excluded** factor.

The factors in Kysuce were more dispersed. The current unfavourable state of forests in the region was reflected in the highest positions of the ecological factors *Climate change* (ECO3), *State and structure of forest* (ECO1), and *Abiotic and biotic harmful factors* (ECO2). The latter two factors formed the group of **dynamic** factors along with *Subsidies and compensations* (POL5), *Forest policy and legislation* (POL2), *Forest management costs* (ECN5), *Qualified workforce* (SOC2), *Forest owners' economic situation* (ECN1), and *Timber market* (ECN2). *Climate change* (ECO3) and *Forest ownership structure* (SOC4) were deter-

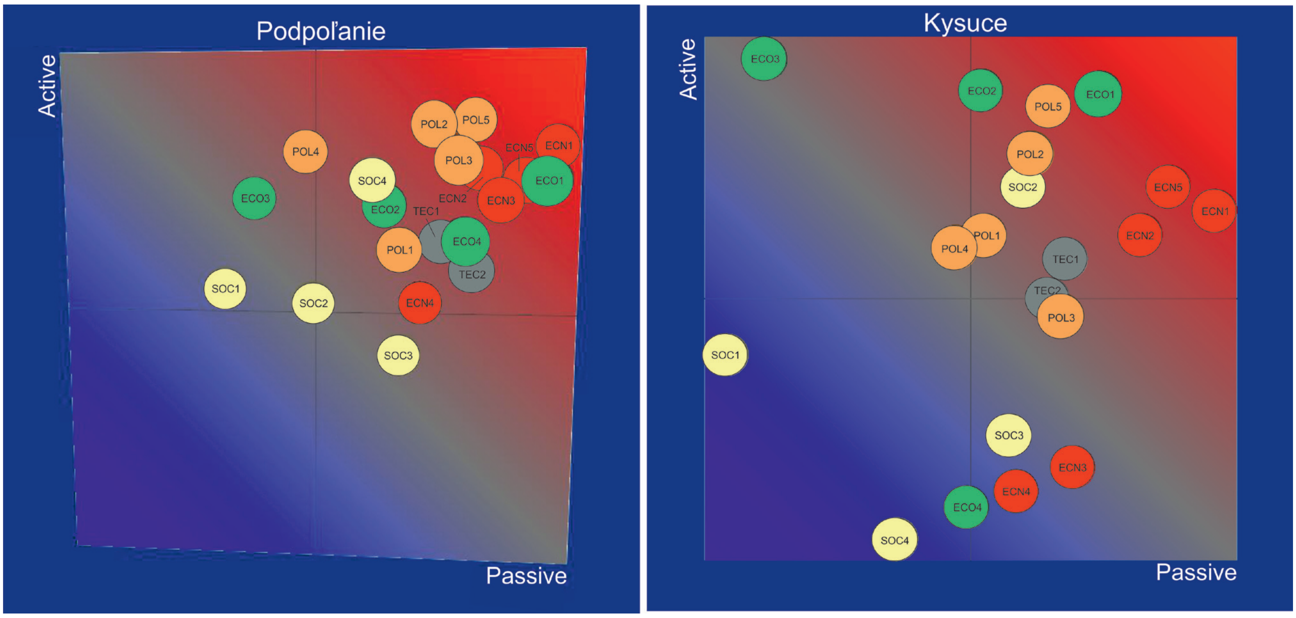

Fig 3. Active/Passive Maps for Podpoľanie and Kysuce regions (Society – yellow, Technology – grey, Economy – red, Ecology – green, Policy – orange).

mined to be **active** factors. The lower left quadrant contained the **passive** factors *Public opinion* (SOC3), *Bioenergy market* (ECN3), *Tourism* (ECN4), and *Non-wood ecosystem services* (ECO4). Two societal factors, *Demography development* (SOC1) and *Codes of conduct* (SOC4), formed the group of excluded factors.

3.5. Selection of key factors according to Active/ Passive maps and discussion in participatory workshops

The visualization of results via the Active/Passive maps (Fig. 3) supported discussion with workshops participants, who helped to detect the subtle differences between the Podpoľanie and Kysuce regions, which in turn aided the final selection of key factors for future forest management in both regions.

Comparison of the Active/Passive maps of Podpoľanie and Kysuce revealed apparent dissimilarities as well as commonalities between the regions. The most dynamic factors in Podpoľanie were political and in Kysuce were ecological. In other words, in Kysuce the position of factors *State and structure of forest* (ECO1), and *Abiotic and biotic harmful factors* (ECO2), mirrored the current poor health of forest stands and excessive incidental felling, which was confirmed by Kysuce's stakeholders in the workshop discussion.

Looking at the distribution of policy factors (Fig. 3), it is evident that in both regions all factors are in the right upper quadrant or on its border. While the *Rural development policy* (POL3) was classified by stakeholders in Podpoľanie as a clearly dynamic factor, in Kysuce it was located on the border of passive factors. In both maps, the leftmost policy factor *Forest ownership structure* (POL4) influenced the remaining factors much more strongly than it was influenced. Despite the diametrically different situation in the ownership structure between these two regions (state ownership predominance in Podpoľanie; highly fragmented ownership structure in Kysuce), stakeholders in both regions expressed the opinion that forest ownership significantly affects forest management, but it is hard to control its arrangement. Thus, *Forest ownership structure* was regarded by stakeholders as a stable factor, although stakeholders from Kysuce especially stressed the need for an adjustment of fragmented ownership structure.

With the exception of *Tourism* (ECN4) and *Bioenergy market* (ECN3, in Kysuce), in both maps all other economic factors were very influential and at the same time very dependent. The dynamic factors *Forest owners' economic situation* (ECN1), *Timber market* (ECN2), and *Forest management costs* (ECN5) were in close proximity, situated furthest to the right of all factors. This illustrates the stakeholders' perception that those factors significantly affect forest management in their regions but, at the same time, could be seriously influenced by other factors. Thus, stakeholders from both regions stated during discussions that these factors might be classified as crucial factors. While the *Bioenergy market* (ECN3) factor was classified as dynamic factors in Podpoľanie, surprisingly, it was classified as a passive factor in Kysuce. Stakeholders from Kysuce have mentioned that they still consider the *Timber market* factor more important than the *Bioenergy market* factor.

In both regions, the factor *Non-wood ecosystem services* (ECO4) had the least importance of all ecological factors that were considered; even in Kysuce the factor was located on the boundary between excluded and passive factors. In both maps, the most affected (rightmost) ecological factor was *State and structure of forest* (ECO1). Contrariwise, the leftmost ecological factor *Climate change* (ECO3) illustrates the stakeholders' perception that one of the major ecological drivers can be influenced very little.

The distribution of societal factors in both maps showed that in each region just one factor was determined to be dynamic. While in Podpoľanie the *Codes of conduct* (SOC4) was rated as very influential and at the same time a very dependent social factor, conversely, in Kysuce this factor was determined to be the least influential factor of all 20 assessed factors. It seems that in Podpoľanie stakeholders perceived the significance of informal institutions, while stakeholders in Kysuce were more worried about different problematic issues. In subsequent discussions, stakeholders in Podpoľanie confirmed the impact of informal institutions (e.g., clientelism, lobbying, and networking) and expressed their concerns about the influence of political or financial groups. Although stakeholders in Kysuce also perceived these types of influences, they did not consider it as serious a problem. Kysuce's stakeholders considered fragmented ownership structure the main problem. As the size of state owned forests in Kysuce (19.5%) is smaller than that of Podpoľanie (84.7%), the influence of the political and financial groups is less pronounced. On the other hand, the lack of skilled labour in Kysuce was reflected in the position of *Qualified workforce* (SOC2), which was classified as a dynamic factor. Stakeholders in Kysuce confirmed in discussion the concerns about shortages of skilled workers in the near future. *Public opinion* (SOC3) was placed in both maps more among passive factors than active ones. Even in Podpoľanie, this factor received the lowest active sum of all the assessed factors; thus, according to stakeholders, it was influenced more strongly by other factors than it acted on them. In both cases, the leftmost factor was clearly *Demography development* (SOC1). Despite its higher active value compared to other social factors, *Public opinion*, *Qualified workforce* (in Podpoľanie), and *Codes of conduct* (in Kysuce), stakeholders perceived this social factor in both case study areas as a societal driver that was influenced very little by other factors.

In both maps, the technological factors *Innovation and technology* (TEC1) and *Wood processing industry* (TEC2) were in close proximity to each other. Although they were in the upper right quadrant, their position near the boundary of passive factors indicates that they had less influence because they were affected by other factors. Subsequent discussions confirmed stakeholders' perception that innovations and the renewal of vehicle fleet are influenced mainly by availability of finances.

Table 9. Key strategic drivers and barriers of forest management in Podpoľanie and Kysuce regions.

Podpoľanie region		Kysuce region	
Rank	Isolated key factor	Rank	Isolated key factor
1.	POL5 – Subsidies and compensations	1.	ECO1 – State and structure of forest
2.	POL2 – Forest policy and legislation	2.	ECO2 – Abiotic and biotic harmful factors
3.	ECN1 – Forest owners' economic situation	3.	POL5 – Subsidies and compensations
4.	POL3 – Rural development policy	4.	POL2 – Forest policy and legislation
5.	ECN2 – Timber market	5.	ECN5 – Forest management costs
6.	ECO1 – State and structure of forest	6.	ECN1 – Forest owners' economic situation
7.	ECN5 – Forest management costs	7.	SOC2 – Qualified workforce
8.	ECN3 – Bioenergy market	8.	ECN2 – Timber market
9.	SOC4 – Codes of conduct		

In summary, according to the Active/Passive map and discussion with stakeholders, in the Podpoľanie region the set of nine key drivers and barriers to forest management was finally isolated (Table 9). The highest ranked were policy factors (*Subsidies and compensations*, *Forest policy and legislation*, and *Rural development policy*) and the economic factor *Forest owners' economic situation*. Ecological and societal factors were represented by *State and structure of forest* and *Codes of conduct*. In the Kysuce region eight key factors were selected that will affect forest management in the future (Table 9). The most important were two ecological factors (*State and structure of forest*, *Abiotic and biotic harmful factors*), followed by policy, economic factors, and the societal factor *Qualified workforce*.

4. Conclusions

Findings of structural analysis showed similarities as well as differences between the Podpoľanie and Kysuce regions. Although in both regions, political factors were among the dominant factors, stakeholders in the Kysuce region also very strongly perceived the adverse impact of harmful factors on the current state of their forests, and thus on the entire forest management in Kysuce. Results in Podpoľanie indicated that if the forests are relatively healthy and in good condition, the main societal domains driving forest management are Policy and Economy. The Active/Passive maps which resulted and subsequent discussions during workshops also revealed a slightly different perception of societal factors in both regions. In Podpoľanie, the prevalence of state owned forests is an obvious influence of the informal institution of forest management. In contrast, in Kysuce, with its highly fragmented ownership structure and prevalence of non-state owners, this impact is not so significant.

Commonalities and dissimilarities were also revealed between Slovak and other European regions involved in the INTEGRAL project. The STEEP category Policy seems to be the main societal domain affecting forestry and forest management across Europe. In Slovak and INTEGRAL regions, the Policy category dominated by influencing a number of factors and also through its overall impact. In general, forest, environmental or rural development policies, and laws and regulations were perceived by stakeholders from other European regions as the factors with the highest importance for forest management. Additionally, the technological factors were considered to follow forest development rather than drive it. Differences in results concerned perception of social factors. While the STEEP category Society was ranked high in INTEGRAL regions, stakeholders in Slovak regions preferred economic and ecological factors.

This study's contribution was on a theoretical level as well as on a methodological level. The future research method of structural analysis proved to be a suitable instrument for comparing a mixture of qualitative and quantitative factors influencing forest management. Since the analysis compares the relevant factors based on their mutual influence, it is essential to properly select the relevant factors to be analysed. It is important to include all relevant factors that affect the analysed system, which in this case is forest management. As the structural analysis allows comparison at first glance of seemingly incomparable qualitative (e.g., climate change) and quantitative (e.g., timber market) factors, it appears to be a suitable method of application in forestry.

Using Active/Passive values was particularly appropriate for evaluation of the overall impact of individual STEEP categories. Active/Passive maps allowed more detailed comparison of the various factors that were considered. The Parmenides Eidos™ analytical tool allowed visualization of the individual stakeholder's perception of a factor's importance. Distribution of factors in the map's quadrants is much more readable and transparent as simply Active or Passive values.

The application of the structural analysis in participatory manner proved to be very suitable for identification of drivers and barriers to forest management. For correct implementation of the method it was necessary that the workshop participants represented different interest groups of regional stakeholders. Our results confirmed other researches that stakeholder's participation in forestry decision-making might provide regional expertise, increase the legitimacy of final outcome (e.g. Beckley et al. 2005) and strength the involvement of local stakeholders in policy-making processes (e.g. Sarvašová 2014; Marzano et al. 2015; Sarvašová 2016).

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ORIGINAL PAPER

Ultrasonic technique for evaluation of initial stadium of wood degradation in exterior conditions without ground contact

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Abstract
The experiment evaluate the possibility of using non-destructive measure techniques of the mechanical properties of wood using ultrasonic to determine the initial stages of degradation by biotic and abiotic factors in the outdoors without ground contact. Nine tree species were tested: spruce, pine, Douglas fir, larch, oak, black locust, maple, poplar and alder. Test specimens were exposed to the exterior according to EN 927-3, Prague-Suchdol in the Czech Republic. Measuring changes in velocity of ultrasonic using the apparatus Ultrasonic Timer and moisture content change were measured after 1, 2, 3, 4 and 6 months. Certain ways of detecting the initial stages of damage have been demonstrated to trees oak, larch and spruce. The initial stages of damage by molds at non-durable maple, alder and poplar had not a clear impact on the decrease in the speed of ultrasonic, as well as hairline surface cracks at the Douglas fir.

Key words: wood; exterior; biotic and abiotic degradation; detection; ultrasonic velocity

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1. Introduction

Exterior wood applications are widely used in building industry, in the garden architecture and for outdoor mobiliar, but also in various wood structures such as fences, wooden houses, bridges, etc. (Štefko & Reinprecht 2004). The advantages of wood as renewable raw material can be sorted by excellent workability, strength and structural characteristics in comparison with steel, ceramic and silicates (Požgaj et al. 1993). The downside is, particularly for non-durable wood species, the possibility of damage to the timber by biotic and abiotic factors. Especially fungi and insects are able to completely disrupt the static function of the timber element or the whole building in a relatively short period of several years (Schmidt 2006; Reinprecht 2008). Abiotic degradation, particularly atmospheric degradation is also not negligible detrimental factor for the function of wood in construction. First cause esthetic color changes (Evans 2008), but there is also a significant formation of cracks that allow deeper penetration of water into the timber. This creates better conditions for the subsequent attack by decay fungi, which are tied up with wood moisture above 20%. For proper function of wooden buildings and structures is required regular maintenance and inspection status. To determine the degree of damage to the timber is possible to use a variety of diagnostic procedures (Koiber & Drdácký 2015). The simplest is a visual assessment, which is necessarily subjective, so it is advisable to use instrumentation and technical methods. These methods can be destructive – based on assessment of mechanical tests and as well as non-destructive techniques nowadays used in industrial practice (Rohanová 2013). Besides the use of sound (Bucur 2006), optical methods, including the use of microscopy and SEM (Panek et al. 2009), of using radiography (Gardner et al. 1980) is available the use of ultrasonic.

Measurement of ultrasonic speed is suitable for determining the mechanical properties of wood and damage of the elements (Bucur 2006; Tippner et al. 2016). Relatively well-researched areas is detection of damage by wood-destroying fungi (Wilcox 1988; Reinprecht & Hybky 2011), or wood-destroying insects (Reinprecht & Panek 2013).

Non-destructive testing using ultrasonic would allow quick and efficient detection of incipient damage and predict the next stage of serious action of atmospheric factors causing cracks (Raczkowski 1980) and wood-destroying fungi causing white or brown rot (Wilcox 1988). Less explored area is the ability to detect damage to the timber at the initial stage of exposure outdoors (Raczkowski et al. 1999; Oberhofnerová et al. 2016). Raczkowski et al. (1999) have demonstrated that even at low mass loss <1% due to the decay can be used detection method combining acoustic emission perpendicular with the grain test compression in radial direction. Research Oberhofnerová et al. (2016) focused on testing spruce and oak exposed to weathering for four months. A trend of the decline in the velocity of propagation of ultrasonic was observed but was not statistically significant.

For the detection of damage of the timber by waves of ultrasonic are used mainly anatomical measurements of the transverse directions (Kloiber & Drdácký 2015). It comes both from the possibility of access to most of the built-in elements in wooden structures such as bridges, timber beams, poles etc. The cellular elements forming in transverse directions with more interconnections as it is known from wood anatomy (Wagenführ 2002), brings further advantage of this detection method. Higher amount of damaged cell walls, or

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cracks which arise mainly in the longitudinal direction may indicate attenuation of the ultrasonic velocity.

The aim of this experiment was to explore the possibility of using ultrasonic velocity in the radial direction for the determination of the early stages of degradation of wood in the exterior without contact with the ground (use class 3 according to EN 335-2013) with nine tree species: spruce, pine, Douglas fir, larch, oak, black locust, maple, poplar and alder.

2. Material and Methods

Samples of nine tree species (Table 1) with dimensions of 375 × 78 × 20 mm (L × R × T) with the initial moisture content of 12% were exposed to the exterior without contact with the ground in a rack at 45 degrees south according to EN 927- 3 (2006). Exposure place was Prague-Suchdol time from 15th December 2014 to 15th June 2015 and the climatic conditions during the experiment are shown in Table 2.

Measurement of ultrasonic velocity (*v*) with number of 12 measurements for each tree species was performed initially and after 1, 2, 3, 4, 6 months of exposure using the apparatus Fakopp Ultrasonic Timer in the radial direction (Fig. 1) and for the calculation was used equation (Eq. 1):

$$v = \frac{size\ (mm)}{time\ (\mu s)} \cdot 10^3\ \ [\mathrm{m\ s^{-1}}] \qquad [1]$$

Size is 78 mm in this experiment.

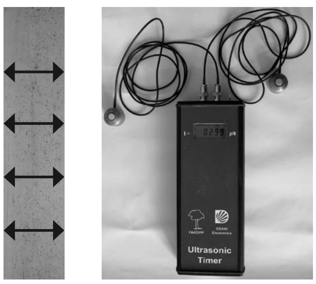

Fig. 1. Scheme of measurements and used testing equipment Fakopp Ultrasonic Timer.

To determine changes in velocity of ultrasonic in the experiment was used equation (Eq. 2):

$$\Delta v = \frac{v_1 - v_0}{v_0} \cdot 100\ \ [\%] \qquad [2]$$

where subscript v_0 denotes the ultrasonic velocity values before exposure and v_1 denotes the values after exposure.

During the experiment was before each measurement determined moisture content of wood, which is an important factor affecting the speed of ultrasonic (Mishiro 1995). Moisture content was calculated by weight method according to the equation (Eq. 3):

$$MC = \frac{m_w - m_0}{m_0} \cdot 100\ \ [\%] \qquad [3]$$

where m_w is the weight of wet wood and m_0 is the weight of absolutely dry wood.

Further was conducted a visual monitoring of evidence of cracks, molds and other damages with tenfold magnification.

For evaluation of the data with basic statistical characteristics, correlation tests and Duncan's test was used software Excell and Statistica.

3. Results

Results of the measurement of ultrasonic velocity changes are shown in Fig. 2 and 3. Moisture content changes during exposure, affecting the measurement results are shown in Fig. 4. The correlation between moisture content, occurrence of initial timber damage and the drop velocity of ultrasonic is analyzed in Fig. 5 and Table 3.

Figures 2 and 3 indicates for hardwoods and softwoods some similarities and differences. For all tested tree species, there were various Δv during exposure, therefore it is obvious that the decisive factors in addition to the length of exposure and the variation of moisture content (Fig. 3), or other factors that are further analyzed in Figs. 5 and Table 3. Overall, it can be deducted that for softwoods was a great variance of measured values (Fig. 2), making difficult correct interpretation of the results. By contrast for hardwoods were measured values Δv relatively low and the variability of the ave-

Table 1. Tested wood species and their initial characteristics (initial value of ultrasonic velocity in radial direction, density and natural durability against fungi).

Wood species	Latin name	Ultrasonic velocity [m s^{-1}]	Density [kg m^{-3}]	Natural durability against fungi (EN 350-2015)
Norway spruce	*Picea abies* L. Karst	858.75 (60.60)	533	4
Scots Pine	*Pinus sylvestris* L.	1095.47 (223.42)	698	3–4
Douglasce fir	*Pseudotsuga menziesii* (Mirb.) Franco	925.65 (29.03)	605	3
European larch	*Larix decidua* [Mill.]	854.06 (38.89)	559	3–4
English oak	*Quercus robur* L.	1451.34 (59.23)	710	2
Black locust	*Robinia pseudoacacia* L.	1367.57 (53.03)	827	1–2
Poplar	*Populus* sp.	1016.57 (20.77)	413	5
Sycamore maple	*Acer pseudoplatanus* L.	1183.61 (53.00)	599	5
Black alder	*Alnus glutinosa* (L.) Gaertn	1258.83 (203.05)	534	5

Note: Numbers in parentheses are standard deviations.

Table 2. An overview of climatic conditions during 12 months of natural weathering.

Variable/month	0–1	1–2	2–3	3–4	4–5	5–6
Average temperature [°C]	3.2	0.7	3.4	7.0	12.3	15.9
Average max. temperature [°C]	5.5	3.1	7.8	12.5	17.9	21.3
Average min. temperature [°C]	–0.3	–1.8	–1.1	1.5	6.4	10.7
Average RH [%]	76.1	78.4	70.7	63.5	60.7	62.2
Total precipitation [mm]	21.9	9.1	11.8	26.3	39.9	32.3
Average global solar rad. [kJ/m^2]	2086	3405	7453	12567	18164	19039

rage values of the individual exposure times was not as great as for most softwoods (Fig. 3).

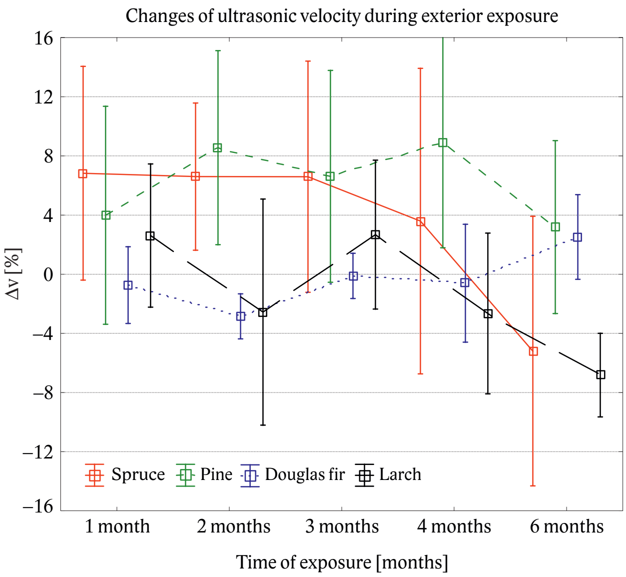

Fig. 2. Two sides confidence intervals of Δv in softwood species during exterior exposure.

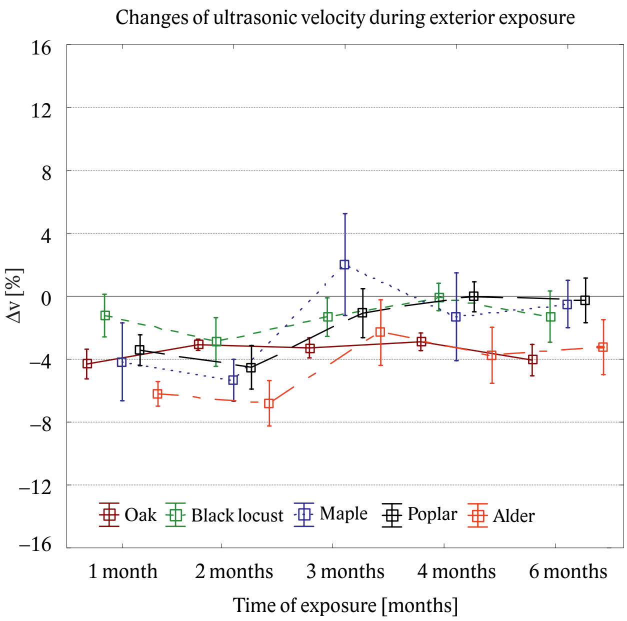

Fig. 3. Two sides confidence intervals of Δv in hardwood species during exterior exposure.

Moisture content of samples decreases mostly during exposure and naturally follows the effects of climate factors shown in the Table 2.

Visual evaluation of samples revealed the presence of molds or wood-stain fungi on non-durable hardwood species, maple, alder and poplar 3 months after exposure and gradually grew up. For Douglas fir wood occurred hairline surface cracks and the other woody species including the above mentioned there were changes of color, graying, which is on a wood exposed outdoors well known (Evans 2008).

Linear relationship between ΔV and MC for all of the trees is relatively low ($R^2 = 0.11$), what makes the assumption that changes in the velocity of propagation of ultrasonic to test tree species were affected mainly by other factors. Mainly by incipient degradation caused by atmospheric agents and biodegradation (Fig. 5).

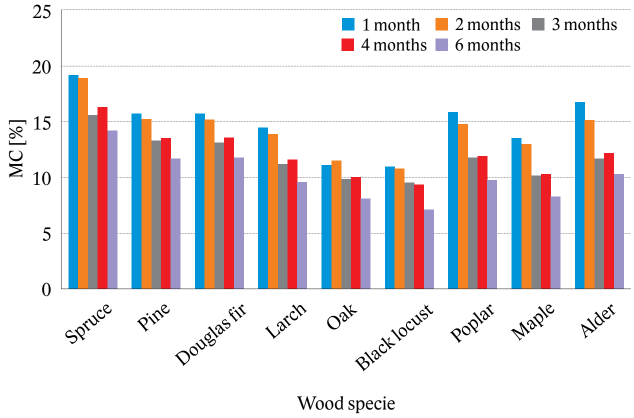

Fig. 4. Changes of moisture content (MC) of wooden samples during exterior exposition.

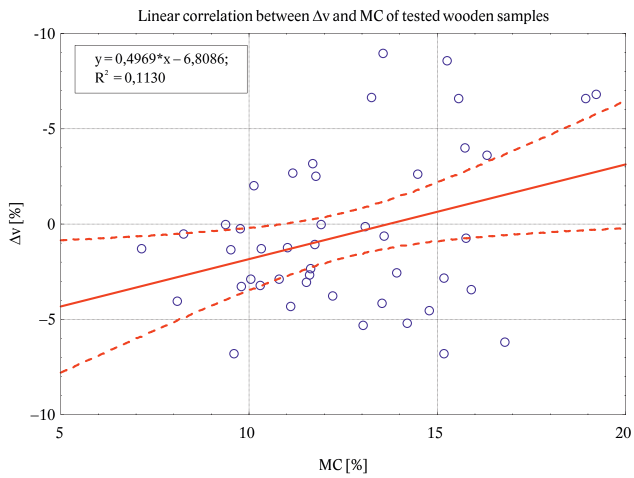

Fig. 5. Correlation between Δv and MC for all tested wood.

Separate analyses of each tested trees were conducted in next step (Table 3).

Table 3. Linear correlation between Δv and MC for each kind of wood and Duncan´s test for Δv changes after 1, 2, 3, 4 and 6 month of weathering.

Kind of wood	Linear correlation	Coeficient of determination [R^2]	Duncan test*
Spruce	$\Delta v = -26.05 + 1.76*MC$	0.56	d (only 6 months versus others c)
Pine	$\Delta v = 0.24 + 0.43*MC$	0.07	d (for all cases)
Douglas fir	$\Delta v = 13.26 - 0.98*MC$	0.67	—
Larch	$\Delta v = -14.63 + 1.09*MC$	0.30	d (only 6 months versus 1 and 3 months c)
Oak	$\Delta v = -4.67 + 0.11*MC$	0.06	d (only 1 months versus 2 and 3 monts c and versus 4 months b; 4 months versus 6 months c)
Black locust	$\Delta v = 0.79 - 0.22*MC$	0.12	—
Maple	$\Delta v = 9.89 - 1.06*MC$	0.62	—
Poplar	$\Delta v = 7.21 - 0.71*MC$	0.77	—
Alder	$\Delta v = 4.10 - 0.65*MC$	0.79	—

Note: Duncan´s tests for each kind of wood and months of exposition was done for wood species, which did not confirm decrease of ultrasonic velocity with increase of moisture content in range 0 – Fibre saturation point (FSP): 99.9% significance level (a); 99% significance level (b); 95% significance level (c); and less as 95% significance level at p ³ 0.05 (d).
"—": wood species, which confirmed decrease of ultrasonic velocity with increase of moisture content in range 0 – Fibre saturation point (FSP).

In Table 3 is analysed decreasing of ultrasonic velocity in dependence on the increase in moisture content. For wood maple, poplar, alder, black locust and Douglas fir, this dependence is confirmed (in addition to the black locust with high coefficient of determination), and therefore we can assume that it was the most important factor causing attenuation of ultrasonic. On the contrary, trees oak, spruce, pine and larch doesn't confirm this trend, which makes the assumption of superiority of other influences caused by the degradation of wood. Therefore, their significance was further analysed for each tree species separately using Duncan's test for different levels of significance (Table 3). For oak and pine was correlative dependence relatively low (see Coefficient of determination in Table 3), but for oak were found statistically significant decreases of ultrasonic velocity at lower moisture content after 6 months of exposure. The same results were also observed with spruce and larch, where have been recorded even higher coefficient of determination (Table 3).

4. Discussion

For wood we can assume that with a decrease in moisture content within 0 - FSP will increase the speed of ultrasonic (Mishiro 1995; Montero et al. 2015), what was confirmed for Douglas fir, black locust, maple, poplar and alder. Thus, for these kinds of wood, the ultrasonic cannot clearly detect the initial stages of damage. This was reflected mainly in non-durable trees maple, poplar and alder, which was visible mold or wood-stain fungi damaged, but did not show what is expected to drop of ultrasonic velocity. Conversely, simply copying the changes in humidity (Table 3). In Wilcox (1988) and a depth of Reinprecht (2011) was observed to reduce the speed of sound, but only at higher mass loss as 5 – 10% (Wilcox 1988). Such a big mass loss cannot be assumed after just short-term exposure and as effects of wood coloring fungus (Fojutowski 2004). Conversely Raczkowski et al. (1999) demonstrated the sensitivity of ultrasonic detection of damage to the timber by fungi already when the mass loss is less than 1%, but in combination with perpendicular to grain compression test in radial direction.

For woods spruce, pine, larch and oak cannot be assumed that the drop in moisture content led to an increase in velocity of ultrasonic (see linear correlation in Table 3). Interesting result is the significant decrease in velocity of ultrasonic in spruce after 6 months of exposure that may relate to the fact that out of the softwoods has the lowest natural durability (Table 1). Although there was not found the evidence of fungus infestation, spruce belongs to the class of durability 4 (EN 350). Exposure of spruce to outdoor applications - the use of class 3 (EN 335) – without a barrier or chemical protection is not recommended (EN 460). Ultrasonic propagation velocity changes in pine were not statistically significant for any of the tested months. For larch, like oak it is interesting to note that despite the low moisture content after 6 months of exterior exposure the velocity of ultrasonic in the radial direction was the lowest in several cases even significantly compared to the other values (Fig. 2 – 4 and Table 3). It is an interesting result because they are wood species with a relatively high natural durability (EN 350), which are often used in outdoor applications and they can withstand long term exposure of biotic factors (Reinprecht 2008). Explanation is possible by a high content of extractive substances in these woods, if larch arabinogalactans and in case of oak tannins (Bučko & Šutý 1988) which, after leaching from the cell walls caused the reduction of the velocity. This effect was confirmed also in work Farvardin et al. (2015) for persian silk wood. The effect of extractive substances leaching from some tree species has to be calculated using ultrasound as detection method in practice.

Oberhofnerová et al. (2016) investigated the effect of the exterior load of spruce and oak wood in outdoor areas without ground contact. There was observed a decrease in velocity of ultrasonic in native wood, but statistical significance was not demonstrated. It could be caused on the one hand by a shorter exposure time - only 4 months, on the other hand, the measurement in the longitudinal direction not so sensitively detects a beginning damage wood, due to fewer connection of cellular elements.

In contrast, the pine and Douglas fir resins and black locust extracts appearing to have stabilizing effect on the weather. On the basis of these results look out these extracts more stable as oak tannins.

Black locust belongs to a class of 1 – 2 natural durability (EN 350), and in pine wood is known relatively high content of water resistant resins (Bučko & Šuty 1988), which also provide some hydrophobic protecting (Oberhofnerová & Panek 2016). Douglas fir also contains extractive substances based resins but also biflavonoids dihydroquercetin, which causes a relatively high natural durability (Taylor et al. 2003).

From these results it is clear that the mere use of ultrasonic does not provide sufficiently accurate information about initial wood damage by biotic and abiotic factors. It is mainly due sensitivity of the method, which is probably better suited to the detection of more serious damage of structural timber, where the results are conclusive (Wilcox 1988). Initial stages are better diagnosed by the direct assessment of microscopic analyzes, which are visible hyphae infiltrating of cellular structure of wood (Pánek et al. 2009), or microruptures caused by the abiotic degradation (Masaryková et al. 2010). More sensitive detection method seems to be the use of destructive testing - impact strength in bending (Sonderegger et al. 2015). This sensitively respond even to wood-staining fungi that still does not significantly deform cell walls of wood (Fojutowski 2004).

The disadvantage of both methods is the need to remove test samples from the tested structure and their subsequent analysis in the laboratory. By this method can be created reliable overview of the state of the structure, but more precise and intensive measurements have to be done.

5. Conclusion

From the above experimental results, it is possible to provide the following conclusions:

1. The speed of ultrasonic in wood is affected during the initial stages of degradation of wood exposed outdoors without ground contact without shelter, although the changes are

relatively low. Statistically significant decrease was observed in some kinds of tested woods: spruce, larch and oak, especially after 6 months of exposure.

2. Considerable influence as a degradation of biotic and abiotic agents is in the early stages of exposure for most kinds of wood tested, has especially fluctuations in wood moisture content due to the local climatic conditions. Therefore, this factor has to be calculated at any non-destructive testing of structures using the ultrasonic.

3. There was not confirmed the possibility of using ultrasonic to determine the initial stages of fungal damages (Mainly by the molds or the wood-staining fungi) in non-durable woody species tested: maple, poplar and alder.

4. Based on these results it can be stated that the mere use of ultrasonic as a screening method of initial stages of timber damage is inadequate and does not provide a perfect idea of their range in wood. Analysis can be refined using microscopic analysis and SEM analysis of damage. Another option is providing of destructive analysis where, for example, impact strength in bending sensitively detects the already emerging biotic damage. The disadvantage of both is the higher effort, the need for the sampling and subsequent laboratory evaluation.

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ORIGINAL PAPER

Effects of Northern red oak (*Quercus rubra* L.) and sessile oak (*Quercus petraea* (Mattusch.) Liebl.) on the forest soil chemical properties

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Abstract

Northern red oak (*Quercus rubra* L.) is one of the most important introduced tree species in the Czech Republic, occupying about 6,000 ha with ca. 900,000 m^3 of the standing volume. The presented study aims to evaluate its soil forming effects on natural oak sites. Soil chemistry of the upper soil layers (F+H, A_h, B horizons) was studied in three pairs of stands of both species. In each stand, four bulk samples were taken separately for particular horizons, each consisting of 5 soil-borer cores. The soil characteristics analysed were: pH (active and potential), soil adsorption complex characteristics (content of bases, exchangeable cation capacity, base saturation), exchangeable acidity (exchangeable Al and H), total carbon and nitrogen content, and plant available nutrients content (P, K, Ca, Mg). Total macronutrient content (P, K, Ca, Mg) was analysed only in holorganic horizons. Results confirmed acidification effects of red oak on the upper forest soil layers such as decreased pH, base content, base saturation, all nutrient contents in total as well as plant-available form and increased soil exchangeable acidity (exchangeable Al) in comparison to the sessile oak stands, especially in holorganic horizons and in the uppermost mineral layer (A_h horizon). Northern red oak can be considered as a slightly site-soil degrading species in the studied sites and environmental conditions in comparison to native oak species.

Key words: red oak; sessile oak; humus forms; forest sites; pedochemical characteristics

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1. Introduction

Northern red oak (*Quercus rubra* L.) is one of the most important introduced tree species in many European countries, including the Czech Republic. It was planted for gardening purposes and especially for timber production on less favourable and degraded soils. Nowadays, it is recognized as an invasive alien plant very often and its valuation changed to negative one (Oosterbaan & Olsthorn 2005; Chmura 2013). Its stand area is about 6,000 ha with the growing stock of 900,000 m^3 in the Czech Republic according to summary forest management plans. The red oak area is like that of Douglas-fir even the latter species has higher growing stock (about 1,250,000 m^3) having lower mean age (Kouba & Zahradník 2011). It should be stressed that Douglas fir is the most productive species of all introduced species with site improving effects in the stands of domestic coniferous species (Podrázský et al. 2013, 2014; Kubeček et al. 2014; Pulkrab et al. 2014, 2015). On the other hand, northern red oak is a species quite common in parks and it is used for restoration of spoil banks. It is not understood as a species important for its production capacity only. The other interesting aspect is its resistance to tracheomycosis which is higher than of domestic oaks (Burkovský 1985; Gubka & Špišák 2010; Štefančík & Strmeň 2011). Dressel and Jäger (2002) recommend rather dry and acid sites as suitable or tolerable for northern red oak. Quite rare studies demonstrate higher wood production of red oak when compared to domestic oaks (Seidel & Kenk 2003; Kouba & Zahradník 2011). There is very limited evidence on the soil forming effects of this species comparing to native trees. The partial studies indicate no site improvement effects in European conditions, even slight soil degrading effects comparing to native broad-leaved species (Kantor 1989; Podrázský & Štěpáník 2002; Jonczak et al. 2015; Bonifacio et al. 2015). On the contrary, Northern red oak can significantly contribute to the afforestation of agricultural lands (Vopravil et al. 2015) due to its character of pioneer species.

The aim of the presented study is to evaluate the Northern red oak effects on the upper layers of forest soils in the stands of native Sessile oak (*Quercus petraea* (Mattusch.) Liebl.) and partly mitigate the lack of information on the effects of this species in the forest environment.

2. Material and methods

The study was performed in oak stands in the North-Western Bohemia. The area is a West part of the Natural Forest Area PLO 17 Polabí Lowland. Location of plots is given in the Table 1. The altitude of all plots varied between 220 – 330 m a.s.l. The investigated stands grow on comparable forest type: acid to medium rich oak and oak-beech sites (Viewegh 2003). Mean annual temperature of the area is 9 °C and mean annual precipitation 520 mm. The soil forming substrate is represented prevailingly by deep blown sands; this soil types of Arenic Cambisol (with gleying indices) developed prevailingly on this substrate (Němeček et al. 2011).

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There were three pairs of stands (red oak and sessile oak). In each stand, four bulk samples (distance ca. 50 m) were taken from particular horizons F+H, A_h, B. Each bulk sample consisted of 5 individual sampling cores (distance ca. 5 m) taken by soil borer of 6.5 cm diameter, separated for given horizons. Individual bulk samples were dried and analysed in the Laboratory Tomáš, Opočno, by standard methods (see e.g. Zbíral 2001; Špulák et al. 2016):

– Active and potential pH in H_2O and KCl respectively by potentiometric method,
– exchangeable acidity, content of exchangeable aluminium and hydrogen,
– sorption complex characteristics by Kappen (1929): S – base content, CEC – cation exchange capacity, BS – saturation of sorption complex by bases),
– content of total nutrients in holorganic horizons (N, P, K, Ca, Mg) after digestion with sulphuric acid and with selenium as a catalyst (Zbíral 2001),
– content of combustible matters, percentage of total oxidizable carbon (humus) and nitrogen was determined according to Kjeldahl methods, the combustible matter and Cox according to Springer-Klee method (e.g. Ciavatta et al. 1989; Kirk 1950),
– content of available nutrients (P, K, Ca, Mg) by Mehlich III method.

In each sampled stand, a bulk sample of the litter from the soil surface was collected, a part of it from particular cored points. Only content of total nutrients was determined for this material.

One way analysis of variance (ANOVA using software Statistica 12.1) was used after checking the normality of the data for soil analysis evaluation followed by post-hoc Tukey tests where corresponding horizons were compared on the usual level of significance ($p < 0.05$).

Table 1. Basic data on research plots of Northern red oak and sessile oak stands.

Species	Age [years]	Forest type	Elevation a.s.l. [m]	Latitude	Longitude
Red oak	49	1S6	276	50°21,575’	14°19,288’
	50	1K1	276	50°21,737’	14°19,398’
	103	1S6	300	50°22,172’	13°59,071’
Sessile oak	73	1S6	275	50°21,721’	14°19,964’
	111	1S6	280	50°22,228’	14°20,978’
	159	1C2	329	50°21,855’	13°58,966’

Notes: Forest types – 1 – oak vegetation altitudinal zone, 2 – beech-oak vegetation altitudinal zone, K – acid sites, S – medium rich sites, C – drying sensitive; third digit indicates more detailed forest type.

3. Results

There were documented differences between different soil horizons (F+H, A_h, B), in both set of stands, which is typical for the dynamics of forest soils. Differences in the studied characteristics between both species for the same soil layer were much less distinct. The pH/H_2O and pH/KCl in upper humus horizons and in horizons A_h, B under both species are given in Table 2. The pH/H_2O in humus layers under both species did not differ significantly; however, pH/KCl under red oak stand is significantly lower than under sessile oak in holorganic layer. There is a tendency of higher values of pH in F+H and A_h horizons while the values were practically identical in the B horizons.

Table 2. Soil reaction in particular horizons under red oak and sessile oak stands.

Horizon	pH/H_2O		pH/KCl	
	Red oak	Sessile oak	Red oak	Sessile oak
F+H	4.47 a	4.73 a	**3.53 a**	**3.94 b**
A_h	4.18 a	4.25 a	3.38 a	3.47 a
B	4.33 a	4.31 a	3.75 a	3.69 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

The exchangeable titration acidity was significantly higher in holorganic horizon under red oak as well as in organo-mineral horizon A_h (Table 3). The similar results show the Al^{3+} content. On the other hand, hydrogen content did not show significant differences under both species. The results suggest less favorable status of soils and tendency to acidification under red oak compared with sessile oak.

Table 3. Exchangeable acidity, hydrogen content and aluminium in particular horizons under red oak and sessile oak stands.

Horizon	Acidity		H^+ [meq kg^{-1}]		Al^{3+}	
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	**44.66 a**	**24.26 b**	9.70 a	8.69 a	**34.96 a**	**15.57 b**
A_h	**62.31 a**	**47.57 b**	2.20 a	2.75 a	**60.11 a**	**44.82 b**
B	49.78 a	41.42 a	1.20 a	1.07 a	48.58 a	40.35 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

Base content and base saturation are significantly higher in the holorganic horizons in the sessile oak stands. The same tendency was observed also in the organomineral A_h horizons; however, the differences were not significant. The significant differences were not pronounced in lower horizons (Table 4).

Table 4. Soil adsorption complex characteristics of the soil horizons under red oak and sessile oak stands.

Horizon	S		CEC [meq kg^{-1}]		BS [%]	
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	**27.39a**	**41.79b**	72.15 a	78.88 a	**37.35a**	**52.53b**
A_h	1.60 a	3.84 a	18.23 a	23.77 a	8.56 a	14.28 a
B	0.97 a	0.83 a	6.96 a	7.20 a	13.11 a	9.96 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

The content of combustible substances is lower under red oak but not significantly (Table 5). The same dynamics showed the total nitrogen and carbon content in the whole studied profile, the significant difference was documented for carbon in the Ah horizon while for nitrogen for both horizons A_h and B. This results in less favourable C/N ratio in the stands of red oak in all horizons (Table 5), even the differences were not significant.

Table 5. Total carbon and nitrogen content, its C/N ration and combustible substances in upper soil horizons under red oak and sessile oak.

Horizon	Total C ox [%]		Total N		C/N		Combustible substances [%]	
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	30.33 a	29.34 a	1.78 a	1.87 a	17.07 a	15.69 a	78.62 a	74.49 a
A_h	**6.46a**	**8.64b**	**0.40a**	**0.60b**	18.38 a	14.96 a	18.62 a	24.85 a
B	1.31 a	1.77 a	**0.09a**	**0.14b**	13.01 a	12.43 a	4.54 a	5.40 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

Plant available nutrient content is higher in the soil horizons under sessile oak in general (Table 6). For available phosphorus, statistically significant differences were found in the horizons F+H and A_h, for available potassium in the layers A_h and B, for available calcium and magnesium for F+H and A_h again.

Table 6. Plant available nutrient contents in particular horizons under red oak and sessile oak stands.

Horizon	P		K		Ca		Mg	
	[meq kg^{-1}]							
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	**29a**	**59 b**	744 a	1032 a	**2453 a**	**3964 b**	**443a**	**652b**
A_h	**3 a**	**13 b**	**108 a**	**201 b**	**280 a**	**527b**	**80a**	**127b**
B	3 a	2 a	**42 a**	**71 b**	263 a	280 a	59 a	67 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

The content of total nutrients was significantly higher in the horizon L under sessile oak with exception of calcium and magnesium (Table 7). The same trend was documented for F+H horizon for P and K, the differences were significant while the differences for N, Ca and Mg were not.

Table 7. Total nutrient content in the litter and F+H horizons under red oak and sessile oak.

Horizon	N		P		K		Ca		Mg	
	[%]									
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
L	**0.59a**	**0.80b**	**0.01a**	**0.03b**	**0.30a**	**0.43b**	1.15 a	1.24 a	0.15 a	0.16 a
F+H	1.70 a	1.80 a	**0.05a**	**0.07b**	**0.15a**	**0.21b**	0.19 a	0.38 a	0.05 a	0.06 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

4. Discussion and conclusion

Data concerning the effects of Northern red oak on forest soil are very limited. The data show distinct differences among the horizons which document the transformation of organic matter and changes of pedochemical soil characteristics typical for Cambisols (Němeček et al. 2011). Kantor (1989) compared the litter quality in the stands of different tree species in the Trutnov region. In contrast to other broadleaved species, especially to birch and alder, the litter quality of the red oak was not so high. This author groups red oak together with Scots pine as a species without site improving effects comparing to other broadleaved species (aspen, willow, beech, birch, alder). As the site degrading species were evaluated spruce species and Eastern white pine (*Pinus strobus* L.), which consists with our findings. Podrázský & Štěpáník (2002) studied the effects of particular tree species on afforested agricultural soils in the region of Český Rudolec. They compared the humus forms in the stands of red oak, birch, Norway spruce and European larch. Red oak did show more favorable effects on the new upper soil formation comparing to conifers (pH, soil adsorption complex characteristics, nutrient content), but less when compare to birch. The data suggests the red oak is more nutrient demanding, leading to decrease of nitrogen content under this species.

Also Bonifacio et al. (2015) documented slower litter decomposition and worsened nutrient dynamics under red oak stands. They demonstrated the accumulation of more extreme humus form (Mor instead of Dysmull-Hemimoder), slower litter decomposition and worsened phosphorus and calcium availability on natural site of English oak and well developed less fertile soils. Jonczak et al. (2015) studied the decomposition intensity of litter of different tree species (alder, beech, red oak, maple) using litter bags method. Alder produced leaf litter with the fastest decomposition, accelerating profoundly the nutrient dynamics, other broadleaves had very similar character of these processes. Comparing to our results, it can be concluded, that prominent site improving effects of the red oak on broadleaved species sites are not realistic. On the contrary, slight acidification effects can be expected comparing to native oaks. But red oak can play considerable stand forming and site improving role due to its resistance to extreme site conditions on degraded and devastated sites (Dimitrovský 1999, 2001; Kupka et al. 2007; Dimitrovský et al. 2008). Good growth of this species was confirmed also on abandoned agricultural lands, but protection against browsing is necessary in this case (Tužinský et al. 2015). These areas are relatively large throughout Europe, including the Czech Republic (Vopravil et al. 2015) and therefore the introduced species can play important role in this process (Podrázský et al. 2015, 2016). The evaluation of their effects on the soil ecosystem compartment can prevent many mistakes (Ehrenfeld 2003).

Significant effects of the red oak can be detected also on under storey vegetation. Its dynamic indicates more acid and nutrient poor sites with limited abundance of the nitrophilous vegetation. Also Kantor (1989) confirmed similar results for this species together with Scots pine. Straigyte et al. (2012) and Chmura (2013) described consistently the influences on the ground vegetation tending to more acid and nutrient poor sites. It is emphasized especially for lower nitrogen content in the soil, which is clearly indicated by the ground vegetation. They documented very good natural regeneration of the red oak, it can be considered as invasive one in many cases (Major et al. 2013).

Results confirmed visible negative effects of the Northern red oak on the sites, corresponding to the native sessile oak ecosystems. Higher acidity, lower soil reaction as well as bases and nutrient contents were documented in the holorganic and upper mineral soil horizons. In contrast to devastated soil remedial, this species can be considered as site degrading to some extent

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ORIGINAL PAPER

Effect of different tree mortality patterns on stand development in the forest model SIBYLA

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Abstract

Forest mortality critically affects stand structure and the quality of ecosystem services provided by forests. Spruce bark beetle (*Ips typographus*) generates rather complex infestation and mortality patterns, and implementation of such patterns in forest models is challenging. We present here the procedure, which allows to simulate the bark beetle-related tree mortality in the forest dynamics model Sibyla. We explored how sensitive various production and stand structure indicators are to tree mortality patterns, which can be generated by bark beetles. We compared the simulation outputs for three unmanaged forest stands with 40, 70 and 100% proportion of spruce as affected by the disturbance-related mortality that occurred in a random pattern and in a patchy pattern. The used tree species and age class-specific mortality rates were derived from the disturbance-related mortality records from Slovakia. The proposed algorithm was developed in the SQLite using the Python language, and the algorithm allowed us to define the degree of spatial clustering of dead trees ranging from a random distribution to a completely clustered distribution; a number of trees that died in either mode is set to remain equal. We found significant differences between the long-term developments of the three investigated forest stands, but we found very little effect of the tested mortality modes on stand increment, tree species composition and diversity, and tree size diversity. Hence, our hypothesis that the different pattern of dead trees emergence should affect the competitive interactions between trees and regeneration, and thus affect selected productivity and stand structure indicators was not confirmed.

Key words: *Ips typographus*; dispersal pattern; empirical forest modelling; tree mortality

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1. Introduction

Models of forest dynamics have become important tools that supported forest management and increased our understanding of forest development under diverse management and natural conditions. Because forest damage is among the most important drivers of forest development with effect on the quality of ecosystems services provided by forests (Thom & Seidl 2015; Thom et al. 2016), a great deal of attention has been paid to the implementation of forest mortality processes into models (Pietsch & Hasenauer 2006; Merganičová & Merganič 2014; Seidl & Rammer 2016). At the same time, models were found highly sensitive to the mortality assumptions adopted (Bircher et al. 2015; Hlásny et al. 2014), which highlights the importance of proper implementation of algorithms driving the mortality-related processes. Despite these efforts and increasing complexity of models, Keane et al. (2001) and Bircher et al. (2015) argue that mortality algorithms implemented in models are generally based on simple assumptions and insufficient data.

Bark beetles of the genus *Ips*, and particularly the spruce bark beetle *Ips typographus* (L., 1758) (Curculionidae: Scolytinae), are the most damaging biotic agents in central European forest (e.g. Berec et al. 2013). Bark beetle-related tree mortality is a highly complex process that is driven by both the host susceptibility, bark beetle population size and diverse environmental perturbations (Wermelinger 2004; Hlásny & Turčáni 2013). Interactions between the host tree distribution, tree susceptibility and density-dependent bark beetle dispersal capacity, generate specific patterns of infested trees. Such patterns might range from the scattered occurrence of infested trees, which is typical of small beetle densities, to patchy and even a large scale infestations that typically occur when the populations are in the outbreak phase (Hlásny & Turčáni 2013). Because tree mortality patterns might affect stand structure and the quality of ecosystem services in the period following the infestation, it is desired to include such information into forest models, which operate at a scale of trees.

Among such models, the forest model Sibyla (Fabrika & Ďurský 2005) has received an increased recognition in recent years (e.g. Vacek et al. 2013; Hlásny et al. 2011, 2014, 2016; Ambrož et al. 2015; Härtl et al. 2016). The model simulates mortality at a scale of trees and considers both the inherent tree mortality (Ďurský et al. 1996, 1997) and mortality related to disturbances (Fabrika & Vaculčiak 2009). Particularly the disturbance-related mortality shows significant differences between tree species, depending on tree species vulnerability to various disturbances. Hlásny et al. (2016) developed an application that simulates the disturbance-related mortality in the model Sibyla based on the species and age-specific mortality rates derived from the 10-year records on forest damage in Slovakia; this is the algorithm we use and evaluate in this study.

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Because the used mortality rates contain the cumulative effect of all damage agents (biotic and abiotic), each of them generating a specific pattern of tree mortality, the preference of any specific tree mortality pattern might be irrelevant. However, such an approach might generate biased outputs for regions, where mortality with patchy pattern, such as that related to bark beetle infestation, prevails. It is, however, not clear whether and how the consideration of such a mortality pattern might affect stand development in the period following the infestation.

To shed a light on this issue, we present a modelling exercise that evaluates in several virtual Norway spruce-dominated stands how biomass production, tree species and stand structure diversity can develop under the random and clustered mortality modes. We hypothesize that the appearance of clearings in response to the clustered emergence of dead trees could induce regeneration processes different from those induced by the random emergence of dead trees, and thus, in the long-run, affect tree species composition of the stands. Further, we hypothesize that the different patterns of dead tree emergence will affect the competition between trees and tree increment, and that such a difference will be translated from the tree scale to the stand scale. Finally, we hypothesize that mainly stand structure diversity will be affected by the tested mortality modes, while effect on biomass production will be less pronounced. Such a research is intended to contribute to mortality parameterization in tree-based forest models and to improve the reliability of forest development simulations.

2. Data and methods

2.1. Used model and simulation design

We used here the forest model Sibyla developed by Fabrika & Ďurský (2005) (available at http://sibyla.tuzvo.sk) and repeatedly used for research, for example, by Hlásny et al. (2011, 2014, 2016), Härtl et al. (2016) and others. Sibyla is empirical single-tree oriented climate sensitive forest model with a one-year simulation step, and the core components of the model are based on the Silva model (Pretzsch et al. 2002). A detailed description of the model can be found in the studies we referred to earlier.

We used three virtual forest stands with identical site conditions to secure the comparability of simulation outputs (Table 1). The used stand parameters represent the conditions in which spruce typically grows in Slovakia. The three stands were with a different share of Norway spruce (*Picea abies* L. Karst.). (Stand code: S100 – 100%; S70 – 70%; and S40 – 40%) and with a different admixture of other species (Table 2). The admixed species were European beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.), and Scots pine (*Pinus sylvestris* L.).

The inherent tree mortality (i.e. mortality related to competition) is implemented according to Ďurský et al. (1996) and Ďurský (1997). The disturbance module that is inherently implemented in the model (Fabrika & Vaculčiak 2006) was not used in this study, and we used an external module developed by Hlásny et al. (2016) instead. The latter module was developed in the Python and SQL languages, and the module allows flexible adjustments of a number of mortality settings. The disturbance mortality rates used here were specific to tree species and age class, and were parameterized based on the forest disturbance records for the period 1998–2009 using the data from the whole of Slovakia (Hlásny et al. 2016) (Table 3).

Table 1. Stand and site condition of the three simulated forest stands.

Stand and site parameters	Value
Elevation [m a.s.l.]	982
Soil type	Cambisol
Stand density	0.95
Initial age [years]	40
Mean air temperature during vegetation season [°C]	12.5
Precipitation totals during vegetation season [mm]	727

Table 2. Types of tree species composition in the three simulated forest stands.

Stand / species proportion [%]	Spruce	Fir	Beech	Pine
S100	100	0	0	0
S70	70	15	15	0
S40	40	25	25	10

Such initial rates were modified to consider the reduced susceptibility to infestation for stands with the admixture of non-spruce species based on Griess et al. (2012). The correction accounted for 3% for stands with spruce up to 80% and 15% with spruce below 60%.

Development of each stand was evaluated during a 200-year period, because the divergence of the tested stand development indicator is likely to occur in longer runs only. The simulations were run with the natural regeneration module activated (Merganič & Fabrika 2011). No management operations except for the removal of dead trees were applied. Each simulation was run ten-times to consider the variability related to the differences in the initial tree positions and stochasticity related to tree mortality and other model parameters.

Table 3. Tree species- and age class-specific mortality rates used to drive the forest mortality in the current study.

	Tree species- and age class-specific mortality rates					
	Spruce proportion in a stand [%]			Beech	Fir	Pine
Age class	>80	60–80	<60			
<30	0.10	0.10	0.08	0.01	0.08	0.05
31–40	0.11	0.11	0.10	0.01	0.05	0.04
41–50	0.13	0.12	0.11	0.01	0.03	0.02
51–60	0.15	0.14	0.13	0.01	0.03	0.02
61–70	0.16	0.16	0.14	0.01	0.02	0.02
71–80	0.19	0.18	0.16	0.01	0.03	0.02
81–90	0.20	0.19	0.17	0.02	0.03	0.03
91–100	0.20	0.20	0.17	0.02	0.03	0.03
101–110	0.20	0.19	0.17	0.02	0.03	0.03
111–120	0.20	0.19	0.17	0.02	0.03	0.02
121–130	0.20	0.19	0.17	0.01	0.04	0.02
131–140	0.21	0.20	0.18	0.01	0.04	0.02
141–150	0.20	0.19	0.17	0.01	0.04	0.01
>150	0.17	0.16	0.14	0.01	0.03	0.00

2.2. Tested mortality patterns

Two mortality set-ups were tested – a random occurrence of dead trees driven by species- and age class-specific mortality only (Table 3, mode RAN) and a clustered occurrence of dead trees (mode CLUST), where mortality is also driven by the proximity of an evaluated tree to the trees that died in the previous period. Hence, the CLUST mode generates the dead trees in a patchy pattern typical of bark beetle infestation in the epidemic phase.

In case for the RAN mode, a specific mortality rate from Table 3 is assigned to each tree in a stand based on the species and age class. Then, a real number in the 0 – 1 interval with the uniform distribution is generated for each tree to specify a threshold to which a mortality rate is compared. In case the threshold is exceeded a tree survives, otherwise a tree dies. Such a procedure is applied with a 10-year step.

In case for the CLUST mode, the procedure described above is modified based on the proximity of each tree to the trees which had died in the former simulation step. The literature review indicated that under high beetle densities (epidemic phase) most of beetles disperse over short distances (up to 100 m), and the dispersal (or the appearance of new infestation spots) disappears within 500 – 1,000 m from old infestations (Wichman & Ravn 2001; Kautz et al. 2011; Hlásny & Turčáni 2013; Stadelmann et al. 2014). Therefore, we modified the RUN algorithms so as we define the affinity of the newly infested trees to the trees infested in the previous period. The affinity with magnitude 1 causes that all new infestations might occur in trees adjacent to the old infestations, and the age effect does not apply in this case; however, the age threshold of 50 years is applied to avoid the infestation of trees, which are very unlikely to be infested. The 50-year age limit was applied though spruce bark beetle is thought to infest trees older than 70 years (Wermelinger 2004), but much younger stands have been recently found to be infested, for example, in the Czech Republic (J. Holuša, pers. comm.).

The affinity with the magnitude of 0 indicates no clustering effects and CLUST is equal to RUN. The transient affinity values can be applied to model various bark beetle dispersal patterns. The algorithm was developed in the SQLite using the Python language.

2.3. Evaluated stand development indicators

We evaluated effect of the two mortality setting on several production and stand diversity indicators. We evaluated the effect on volume increment of a stand (m^3 ha^{-1} year^{-1}); species-specific relative standing volume (% of the total stand volume), which is indicative of tree species composition; volume of dead wood (m^3); tree species and tree size diversity. The true diversity index (Jost 2006), which is the exponential form of the Shannon`s diversity index, is used as the indicator of tree species diversity; species-specific basal area is used as a weight. Tree size diversity index (H), which aggregates the diversity of tree heights and diameters (Staudhammer & LeMay 2001), is used as the indicator of stand structure diversity.

3. Results

3.1. Volume increment

Different species compositions and related mortality rates caused the mean stand volume increment (m^3 ha^{-1} year^{-1}) to differ significantly between the simulated stands. While in S40 the increment culminated at ca 90th year of the simulation (stand age 130) at 27 m^3 ha^{-1} year^{-1}, the increment was steadily declining during the whole simulation period in the two remaining stands (S70 and S100). Such a decline was primarily related to the progressive mortality of the dominating spruce trees, while such an effect was less pronounced in S40 and S70.

Although we assumed that the two tested mortality modes will affect the stand density differently, and this effect will result in a differential response of stand increment, our simulations showed almost no difference between the RUN and CLUST mortality modes during the whole simulation period; minor deviations of the two curves in Fig. 1 were in the range of the respective error bars.

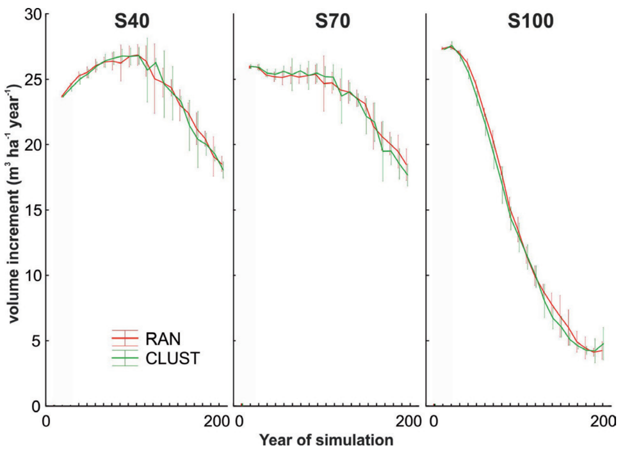

Fig. 1. Development of mean stand volume increment simulated with the random (RAN) and clustered (CLUST) occurrence of dead trees in three forests stands. Stand codes are explained in Table 2. The error bars show the 95% interval calculated based on 10 repeated simulation runs.

3.2. Relative standing volume

Relative standing volume was investigated as an indicator of the change in tree species composition. The simulations shows that fir was performing best and its volume was steadily growing during the simulation period (Fig. 2). The decrease of spruce was related to high mortality rates, while the decrease of beech was related to the unfavorable condition for beech growth in the elevation of 1,000 m a.s.l., where beech production and ability to compete with other species were not sufficient to persist.

As in the case of mean stand volume increment, the two tested mortality modes did not affect the per-species volume significantly during the whole simulation period.

3.3. Dead wood volume

Dead wood volume generated for each year of the simulation period directly reflects the species- and age-class specific mortality rates indicated in Table 3. Development of dead wood volume in all three stands shows the presence of damage culmination phase, where the proportion of spruce and/or other overmatured trees reached maximum (Fig. 3). In S40 the damage culmination occurred ca in year 70 of the simulation period, and then the damage decrease because

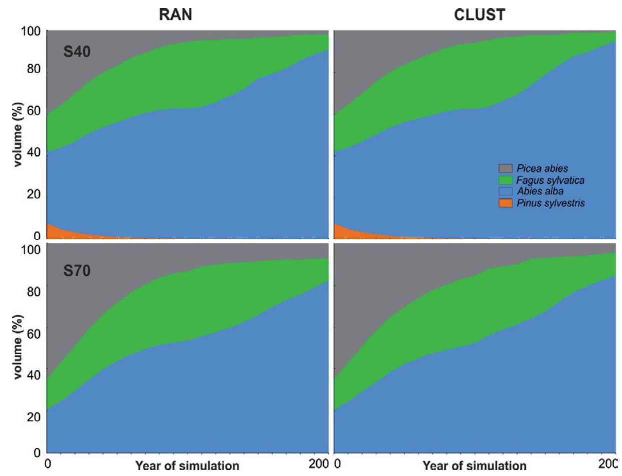

Fig. 2. Species specific standing volume calculated as the per cent of the total standing volume simulated with the random (RAN) and clustered (CLUST) occurrence of dead trees. Stand codes are explained in Table 2. Stand S100 was not presented because of the persisting dominance of spruce.

of the increase abundance of younger and less vulnerable spruce trees. In S40 and S70 the damage peaked in ca year 170 of the simulation period, though the peak in S40 was not as sharp as in the previous stands.

Because of the stochasticity in the algorithm, which is applied to evaluate whether or not a tree dies, the inter-simulation variability is largest of the all investigated indicators. As in the previous indicators, there was no difference between the RAN and CLUST modes. In case of this indicator, however, such an output could have been expected, because the used algorithm was designated so as it affects the distribution of dead trees in a stand, while the total number of dead trees remains equal.

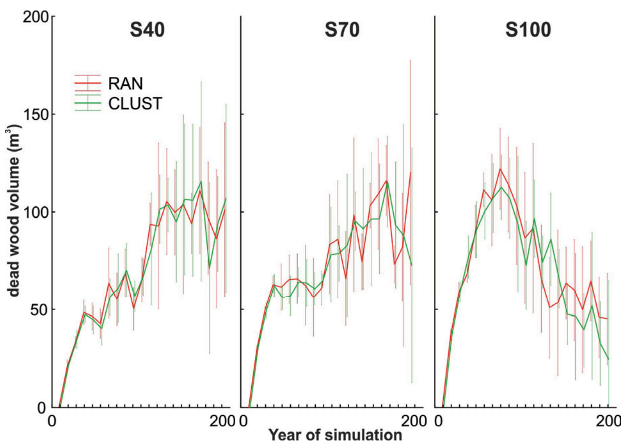

Fig. 3. Dead wood volume simulated with the random (RAN) and clustered (CLUST) occurrence of dead trees. Stand codes are explained in Table 2.

3.4. Tree species and tree size diversity

Tree species diversity was evaluated for stands S40 and S70 but not for S100, where only spruce could regenerate and thus the stand remained monospecific during the whole of the simulation period. In S40 the initial value of the used diversity index was significantly higher than in S70 because of more equal proportions of tree species (Fig. 4). The diversity, however, sharply decreased as fir become to dominate in the stand.

Tree size diversity was increasing in all simulated stands, though the increase was rather erratic in S40. The increase was related to the occurrence of large overmatured trees, which have not died despite their high mortality rates (Table 1), as well as to the occurrence of smaller trees appearing in the new generation of the forest.

Tree species diversity shows minor differences between the development driven by CLUST and RAN mortality modes, the differences are, however, in the range of the variability related to the ten simulation runs. The difference between the mortality modes as well as the inter-run variability of the tree size diversity significantly increased after ca 150 year of simulation in S40, such a pattern, however, lacks interpretation.

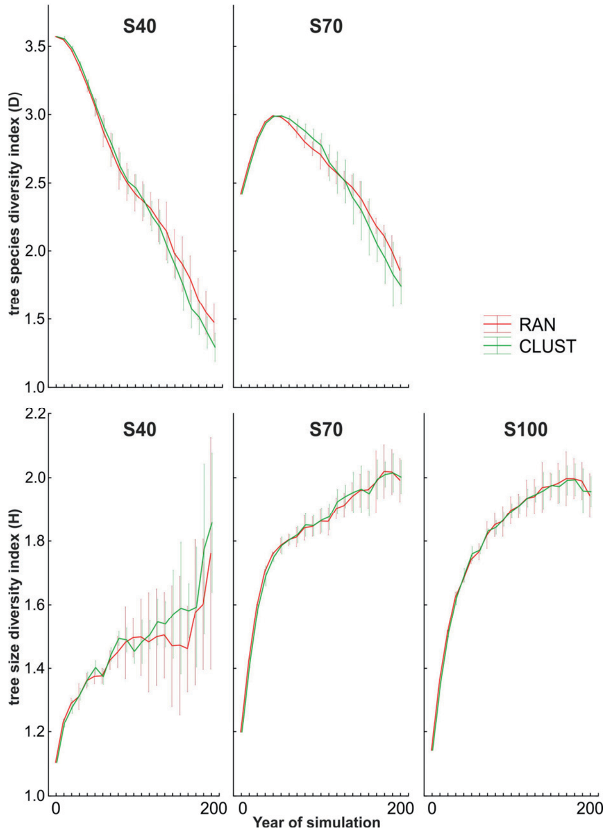

Fig. 4. Tree species (D) and tree size diversity index (H) simulated with the random (RAN) and clustered (CLUST) occurrence of dead trees. Stand codes are explained in Table 2.

4. Discussion

The model Sibyla represents a well-established forest model, which has been repeatedly used in the research of forest development driven by various management types, disturbances or by climate change (Hlásny et al. 2011, 2014, 2016; Vacek et al. 2013; Ambrož et al. 2015; Härtl et al. 2016). That the model operates at a scale of trees facilitated analyses that utilize tree positions, including the assessment of stand structure indicators or change in tree species composition. Still, there are limits in the understanding of model`s behavior, which should be explored to use the model more efficiently and support the proper interpretations of simulation outputs. We explored here how the spatially clustered occurrence of dead trees, which generates mortality patterns similar to those generated by spruce bark beetle, might affect selected stand structure and productivity indicators. Such a research might inform whether it is worth to consider the spatial distribution of dead trees in tree-based forest models, and how the selected indicators are sensitive to differences in the pattern of dead trees emergence.

We focused on three forest stands with different percentage of Norway spruce, which typically occur in central Europe. We found significant differences between the long-term developments of the three investigated forest stands, but we found very little effect of the tested mortality modes on stand increment, tree species composition and diversity, and tree size diversity. This was despite the pattern of dead trees distribution and the overall stand structure was rather different between the simulations driven by the two mortality modes (Appendix A). Hence, our hypothesis that the different pattern of dead trees emergence should affect the competitive interactions between trees and thus affect selected productivity and stand structure indicators was not confirmed.

Therefore, we suggest that different patterns of dead tree emergence might not be considered in tree-based forest model, when basic growth, yield and stand structure indicators are to be evaluated. Still, effect on specific indices of horizontal stands structure (e.g. Clark & Evans 1954, Stoyan & Stoyan 1992), which might be more sensitive to the modified distribution of trees, need to be explored.

There are some limits of the interpretation of our findings related to the used experimental design. We assumed that the prescribed degree of spatial clustering of dead trees remains constant during the whole simulation period. This is, however, not a realistic assumption because various transitions between random and patchy tree mortality patterns are typical of bark beetle population dynamics. Typically, small populations generate a scattered pattern because the beetles search for suitable hosts, while beetles in large populations tend to infest the trees in a closer vicinity (Kausrud et al. 2011; Hlásny & Turčáni 2013). Large populations might tend to collapse after a several-year period of the outbreak culmination because of the effect of diverse density dependent regulation mechanisms (Raffa et al. 2008). Therefore, the coefficient of affinity we used in the current study should change in time depending on a number of factors (e.g. stand age structure) to mimic the real bark beetle dynamics more reliably. We, however, argue that such a complex processes can be better addressed by models that specifically explore bark beetle dynamics (e.g. Netherer & Nopp-Mayr 2005; Jönsson et al. 2012) or process-based forest models (e.g. Seidl et al. 2012), while empirical growth and yield-oriented models, such as that used in the current study, might prefer a simplified design such as that we described here.
Another limitation relates to the technical implementation of our module in the model Sibyla. Because the source code of the model is not publicly available, the disturbance mortality module (including tree species- and age class-specific mortality probabilities described in the text, and the dead tree clustering module) were developed as an independent application in the Python language. The application interrupts the forest development simulation, identifies the trees to die, and retrieves the output set-up to the model. Such an implementation is not that optimal, and it remarkably increases the computational time.

5. Conclusions

We presented here the testing of algorithm, which allowed to simulate various distributions of dead trees, which emerge during the development of spruce stands in the forest model Sibyla. Our study showed that the tested indicators of forest development were not sensitive to the altered distribution of dead trees in the stand and that the hypotheses on the effect of such an alteration on regeneration and increment were not confirmed.

Although the presented findings indicated that tree-based forest models might not consider specific patterns of dead trees emergence in forest stands, there are several limits related to the experimental design used in the current study, which require further investigation. These limits include, for example, the unknown sensitivity of the natural regeneration in the model to the modified stand density induced by the two tested mortality modes. Moreover, there are specific stand structure indicators, which can be more sensitive to tree distribution in a stand than the indicators evaluated here; the sensitivity of such indicators needs to be explored. Still, our study provided a new insight on the development of spruce forest stands in the forests model Sibyla and thus can support the optimized use of the model.

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Appendix A: Differences in the development of Norway spruce stand in the forest model Sibyla with the random and clustered occurrence of dead trees

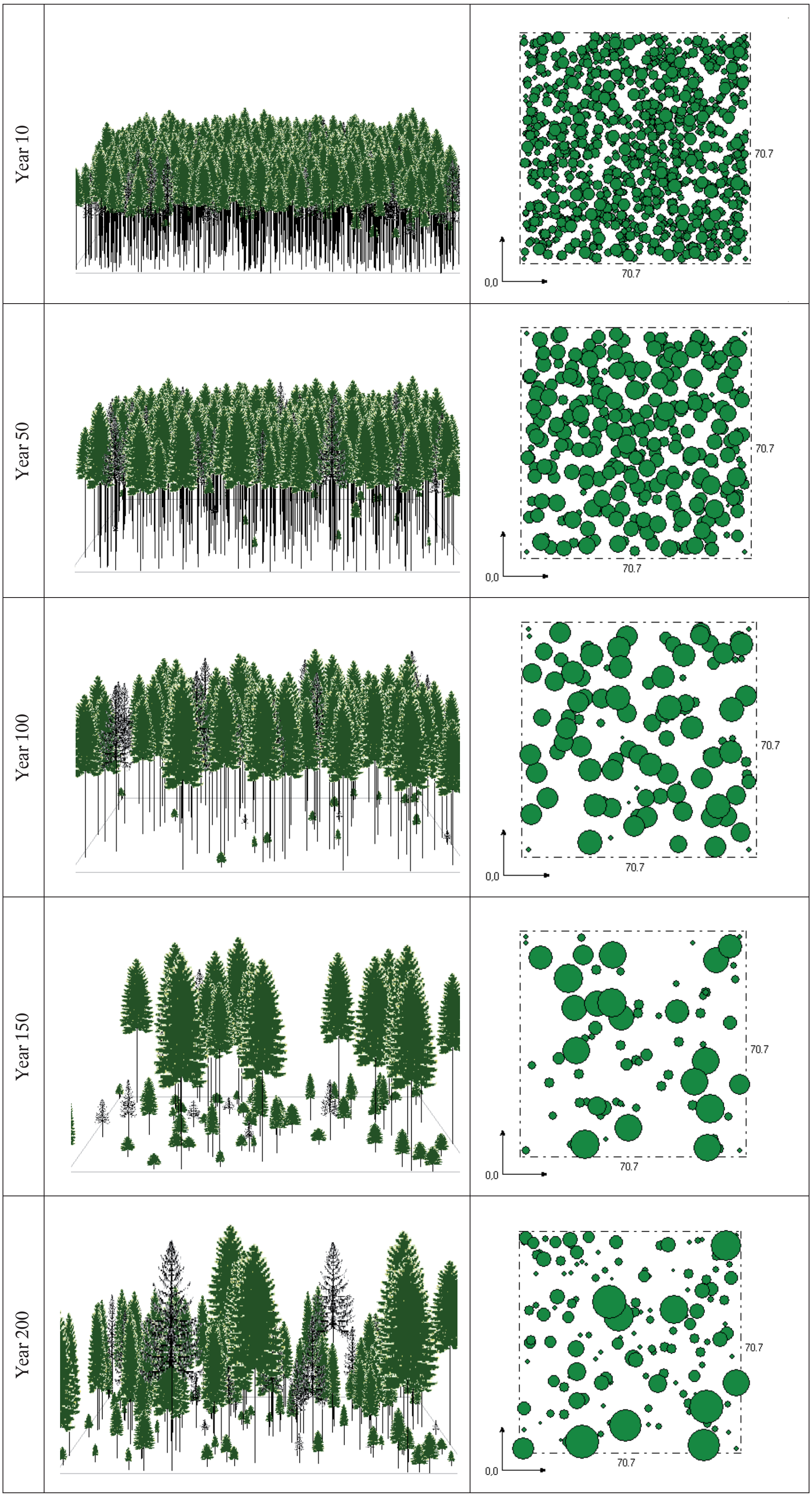

Fig. A1. Example of the development of spruce stand with the random occurrence of dead trees.

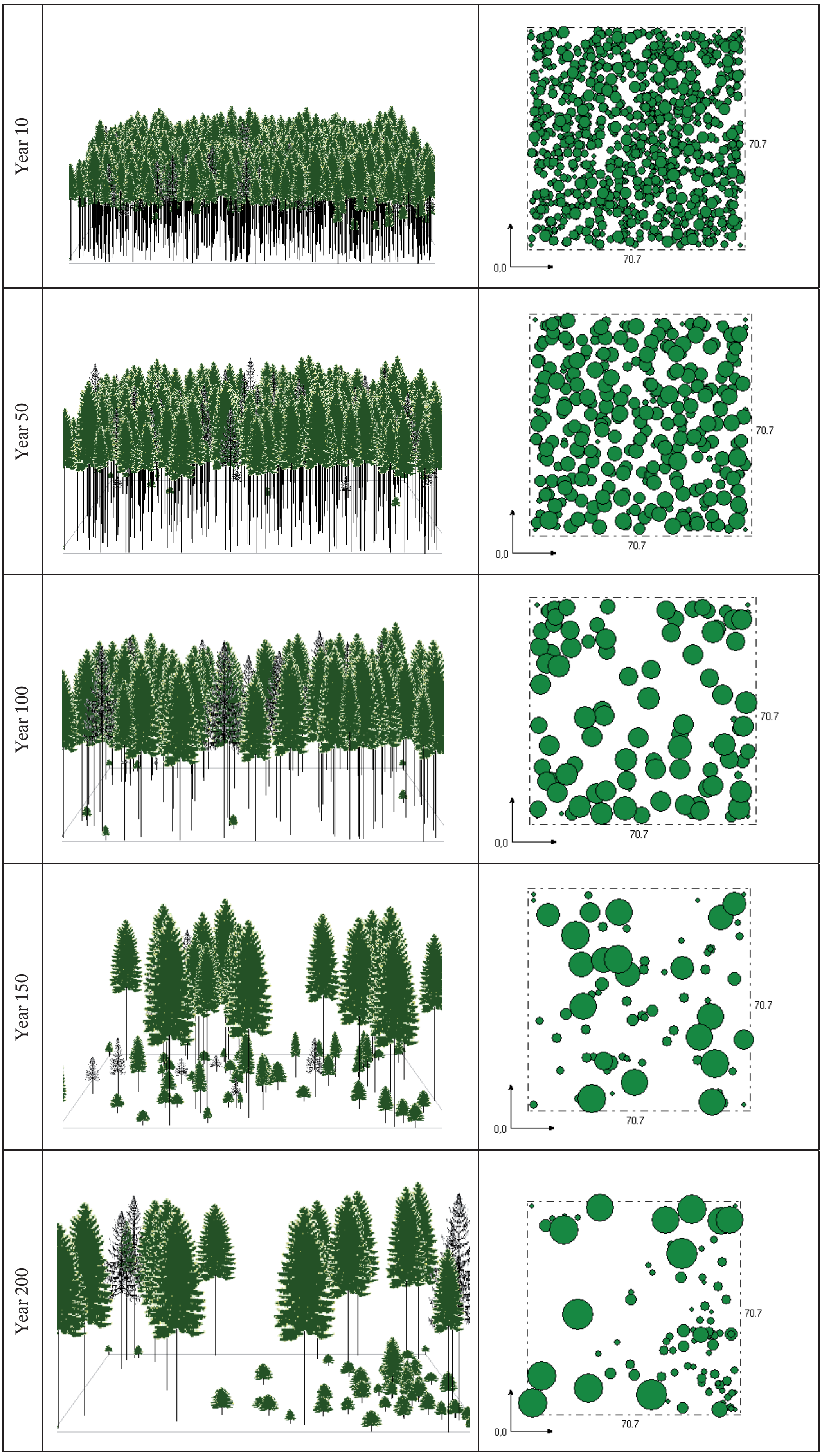

Fig. A2. Example of the development of spruce stand with the clustered occurrence of dead trees.

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ORIGINAL PAPER

Biodiversity and climate change: consequences for upper tree line in Slovakia

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Abstract
Study of the effects of climate change on upper tree limit has mainly focused on the diversity of tree species as a result of the ability of species to tolerate temperature and moisture changes as well as some effects of disturbance regime changes. The tree species diversity changes due to climate change has been analysed via gap model and biodiversity indices. Gap models are individually based on simulations of establishment, growth, and mortality of each tree on the forest plot. Input ecological data for model calculations have been taken from the permanent research plots located in primeval forests in mountainous regions in Slovakia. The results of regional scenarios of the climatic change for the territory of Slovakia have been used, from which the values according to the CGCM3.1 (global) model, KNMI and MPI (regional) models. Model results for conditions of the climate change scenarios suggest a shift of the upper forest limit to the region of the present subalpine zone, in supramontane zone. The most significant tree species diversity changes have been identified for the upper tree line and current belt of dwarf pine (*Pinus mugo*) occurrence. Hill's index of biodiversity in the upper forest line increased by 30 – 35% for horizon of 2050, resp. by 45 – 50% modeled for the horizon of 2075. Calculated values of Shannon's index show an even higher increase due to climate change. For horizon 2050 is a roughly of three fold increase and horizon for 2075 by almost fivefold increase in the value of the index. Results from the gap model indicate the increase of tree species diversity 2 – 2,5 times.

Key words: tree species diversity; climatic factors; upper tree line; forest management, Slovakia

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1. Introduction

Understanding how species and ecosystems respond to climate change has become a major focus of ecology and conservation biology. Modelling approaches provide important tools for making future projections, but current models of the climate-biosphere interface remain overly simplistic, undermining the credibility of projections (McMahon et al. 2011). Global circulation models of climate change predict an increase in mean annual temperature between 2.1 and 4.6 °C by 2080 in the northern temperate zone. The associated changes in the ratio of extinctions and colonizations at the boundaries of species ranges are expected to result in northward range shifts for a lot of species. However, net species colonization at northern boundary ranges, necessary for a northward shift and for range conservation, may be hampered because of habitat fragmentation (Honnay et al. 2002). Climate change can also affect forests and their diversity through disturbances. Disturbances are a natural and integral part of forest ecosystems, and climate change would alter these natural interactions. When disturbances exceed their natural range of variation, the change in forest structure and function may be extreme. Each disturbance affects forests differently. Some disturbances have tight interactions with the species and forest communities which can be disrupted by climate change (Dalea et al. 2000; Mezei et al. 2014).

The high altitude limit of forests, commonly referred to as tree line, timber line or forest line represents one of the most obvious vegetation ecotones. Most authors define tree line as the connecting line between the uppermost forest patches in an area, with trees upright, growing in groups, and at least 3 m in height (Švajda 2008). The upper limit of timber line is conditional on the cumulative effects of several factors. The factor that primarily determines timber line can be used to define types of timber line. Plesník (1971) recognized four types of upper timber line: climatic, orographic, avalanche and edaphic. More recently, Jodłowski (ex Švajda 2008) has distinguished five boundary types using the example of dwarf pine (*Pinus mugo*). These include: orographic, morphological, edaphic, mechanically lowered and anthropogenic dwarf pine line. An orographic timber line is located in the valley bottoms or on the watershed ridges and is controlled by climatic factors (e.g. solar radiation, and wind). An edaphic timber line results from lack of soil cover on talus slopes with block covers. A morphological line corresponds with slope-breaks or footsteps of rockfaces. A mechanically lowered timber line is controlled by avalanches or debris flows. Finally, an anthropogenic timber line exists where sites with intensive mountain-pine reconstruction have moved trees several hundred meters upslope and there is an abrupt transition between mountain-pine thickets and alpine meadows (Švajda 2008).

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The aim of this work is to analyze possible changes in the biodiversity of the upper forest line due to climate change through a range of methodological approaches. Potential changes of selected indices of biodiversity (Hill index, Shannon index) was assessed on the basis of current knowledge derived from actual diversity of trees in mountain forests and the forest line and their relation to climatic parameters (air temperature). Rating changes in tree species composition by Forest Gap Model to add information about changes in the potential range of species diversity, with special emphasis on woody component of ecosystems.

2. Material and methods

2.1. Biodiversity indices

Biodiversity analysis was performed based on model calculations for two diversity indices: Shannon's index and Hill index, which proved to be the most appropriate for assessing the diversity of mountain forests in Slovakia (see work of Minďáš et al. 2000 for more details).

Shannon index is defined as follows

$$H = -\sum_{i=1}^{n} x_1 * log_2 x_i \qquad [1]$$

where:

n – number of species identified on site,

x_i – ecological importance of species identified on site.

On the other hand, Hill index is defined as follows:

where:

$$N_2 = \frac{(\sum_{i=1}^{n} x_i)^2}{\sum_{i=1}^{n} x_i^2} \qquad [2]$$

n – number of species identified on site,

x_i – ecological importance of species identified on site.

Both indices can be calculated separately for tree species, shrub species, and herb species located at the explored plots.

2.2. Forest Gap Model

Forest gap models are included into a group of dynamic models which are able to calculate various characteristics of forest trees in time series. Gap models are individually based in that they simulate establishment, growth, and mortality of each tree on the forest plot. The response of an individual tree to ecological conditions on the plot are defined by a number of environmental response functions, generally expressed as a portion of optimal growth, ranging from 0.0 to 1.0. These environmental response functions have been defined by using various methods. The model requires the following input data for individual trees: maximum tree age, maximum diameter, maximum height, and maximum yearly seedling establishment scaled to plot. This model contains several „response functions" including light, water balance, and climate responses of individual trees, which are described in Minďáš et al. (2000).

2.3. Climate change scenarios for Slovakia

Four general circulation models of the atmosphere (GCMs), two of which are global (Canadian CGCM3.1, German ECHAM5) and two regional (KNMI Dutch and German MPI) have been used for the analyses. All models feature the outcomes of the daily values of a number of meteorological variables from 1951 to 2100. These models belong to the newest category of linked atmospheric-oceanic models with more than 10 atmospheric height levels and more than 20 oceanic depths calculating variables in the network nodes. CGCM3.1 model is close to Slovakia 9 nodes, a model ECHAM5 near Slovakia 12 square grid nodes (about 200 × 200 km) in proportion to smoothed orography. Regional models KNMI and MPI are more detailed integration of dynamic equations of atmospheric and oceanic circulation in the network nodes at a distance of 25 × 25 km, and boundary conditions solving equations taken from the global model outputs ECHAM5. In the area of Slovakia have models KNMI and MPI to 19 × 10 nodes (190) and of real orography with well defined all the mountains with a larger horizontal dimension than 25 km.

Table 1. Rise of mean annual air temperature according to the selected climate change models – Central Slovakia.

Climate Change scenario (SRES)	2050*	2075**
KNMI (A1B)	+ 1.65	+ 2.62
MPI (A1B)	+1.69	+2.58
CGCM3.1 (A2)	+ 2.1	+ 3.29

*Mean value from the period 2025–2075.
** Mean value from the period 2050–2100.

The main outputs from these scenarios are as follows (Table 1):

1) Average air temperature should be gradually increased by 2 – 4 °C compared with the average period from 1961 to 1990, while maintaining the same annual and inter seasonal temporal variability. The scenarios do not foresee significant changes in the annual running of air temperature in the autumn months, but would be smaller than the temperature rise in the rest of the year.

2) Annual precipitation should not change significantly, but rather assumes a slight increase (about 10%), mainly in the north of Slovakia. Major changes should occur in the annual running and temporal modes of precipitation. In the summer, it is widely expected slight decrease in rainfall (especially in southern Slovakia) and in the rest of the year, mild to moderate increase in rainfall (especially in winter and in northern Slovakia). In the warm part of the year it is expected to increase the variability of rainfall, probably will be extended and more frequent drought periods on the one hand and more intensive rainfalls on the other. Snow cover is likely to be higher on average only amounting to over 1200 m a.s.l., but these locations covered in Slovakia less than 5% of the area, which cannot significantly affect drainage conditions. Detailed description of climate change scenarios for Slovakia can be found in the paper of Lapin & Melo (2004).

3. Results

3.1. Influence of climatic factors on biodiversity

Globally, climate factors are crucial for the diversity of the world's biomes (Holdridge 1967), therefore, as a first step in the analysis of the relationship between species diversity and climate change, we performed an analysis of the frequency dependence of indigenous trees in the central region of Slovakia (Fig. 1) from the mean annual air temperature. We got out while data on natural extension of woody species in Slovakia (Minďáš 1998) and vertical change in mean annual air temperature. Maximum abundance of woody species is achieved at a mean annual temperature of around 7 °C from this value drops gradually (inflection point is reached at around 3 degrees, which is about the limit of the 6th altitudinal forest zone) and drops to zero in negative values of mean annual air temperature.

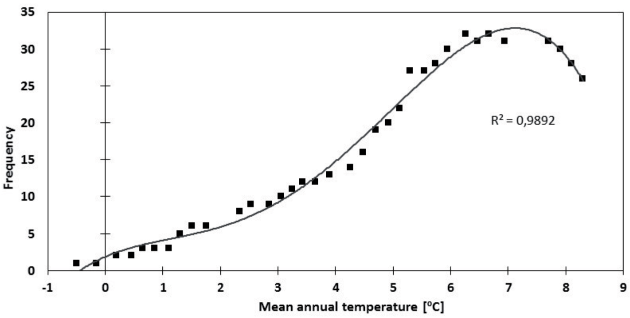

Fig. 1. Frequency changes of original tree species in the central part of Slovakia in relation to mean annual temperature.

Based on knowledge of the vertical distribution of tree species according to the mean annual air temperature and selected climate change scenarios we have implemented the model calculations to changes in the frequency potential of tree species in terms of climate change for the time horizon of 2075 (average period 2050–2100). The results are presented in Fig. 2. For the area of the upper limit of the forest, we can state a significant increase in the potential range of woody plants in the conditions of climate change, and the order of 400 – 500%. The truth must not forget that this bioclimatic potential occurrence of these species may not (and can not be) fulfilled by a number of reasons. In particular, the actual prevalence of trees in a circle from which these plants can spread in a natural way to the forest line. Other limiting factors may be the current protection system, actual management of forests at the upper limit of the forest, the occurrence of natural disturbancies, etc. Nevertheless, the results clearly indicate the growth potential of the diversity of tree species due to climate change within the area of current upper forest line.

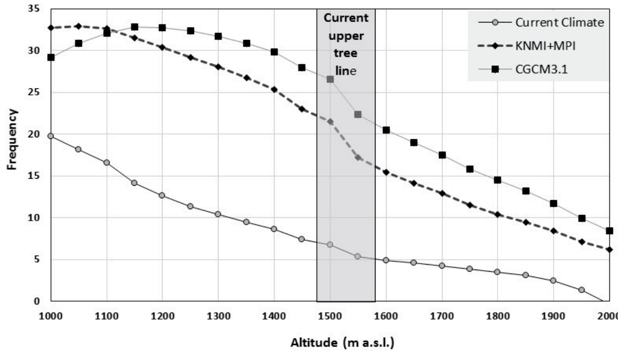

Fig. 2. Changes of original tree species occurrence in the central part of Slovakia in relation to the mean annual temperature for current climate and climate change scenarios.

3.2. Changes of biodiversity indices

As part of research on biodiversity of forest ecosystems were analyzed depending on selected indices of biodiversity and climatic parameters for the model area of the Low Tatras (Minďáš et al. 2000). Thus derived regression dependence of the two indices (Shannon, Hill) diversity of plant species we have used to calculate possible changes in those biodiversity indices for the selected scenarios of climate change.

Hill's index of biodiversity in the upper forest line increased by 30 – 35% for horizon of 2050, resp. by 45 – 50% modeled for the horizon of 2075 (Fig. 3). As regards the derived regression of the realistic assessment of forest ecosystems in this area, we can expect a real increase in the level of biodiversity in the forest line in the Low Tatras in the range of 30 – 50%.

Calculated values of Shannon's index show an even higher increase due to climate change. For horizon 2050 is a roughly of three fold increase and horizon for 2075 by almost fivefold increase in the value of the index. It should be noted that in the case of Shannon diversity index is a component of woody species of forest ecosystems.

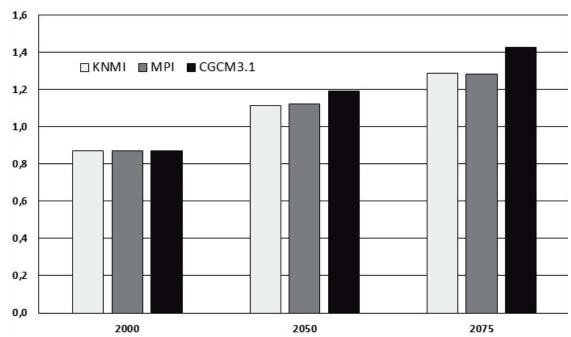

Fig. 3. Results of the calculation of Hill biodiversity index for upper tree line in Low Tatras region for current climate conditions and climate change scenarios.

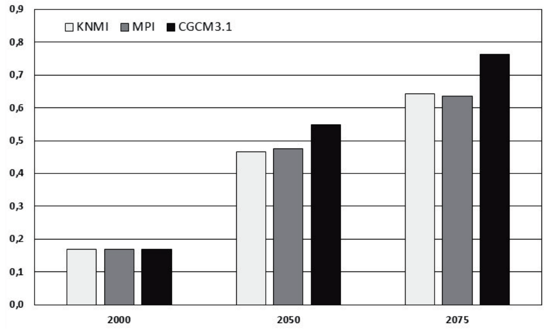

Fig. 4. Results of the calculation of Shannon (tree) biodiversity index for upper tree line in Low Tatras region for current climate conditions and climate change scenarios.

3.3. Forest Gap model

The consequences of climate change on forest ecosystems by Forest Gap model were analyzed for a number of forest ecosystems in Slovakia. For the purposes of this paper, we focused on the issue of changes in abundance (species diversity) of the occurrence of forest trees in the current upper forest limit. Model calculations were carried out for four locations in Slovakia with the appearance of the upper limit of the forest. The results are summarized in Table 2 and we could see from the results presented in each case increase in the number of species of tree to approximately double, being the plants with the occurrence of 5% (within the model calculations). Lower percentage of occurrence in the model does not guarantee real incidence of tree species in the unit. The highest potential increase in the number of trees we identified in the Low Tatras region, at least in the north of Slovakia (Pilsko).

Table 2. Number of tree species with frequency higher than 5 percent – Results from Forest Gap Model (four sites on the upper tree line).

Location	Current Climate	Climate change scenarios KNMI, MPI	Climate change scenarios CGCM3.1(A2)
Pilsko (Oravske Beskydy)	3	6	7
High Tatras	4	7	7
Low Tatras	4	8	9
Low Fatra	3	7	8

4. Discussion

Many studies in recent years have investigated the effects of climate change on the future of biodiversity. According to the review of Bellard et al. (2012) the majority of models indicate alarming consequences for biodiversity, with the worst-case scenarios leading to extinction rates that would qualify as the sixth mass extinction in the history of the earth. Several works analyzed the current situation and last decades changes of upper forest line in Europe. By comparing the altitudinal distribution of 171 forest plant species between 1905 and 1985 and 1986 and 2005 along the entire elevation range (from 0 to 2600 meters above sea level) in Western Europe, we show that climate warming has resulted in a significant upward shift in species optimum elevation averaging 29 meters per decade. The shift is larger for species restricted to mountain habitats and for grassy species, which are characterized by faster population turnover. Our study shows that climate change affects the spatial core of the distributional range of plant species, in addition to their distributional margins, as previously reported (Lenoir et al. 2008).

Forest expansion was also quantified using data from the repeated Swiss land use statistics GEOSTAT. A moving window algorithm was developed to distinguish between forest ingrowth and upward shift. To test a possible climate change influence, the resulting upward shifts were compared to a potential regional tree line. A significant increase of forest cover was found between 1650 m and 2450 m. Above 1650 m, 10% of the new forest areas were identified as true upward shifts whereas 90% represented ingrowth, and both land use and climate change as likely drivers have been identified. Most upward shift activities were found to occur within a band of 300 m below the potential regional tree line, indicating land use as the most likely driver. Only 4% of the upward shifts were identified to rise above the potential regional tree line, thus indicating climate change. Land abandonment was the most dominant driver for the establishment of new forest areas, even at the tree line ecotone. However, a small fraction of upwards shift can be attributed to the recent climate warming, a fraction that is likely to increase further if climate continues to warm, and with a longer time-span between warming and measurement of forest cover.

Dirnböck & Dullinger (2004) evaluate the potential influence of disturbance on the predictability of alpine plant species distribution from equilibrium-based habitat distribution models. Firstly, abundance data of 71 plant species were correlated with a comprehensive set of environmental variables using ordinal regression models. Subsequently, the residual spatial autocorrelation (at distances of 40 to 320 m) in these models was explored. The additional amount of variance explained by spatial structuring was compared with a set of functional traits assumed to confer advantages in disturbed or undisturbed habitats. The mentioned authors found significant residual spatial autocorrelation in the habitat models of most of the species that were analysed. The amount of this autocorrelation was positively correlated with the dispersal capacity of the species, levelling off with increasing spatial scale. Both trends indicate that dispersal and colonization processes, whose frequency is enhanced by disturbance, influence the distribution of many alpine plant species. Since habitat distribution models commonly ignore such spatial processes they miss an important driver of local- to landscape-scale plant distribution (Dirnböck & Dullinger 2004).

The results support earlier hypotheses that alpine plant species on mountain ranges with restricted habitat availability above the treeline will experience severe fragmentation and habitat loss, but only if the mean annual temperature increases by 2 °C or more. Even in temperate alpine regions it is important to consider precipitation in addition to temperature when climate impacts are to be assessed. The maintenance of large summer farms may contribute to preventing the expected loss of non-forest habitats for alpine plant species. Conceptual and technical shortcomings of static equilibrium modelling limit the mechanistic understanding of the processes involved (Dirnböck et al. 2003).

5. Conclusion

The results indicate significant potential for positive changes of ecosystems in the forest line. Our findings clearly indicate significant changes in the current upper limit of the forest, where in the next few decades we can expect further alterations in species composition of these ecosystems. The changes can be expected on tree, shrub and herbaceous species diversities. Important factors that can enhance or dampen growth trends of species diversity, are not only anthropogenic factors, in particular the management of these ecosystems, but also natural factors especially disturbances (e.g. wind, snow, insects).

Biodiversity of forest ecosystems is still open scientific problem, especially in terms of the complexity of the assessment. Most of the work on that topic is mainly focused on diversity of woody components, but this certainly is not sufficient for assessing biodiversity of forest ecosystems as a whole. The results suggest potential and vector direction of possible changes in diversity, particularly forest trees in the forest line impacts of climate change. However, we are aware that in the future we will have to resort to more complex model analysis on the basis of multifactorial models and assessments of biodiversity change (Acton 2013).

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FOREST EUROPE Work Programme: Pan-European Follow-Up of the Madrid Ministerial Conferences

Since 1st January, 2016, Slovakia holds the presidency in the FOREST EUROPE process (formerly known as Ministerial Conference on the Protection of Forests in Europe), therefore, Slovakia also hosts the secretariat of the process – the Liaison Unit Bratislava (LUB) which was established within organisational structure of the National Forest Centre in Zvolen. FOREST EUROPE is a unique forest policy process addressing and developing common decisions on issues of the highest political relevance. Having recently celebrated its 25th anniversary, the process has 47 signatories (46 European countries and the European Union), and a number of other observer countries and organizations also participate. Key outputs include Criteria and Indicators for Sustainable Forest Management, Pan European Approach to National Forest Programs and comprehensive report State of Europe´s Forests, among the others.

FOREST EUROPE Work Programme

The new FOREST EUROPE Work Programme for the period 2016–2020 was prepared by the Liaison Unit Bratislava in cooperation with the former Liaison United Madrid and under the oversight of the General Coordinating Committee. The Work Programme reflects commitments made at the 7th Ministerial Conference and the Extraordinary Ministerial Conference, held on 20–21 October 2016, in Madrid, Spain. In addition, some of the planned actions (broader thematic areas) and activities (such as expert groups, analyses and workshops) also refer to the commitments adopted at previous FOREST EUROPE Ministerial Conferences. The policy goals for European Forests and the European 2020 Targets for Forests adopted at the 6th Ministerial Conference in Oslo (2011) need to be addressed through this Work Programme as well.

The main objective of the Work Programme is to continue to promote sustainable forest management (SFM) in signatory countries, reflecting latest developments, knowledge, and innovations on emerging issues, and to develop common strategies to this end.

The activities of the Work Programme will be carried out in cooperation with FOREST EUROPE signatories and observers, the Liaison Unit, and other relevant regional actors. Cooperation with regional bodies and processes within Europe and, where relevant, in a broader geographical context (e.g. United Nations Economic Commission for Europe - UNECE, Food and Agricultural Organisation - FAO, United Nations Environmental Programme - UNEP, European Forest Institute - EFI, United Nations Forum on Forests - UNFF, Convention on Biological Diversity - CBD, United Nations Framework Convention on Climate Change - UNFCCC, United Nations Convention to Combat Desertification - UNCCD, and International Union of Forest Research Organizations - IUFRO) will be strengthened, and synergies in the implementation of the relevant Work Programmes will be sought, following dialogue with the entities listed, specifically with the UNECE/FAO Integrated Programme of Work. Further efforts to reach out to other sectors will also be made.

The Work Programme is fully aligned with the latest relevant global initiatives, such as the 2030 Agenda and its Sustainable Development Goals (SDGs), the UNFF11 Resolution, and the Paris Agreement, and, where relevant, will seek to contribute to their implementation.

The FOREST EUROPE Work Programme for the period 2016–2020 comprises following actions and activities:

– ***Further development and updating of policies and tools for sustainable forest management.*** This overarching action will contribute to better coordination of policy tools on forests and forest management at global, regional, sub regional and national levels, e.g. the 2030 Agenda including its SDGs, the Aichi Biodiversity Targets, Global objectives on Forests, regional C&I process and their subsets for the assessment of SFM, and Global Forest Resource Assessments (FRAs), and to communication between them and other sectors. The Expert Group will consider implementation of the updated set of SFM indicators, inter alia, monitor and analyse how C&I are developed and how they could be implemented. Apart from that, possible uses of the pan-European C&I subsets and reporting on national and pan-European achievements on Goals and 2020 Targets for European Forests. The output of the analysis should include detailed explanation and clarification of the particular subsets, inter alia, for assessing and communicating the achievements of SFM and addressing other policy areas.

– ***Forest monitoring and reporting.*** Monitoring and reporting on forests and SFM, including the preparation and production of the State of Europe's Forests Report (SoEF), belong to regular FOREST EUROPE activities. Collaborative data collection for the next edition of SoEF 2020 should be done in close cooperation with FAO Global Forest Resources Assessments and Joint UNECE/FAO Forestry and Timber Section. Within this action, also the pilot studies on new indicators will be carried out, in terms of data availability, reliability and feasibility for three newly defined indicators (2.5 Forest land degradation, 4.7 Forest fragmentation, 4.10 Common forest bird species). Pan-European forest monitoring and reporting should also facilitate the evaluation of achievements on Goals and 2020 Targets for European Forests.

– ***Enhancing the role of sustainable forest management in a green economy.*** FOREST EUROPE with the assistance of Expert Group and in collaboration with partners (signatory countries and relevant international institutions) will identify and specify new skills required for forest workers, forest managers and forest owners in the context of green economy as well as other requirements for green jobs in the forest sector. Subsequently, achievements of the Expert Group will be discussed at a workshop. Outcomes of the workshop including recommendations and best practice examples will lead to preparation of guidelines on the promotion of green jobs in the forest sector. Another workshop will be organized to promote long term competitiveness of the whole forest sector and its related value chain, highlighting the role of wood and other forest products and goods from sustainable sources, including innovative materials contributing to transition to a green economy.

– ***Incorporating the value of forest ecosystem services in a green economy.*** FOREST EUROPE Expert Group will carry out an analysis of different approaches, methodologies and best practice examples on valuation of and payments for forest ecosystem services (FES) particularly in the signatory countries. Subsequently, recommendations for policy makers with the aim to facilitate implementation of valuation of and payments for FES will be developed. Outcomes of the analysis will serve as a base for establishment of a web-based portal in order to promote exchange of information and experience on valuation of FES and PES schemes existing in the pan-European region.
– ***Protection of forests in a changing environment, including their adaptation to climate change.*** Within this action, an Expert Group will conduct a questionnaire survey to explore the current state of implementation of adaptation measures to climate change at national levels. Based on the survey, a publication "Integration of adaptation measures into SFM in Europe" will be worked out, comprising knowledge base and work done in the region, identifying the best practices and possible recommendations for the integration of adaptation measures into SFM in the region. Two workshops shall be organized within this action to share expertise, experience and prepare recommendation for policy makers on protection of forests in changing environments combating desertification, land degradation and drought, highlighting the role of forestry and agroforestry to this end.
– ***Enhancing the social dimension of sustainable forest management*** in the context of the benefits of forests to human health and well-being. A group of experts will review international data on social aspects of SFM with special attention to impacts and benefits of forest environment and forest products on human health and well-being. A workshop will be convened to share knowledge, experience and best practice examples relating to impact of forests on human health (mental and physical), well-being and personal development. Outcomes of the review together with recommendations from the workshop will result in publication focused on promotion of entrepreneurship related to forests and businesses based on processing of non-wood products (ecotourism, sport, outdoor learning and therapy programmes). Apart from that, awareness raising and promotion of the topic within and outside forest sector (health sector, tourism, sport, education, etc.) will be crucial for successful implementation of the action.
– ***Review of the FOREST EUROPE process.*** The objective of this activity will be to further develop the FOREST EUROPE process with a view to adapting it to current and future challenges, and to enhance its contribution to the promotion of SFM in Europe. The subject of the Review will be the FOREST EUROPE process, its structure, procedures and work modalities, in order to make it more effective and inclusive.
– ***Discussion on the follow-up to the Madrid Extraordinary Ministerial Conference.*** Building upon the efforts made in previous years, FOREST EUROPE will explore possible ways to find common ground for a Legally Binding Agreement on Forests in Europe.
– ***Communication and outreach.*** The communication activities should further enhance the positive perception of forest and the forest sector's multiple contributions to global and societal needs, as well as the achievements of its overall objectives. Some new communication activities such as "Whiteboard" short animation about FOREST EUROPE, Interactive "story maps" with successfully implemented FOREST EUROPE commitments will be launched. A new FOREST EUROPE webpage will have new, modern and all-devices responsive design, easy orientation or event management system. Moreover, the process will be promoted at the core events (i.e. International Day of Forests, European Forest Week, Sessions of FAO Committee on Forestry - COFO, Sessions of the UNECE Committee on Forests and Forest Industry - COFFI, UNFF meetings etc.).

First FOREST EUROPE meetings organized during the Slovak chairmanship

FOREST EUROPE Expert Level Meeting

On 11–12 May 2016, Bratislava hosted the first Expert Level Meeting (ELM) since the Slovak Republic took over the chairmanship of the FOREST EUROPE process. Nearly 70 delegates representing 29 signatory countries, the European Union and 14 observer organisations attended the meeting. ELM represents the decision-making body of the FOREST EUROPE process in the period between Ministerial Conferences. The recent ELM was prepared by the new Liaison Unit Bratislava under the oversight of the General Coordinating Committee, which currently consists of the Slovak Republic, Spain, Germany, Turkey and Sweden. Ms. Gabriela Matečná, Minister of Agriculture and Rural Development of the Slovak Republic, opened the meeting and expressed in her introductory speech the importance of the task and the responsibility that Slovakia bears for the FOREST EUROPE process. A key objective of the meeting was the discussion and adoption of the new FOREST EUROPE Work Programme and its pan-European actions and activities in follow up to the Madrid Ministerial Conferences. Besides the Work Programme, the ELM also discussed next steps in the Review of the FOREST EUROPE process.

Fig. 1. Expert Level Meeting was opened by Ms. Gabriela Matečná, the minister of Agriculture and Rural Development of the Slovak Republic.

Fig. 2. Delegates of 29 signatory countries and 14 observer organisation discussed at ELM the new FOREST EUROPE Work Programme for the up-coming period 2016–2020.

First meeting of the Working Group on the Future Direction of FOREST EUROPE

At the Madrid Ministerial Conference held in October 2015, the FOREST EUROPE signatories and observers had decided on a review of the process, especially its structures, procedures and work modalities with a view to adapting to current and future challenges. The review was launched by adopting the Terms of Reference with Roadmap, and by appointing two co-chair countries, France and Ukraine, to lead the Working Group on the Future Direction of FOREST EUROPE at the Expert Level Meeting in May 2016.

The first meeting of the Working Group took place on 12–13 October 2016, in Bratislava. Participants from 21 signatory countries and the European Union as well as 7 international observer organizations attended the event, which indicates a keen interest in the momentum generated by the review. The format of the meeting was a discussion forum to enable brainstorming about issues that require attention and will need to be addressed. There was an ample discussion on the multiple factors that influence efficiency, effectiveness, transparency and inclusiveness of the process. Outcomes of the discussion provide a key input to the comprehensive, web-based questionnaire survey of opinions of all signatories and observers to be conducted in the beginning of 2017.

Fig. 3. Mr. Peter Kicko, Director General of the Forestry and Wood Processing Section of the Ministry of Agriculture and Rural Development officially opened the first meeting of the Working Group on the Future Direction of FOREST ERUOPE.

Fig. 4. Meeting of the Working Group was led by two co-chairs Ms. Claire Morlot (France) and Ms. Liubov Poliakova (Ukraine) with technical and administrative support by the Liaison Unit Bratislava.

According to the roadmap discussed at the meeting, the second meeting of the Working Group to evaluate survey results and produce a draft report will take place by June 2017. The final report with recommendations will then be presented to the Expert Level Meeting in autumn 2017.

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Linking belowground biodiversity and ecosystem function in European forests – the 5th meeting of the COST Action FP1305 in Průhonice

Soils belong to the most complex and heterogeneous components of ecosystems. They exhibit a great abundance and diversity of soil organisms, e.g. up to 10^6 species of bacteria were identified per gram of soil. There is currently much interest in the relationship between soil microbial diversity and ecosystem functioning. The main question is whether diverse microbial community is better adapted to promote ecosystem functioning in comparison to species poor microbial communities. This is also one of the reasons why in May 2014 the COST Action FP1305 "Linking belowground biodiversity and ecosystem function in European forests (Biolink)" started. Biolink is aimed to create a forum where current understanding of functional belowground biodiversity at different scales and trophic levels in European forests can guide development of prescriptions for sustainable forests and tree crop management.

The 5th meeting of Biolink carried out during 24 – 26 October 2016 in Průhonice near Prague. The meeting attended over 90 participants from 26 countries of Europa, Near East and Africa. The introduction of the meeting was carried out on Monday, 24 October 2016, late afternoon by **Martin Lukáč** from the University of Reading (UK), the COST Action Chair, and **Pavel Cudlin** from the Czech Academy of Sciences in Prague (CZ) as the main local organizer, who shortly presented the aim and program of the meeting and opened a poster session where especially young researchers could present their work and discuss it with others.

The plenary lectures in next two days were organized in five sessions and twenty oral communications. On Tuesday, 12 researchers including three invited speakers presented their results during three sessions. **Miroslav Vosátka**, the director of the Institute of Botany by the Czech Academy of Sciences, informed shortly about the history and focus of the Institute. As he stated, the Institute of Botany is located in the Průhonice Castle since 1962. It performs research on vegetation at the level of organism, population, communities of plants and ecosystems, and in the whole scope of disciplines such as taxonomy, biosystematics and phytogeography of higher and lower plants including selected groups of fungi, plant ecology, mycorrhizal symbioses etc. Currently, the institute is especially concerned on biodiversity and evolutionary trends among plants, ecology of invasive species, responses of plants and vegetation to environmental changes and the mechanisms that enable species to coexist in ecosystems.

Matty Berg (NL), the first invited speaker, pointed during his presentation "Reaction of communities and ecosystems to environmental change: a trait approach" that the prediction of species distribution across time and space is very difficult and we need more information to understand the link between stress – community response to stress – community effect on processes – ecosystem function. On the example of snails and isopods he demonstrated a trait approach, the linkage between response and effect traits and a need for quality trait databases. The presentation of **Christoph Rosinger** (AT) dealt with ectomycorrhiza (ECM), especially with the significance of rare ECM species for biodiversity. As he stated, 20–25 thousands of ECM species were globally identified until now. The study in 72 stands of beech, spruce and pine forests showed that while 67% of ECM species were found solely on one site, only 4% of species were found on more than five sites. The most important driver of ECM occurrence seems to be the host taxon; there is only a few rare multi-host species. **Elena Vanguelova** (UK) discussed the effect of tree species on soil microbial community in young as well as mature stands. The results showed that in young stands soil movement during site preparation and planting might have a major effect on soil microbial community during first five years of stand development. In mature stands, the effect of trees was identified, but it differed depending on soil type and climate. **Paolo Nannipieri** (IT), the second invited speaker, pointed that by knowing microbial diversity it may be possible to manipulate soil and the capacity of soil to resist to stress may depend on microbial diversity. While there is a redundancy for C and N-mineralisation (different species have the same role), some soil processes, e.g. nitrification depend only on some microbial species. He pointed also on the role of omics in analysing microbial community. **Johannes Rousk** (SE) investigated how warming (+1.1 °C) and litter addition treatments in the subarctic influence the

Fig. 1. A group of the participants at the COST meeting (photo by Peter Železnik).

susceptibility of soil organic matter (SOM) mineralization to priming. He showed that labile C appeared to initiate catabolic responses of the microbial community that shifted the SOM mining to N-rich components, an effect that increased with higher fungal dominance. **Petr Baldrian** (CZ) pointed that tree harvest changes the functioning of forest soils as 31% decrease in root dry mass was found six months after harvest. While in died roots the fungal biomass as well as activity increased, in rhizosphere the decrease of fungal biomass and activity (except Mn-peroxidase) was observed. At the same time, changes in the composition of fungal community were observed. **Tereza Mašínová** (CZ) presented results of a soil yeast communities study in the topsoil of beech, oak and spruce stands. The results showed that yeast represents a significant proportion of fungal community in forest soils. They are dominant in mineral soil unlike of litter; on the other hand, in soil they are less diverse than in litter. While the effect of dominant trees on yeast was more pronounced in the litter, the effect of soil chemical properties was distinct in the mineral horizons. Generally, vegetation had lower effect on yeast than other fungi. **Flavia Pinzari** (IT), the third invited speaker, highlighted that metals and microelements in plant and microbial uptake receive less attention than carbon or nitrogen. Metals mobilise K release, contrasting results are about Ca, Mg and Mn mobility. Fungi accumulate more minerals than foliage; significant differences were observed in the accumulation of metals also between oak and beech. **Ina C. Meier** (DE) in her presentation dealt with the type of mycorrhization on root functions of temperate forests. She pointed on the differences between ectomycorrhiza (ECM) and arbuscular mycorrhiza (AM) and showed that increased root exudation in ECM tree species especially under drought stress lead to the increase in the decomposition of less bioavailable C sources. Also greater variability in ECM than AM communities was found. According to the presentation of **Taina Pennanen** (FI), spruce clonal trial demonstrated that ECM diversity correlates with the host tree growth. In the last presentation on Tuesday, **Evsey Kosman** (IL) explained how to understand and express the characteristics such as dispersion (amount of dispersion, evenness of dispersion), species richness etc. used in the description of the diversity and variability in communities and populations.

Next day, on Wednesday 26th October 2016, the presentations continued in two sessions. **Marie Spohn** (IT), invited speaker from Italy, analysed the phosphorus cycling in *Fagus sylvatica* forests. It was shown that while there are seasonal differences in the P uptake by beech with distinct increase in June, the P uptake by microorganisms and ECM was on the same level during the whole period of observation. Phosphatase activity in the rhizosphere depends on P availability and is stimulated by root exudates. The results also reflect the direct competition between microbe and plant uptakes. **Katarzyna Hrynkiewicz** (PL) evaluated the total metabolic activity as well as siderophore producing bacterial strains in forest stands with birch and alder located in areas contaminated with heavy metals and their potential in phytoremediation. **Iftekhar U. Ahmed** (ET) introduced the participants into the Ethiopian Highland where the effect of changes in land use on soil microbial community were evaluated. Soil microbial biomass C and N, as well as enzyme activities were determined in soil samples taken from the natural forest, plantation forest and grazing land. The results showed that the natural forest exhibited the highest microbial biomass as well as activity, the lowest microbial biomass was found in grazing land. The effect of tree species was most pronounced in the plantation forest. **Edda Sigurdis Oddsdottir** from Iceland pointed out that while several hundred years ago 25% of Iceland was covered by forest, the situation in present is quite different and forest is present only on 2% of the Iceland area. Last decades there is a trend of afforestation, ca 1/3 of forest stands are formed by birch, the rest by introduced trees. The earthquake in 2008 caused a shift in the fault line and as the Iceland is known by hot springs, this shift caused also heat increment in a new area under a forest. The changes enabled to study the effect of heat increment on forest stands and also on rhizosphere and ECM. It was found that the heat increment leads to the decline of root tips. Increased temperature did not affect ECM growth and fungal composition, however, ECM on root tips declined.

The last invited speaker **Brian Pickles** (UK) highlighted the importance of mycorrhiza and pointed that mycorrhiza occurs on 93% of angiosperms and 82% of vascular plants. It is able to respond to environmental changes more rapidly than its host. In past climate changes, changes in glaciation caused plant migration in North America and the question is the changes are reflected also in ECM. The study in British Columbia showed that inside the host distribution similar fungal communities occur but with low richness; outside the host distribution lower colonisation with local fungi, but with higher richness was observed. **Irena Maček** from Slovenia pointed on a rare phenomenon of "terrestrial mofettes" which are natural sites with constant geogenic CO_2 exhalations and consequent soil hypoxia. They can be used as a model ecosystem for the study of ecosystem responses to potential CO_2 increase. They used mofettes to determine whether a long-term directional pressure could change AM fungal community structure and drive the selection of particular AM fungal phylotypes. Numerical dominance of two AM fungal phylotypes in hypoxic soils was found. The presentations of Mathias Mayer (AT) and Martina Vašútová (CZ) were focused on soil microorganisms at the windthrow plots. **Mathias Mayer** presented the results from the Austrian Alps where they studied microbial biomass, enzyme activities and soil organic matter decomposition in gaps with and without tree recruitment. Generally, increased soil temperature and moisture was observed in gaps; however, tree recruitment in gaps kept temperature and soil moisture at stand levels. The CO_2 release did not change in gaps as the increase in microbial respiration due to higher temperature was balanced by a decline in root respiration as a consequence of tree death. The formation of gaps after windthrow led to an increase in litter and soil organic matter decomposition. The presence of tree recruitment retarded this process, what indicates that sufficient pre-disturbance tree recruitments could potentially increase ecosystem resilience after forest disturbance. **Martina Vašútová** analysed the management effect on ECM species community ten years after the windthrow. The research was carried out at four plots with different management established after the windthrow in 2004 in the Tatra National Park (Slovakia) when a large part of spruce forests was strongly damaged. She also compared two approaches in the ECM estimation which offered a bit different results. The plenary lectures finished by the presentation of **Tobias Guldberg Froslev** (DK) regarding the "BIOWIDE" project on biodiversity.

Each day after the plenary lectures, the participants continued scientific work in four working groups (WG), focusing specific topics: WG1 link diversity to function, WG2 look at the structure of belowground food webs and WG3 assess the importance of belowground diversity in intensively managed forest ecosystems. WG4 utilise the information gathered by other working groups to evaluate novel modelling concepts to include biodiversity and functional diversity indices.

The participants had also an opportunity to visit Průhonice Park as the meeting took place in its immediate vicinity. During the tour, Mr. M. Vosátka and J. Burda informed about its history and current status. As it was mentioned, Průhonice Park was founded in 1885 by Count Arnošt Emanuel Silva-Tarouca. He introduced tree species of domestic origin uniquely combined with imported foreign species. The combination of groups of different trees with meadows, ponds and streams offers unique park composition, an original landscape architecture of worldwide importance. This was the reason why it became a UNESCO world Heritage Site and Czech National Historic Landmark. The park is also of high dendrological value because of a collection of about 1,600 species of local and exotic plants and of 8.000 rhododendrons with 100 taxa and cultivars.

The three day program provided an opportunity to bring experts in biodiversity, tree ecology, modellers etc. together and exchange knowledge. The next meeting will be on 26–29 June 2017 at the University of Tartu in Estonia.

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Aktuálne problémy v zakladaní a pestovaní lesa 2016 – 4. ročník medzinárodnej konferencie

Dňa 19. – 20. októbra 2016 sa v priestoroch Spoločenskej dvorany Kúpeľného hotela Palace, Kúpeľov Sliač, a. s., konal 4. ročník medzinárodnej konferencie „Aktuálne problémy v zakladaní a pestovaní lesa“, ktorú organizovalo Národné lesnícke centrum - Lesnícky výskumný ústav Zvolen (NLC - LVÚ Zvolen) v spolupráci s Ministerstvom pôdohospodárstva a rozvoja vidieka SR a Slovenskou lesníckou spoločnosťou. Podujatie, ktoré sa už každoročne stalo tradičným, je príležitosťou na prezentáciu najnovších informácií a poznatkov výskumu z oblasti zakladania, pestovania a produkcie lesa širokému okruhu vlastníkov a užívateľov lesa a zároveň aj platformou pre odbornú diskusiu výskumných pracovníkov s lesníckou praxou. Konferencie sa zúčastnilo 92 platiacich účastníkov z lesníckej praxe, výskumu a akademickej sféry.

Na úvod sa prítomným prihovoril riaditeľ odboru štátnej správy lesného hospodárstva MPRV SR Ing. Pavol László, ktorý vyzdvihol význam podujatia zameraného na pestovanie lesa pre produkciu kvalitnej drevnej suroviny a zabezpečovanie všetkých spoločnosťou požadovaných mimoprodukčných funkcií našich lesov. Úspešný priebeh podujatiu zaželal vo svojom príhovore aj riaditeľ NLC - LVÚ Zvolen Dr. Ing. Tomáš Bucha.

S hlavným referátom *„Ekologické a ekonomické zmeny verzus problémy pestovania lesov na Slovensku“* vystúpil prof. Ing. Milan Saniga, DrSc. vedúci katedry pestovania lesa na Lesníckej fakulte Technickej univerzity vo Zvolene. Analyzoval vplyv jednotlivých škodlivých činiteľov (vietor, sucho, deficit atmosférických zrážok, podkôrny hmyz, poškodenie zverou) na lesné ekosystémy. Na základe súčasného stavu lesných porastov a očakávaných scenárov ich vývoja v budúcnosti sformuloval pestovné opatrenia zamerané na zmiernenie vplyvov klimatickej zmeny. Zdôraznil nevyhnutnosť prihliadať na uvedené prejavy pri výchove a obnove porastov. V pestovnom režime navrhuje viac akcentovať štrukturalizáciu porastov formou silných úrovňových prebierok s následným vytváraním viacvrstvových a mozaikových porastov. Zároveň odporúča uplatňovať pestovné systémy založené na princípe prírode blízkeho obhospodarovania lesa.

Doc. Ing. Ivan Repáč, PhD. z katedry pestovania lesa LF TU vo Zvolene predniesol *„Príspevok k poznaniu prežívania a odrastania voľnokorenného a krytokorenného sadbového materiálu vybraných drevín na kalamitných plochách“*. Uviedol poznatky z 5-tich výskumných výsadbových plôch v rôznych orografických celkoch SR. Vo väčšine kombinácií (plocha – drevina – termín výsadby) neboli zistené výraznejšie rozdiely v prežívaní a raste voľnokorenného a krytokorenného materiálu. V niekoľkých prípadoch lepší výsledok väčšinou dosiahol krytokorenný materiál. Najlepšie sa však

Obr. 1. K účastníkom konferencie sa prihovoril aj riaditeľ LVÚ - Zvolen Dr. Ing. Tomáš Bucha

uplatnili výsadby vyspelých voľnokorenných škôlkovaných sadeníc smreka. Veľmi dobre sa tiež osvedčili štandardné semenáčiky buka. Naopak, v podmienkach hodnotených plôch sa neosvedčili 1 – 2-ročné voľnokorenné semenáčiky borovice.

Veľmi zaujímavé výsledky viac ako 15-ročného výskumu koreňových systémov lesných drevín prezentoval prof. Ing. Oldřich Mauer, Dr.Sc. z Ústavu zakládání a pěstování lesů LDF Mendelovej univerzity v Brně v práci *„Vývin kořenového systému jako předpoklad pro zajištění mechanické stability porostů rozhodujících dřevin na rozhodujících stanovištích v České republice“*. Analýzy boli vykonané na 67 stanovištiach, pričom na každom bolo analyzovaných 16 druhov drevín vo veku 35 až 60 rokov. Potvrdilo sa, že morfológiu koreňových systémov jednotlivých drevín výrazne ovplyvňujú konkrétne stanovištné podmienky. Tá istá drevina môže mať na rôznych stanovištiach úplne odlišné koreňové systémy. Medzi najdôležitejšie výsledky patrí zistenie, že k najuniverzálnejším drevinám pre zaistenie mechanické stability patrí jedľa biela a na vodou neovplyvnených stanovištiach aj duglaska tisolistá. Naopak buk lesný nepatrí vždy medzi dreviny, ktoré túto funkciu zabezpečia. Na niektorých stanovištiach (obzvlášť vodou ovplyvnených) môže veľmi dobre spevňujúcu funkciu v poraste plniť smrek obyčajný, pričom najväčší, najhlbší až uniformný koreňový systém na takýchto stanovištiach vytvára jelša lepkavá, ktorá by tu mohla pri vhodnom spôsobe založenia porastu zohrávať aj významnú stabilizačnú funkciu.

Ing. Anna Túčeková, PhD. z odboru pestovania a produkcie lesa (OPPL), NLC - LVÚ Zvolen, uviedla v príspevku *„Dynamika vývoja kultúr cenných listnáčov na demonštračnom objekte Husárik“* poznatky zo 4-ročného sledovanaia vývoja umelej obnovy javora a jaseňa sejbou (klasická a mikrovýsevy vo vegetačných bunkách) a sadbou (voľnokorenné a krytokorenné sadenice). Pri obidvoch drevinách významne lepšie vyklíčili semená vo „vegetačných bunkách“ ako na klasických plôškach. Semenáčiky zo sejby prežívajú s problémami. Jedince zo sadby voľnokorenných a krytokorenných typov sadeníc nepreukázali významné rozdiely rastových parametrov nadzemnej časti v prospech krytokorenných. Krytokorenné sadenice javora mali vyššiu ujatosť, ale podobne ako aj jasene sa po výsadbe horšie adaptovali. V ďalšom príspevku *„Pokusná výsadba drevín pri zazeleňovaní rekultivovaných plôch v rámci Slovenských magnezitových závodov, a. s., Jelšava“* informovala o pokusnej výsadbe na rekultivovaných magnezitových haldách. Pri výsadbe siedmich druhov drevín na jeseň v roku 2015, boli dreviny vysádzané do humusového substrátu v pripravených jamkách s pridaním tekutého hnojiva Riverm*, alginitu a hydrogelu. prvé hodnotenie prežívania a rastu po vegetačnom období roku 2016 preukázalo pomerne pozitívne výsledky. 100%-nú ujatosť dosiahla borovica čierna a najlepšie rastové parametre mal agát, za ktorým nasledoval brest sibírsky.

Analytický príspevok *„Obnova lesov na Slovensku, spôsoby jej zisťovania a súčasný stav“* predniesol Ing. Vladimír Šebeň, PhD. z odboru lesníckej politiky, ekonomiky a manažmentu lesa NLC - LVÚ Zvolen. Vo svojom vystúpení analyzoval súčasný stav v evidovanej prirodzenej a umelej obnove lesa na Slovensku. Rozobral rôzne spôsoby zisťovania stavu obnovy, ktoré majú rôzne ciele, rôzne metódy, rôznu presnosť a samozrejme aj rôznu náročnosť zisťovania. Najväčším problémom sledovania stavu a vývoja obnovy sú vysoké počty jedincov a vysoká dynamika (zmeny) v obnove, čím sa stáva presné evidovanie jedincov obnovy finančne a časovo veľmi náročné a na druhej strane je aktuálne len relatívne krátky čas. Napriek tomu, že oficiálne údaje z LHE uvádzajú aj v súčasnosti na Slovensku vyšší podiel umelej obnovy, výberové metódy založené na priamom spočítavaní jedincov na pokusných plochách poukazujú na výrazne vyšší podiel prirodzenej obnovy. Na základe analýzy viacerých podkladov je autor presvedčený, že skutočný stav prirodzenej obnovy je v údajoch z oficiálnych zdrojov (PSL, LHE) výrazne podhodnotený.

Liberálnejší prístup k vertikálnemu prenosu lesného reprodukčného materiálu vzhľadom na klimatické zmeny odporúčala vo svojom vystúpení Ing. Dagmar Bednárová, PhD. vedúca Strediska kontroly lesného reprodukčného materiálu (SKLRM), OPPL, NLC-LVÚ Zvolen. Vzhľadom na značnú neistotu vývoja klímy v dlhšom časovom horizonte, je zvyšovanie diverzity (genetickej, druhovej, vekovej, priestorovej, ako aj ekosystémovej) jedným z predpokladov možnosti úspešného uplatnenia sa prirodzeného výberu v lesných ekosystémoch aj pri rôznych vývojových trendoch klímy. Striktným obmedzením prenosu reprodukčného materiálu nevhodne umelo zužujeme diverzitu lesných drevín a tým aj schopnosť ekosystému vysporiadať sa so zmenou stanovištných podmienok. Preto aj z praktických skúseností by bolo vhodné povoliť vertikálny prenos ±1 LVS a zrušiť vertikálny prenos o 2 LVS nahor.

Ing. Marian Pacalaj, PhD. zo SKLRM, OPPL, NLC - LVÚ Zvolen v príspevku *„Modelovanie vplyvu obnovných rubov na genetickú štruktúru obnovy v nezmiešanom smrekovom poraste“* prezentoval výsledky modelovania vhodnosti rôznych obnovných rubov z hľadiska reprodukcie genofondu, resp. zachovania genetickej štruktúry materského porastu. Základným kritériom hodnotenia bola tvorba priestorovej genetickej štruktúry, sekundárnym miera diferenciácie potomstva od materskému porastu a posledným miera genetickej variability v potomstve. Po zohľadnení týchto kritérií sa v nezmiešanom smrekovom poraste ukázal ako najvhodnejší dvojfázový okrajový clonný rub a ako najmenej vhodný silnejší jednotlivo výberný rub. Ostatné testované ruby – jednofázový okrajový, skupinový, skupinovitý clonný a slabší jednotlivo výberný rub sa ukázali ako stredne vhodné a mali na genofond potomstva podobný vplyv.

Obr. 2. Pohľad na časť pléna konferencie konajúcej sa v priestoroch Spoločenskej dvorany Kúpeľného hotela Palace na Sliači

Doterajší vývoj dvoch introdukovaných drevín, duglasky tisolistej a jedle obrovskej na plochách, založených formou priemyselných plantáží, zhodnotil v príspevku *„Predbežné výsledky rastu a pestovania introdukovaných drevín na priemyselných plantážach OZ Levice"* doc. Ing. Rudolf Petráš, CSc. z odboru pestovania a produkcie lesa, NLC - LVÚ Zvolen. Duglaska má v súčasnosti vek 39 rokov a jedľa 32 rokov. Pre objektivizáciu rastovej úrovne sa ich hektárové a stredné porastové veličiny porovnali s hodnotami podľa rastových tabuliek. Výsledky poukázali na veľmi vysokú bonitu porastov oboch drevín v týchto podmienkach. Na základe súčasného stavu porastov sa navrhli spôsoby ich ďalšieho obhospodarovania.

Ing. Peter Kaštier, PhD. z odboru ochrany lesa a manažmentu zveri NLC - LVÚ Zvolen poukázal v príspevku *„Početnosť raticovej zveri a škody ňou spôsobované v lesoch na Slovensku"* na neustále rastúci trend škôd, ktorý súvisí predovšetkým so zvyšujúcou sa početnosťou raticovej zveri. V súčasnosti dosahuje početnosť a výška úlovku raticovej zveri na Slovensku historické maximá. Obzvlášť extrémne a nekontrolovane vzrastá početnosť danielej a muflonej zveri. Nárast početnosti súvisí najmä s nesprávnym poľovníckym obhospodarovaním zveri, neplnením plánov jej lovu, nadmerným prikrmovaním jadrovým krmivom a zmenami v pestovaní poľnohospodárskych plodín. K najpoužívanejším a najrozšírenejším metódam ochrany lesa pred poškodzovaním zverou patria dnes aj z ekonomických dôvodov repelenty.

V príspevku *„Potenciál a riziká pestovania klonov paulovnie na Slovensku",* ktorý prezentoval Ing. Jaroslav Jankovič, CSc. z odboru pestovania a produkcie lesa, NLC - LVÚ Zvolen, boli sumarizované poznatky o tejto dnes „módnej" drevine. Okrem základných informácií o drevinách rodu Paulownia, a o šľachtení vysoko produkčných hybridných klonov odzneli poznatky o produkčnom potenciáli klonov paulovnie na základe informácií z literatúry a návštevy plantáží v Srbsku. Uvedené boli aj riziká pestovania klonov paulovnie v podmienkach Slovenska a informácie o možnostiach ich pestovania z pohľadu všeobecne záväzných právnych predpisov. V závere boli uvedené návrhy ako ďalej postupovať pri riešení problematiky testovania klonov paulovnie v podmienkach Slovenska.

Aktuálny stav v oblasti pestovania topoľov uviedol v poslednej prezentácii *„Pestovanie a využitie topoľov na Slovensku"* Ing. Martin Bartko, PhD. vedúci Výskumnej stanice Juh v Gabčíkove, NLC - LVÚ Zvolen. Redukovaná plocha topoľov v lesných porastoch je asi 16,5 tis. hektárov. Šľachtené topole z toho zaujímajú 9,3 tisíc ha. Odhadovaná plocha šľachtených topoľov vysadených mimo lesa vo vetrolamoch, zelených pásoch a v brehových porastoch je asi 3 tis. ha. Najväčšie a najproduktívnejšie lokality pre ich intenzívne pestovanie sú pozdĺž Dunaja a jeho prítokov na juhozápadnom Slovensku. Vo výsadbách šľachtených topoľov na Slovensku dominujú 3 klony: Najväčší podiel (35 %) má taliansky klon I-214 vyšľachtený pred 80 rokmi a maďarský klon Pannonia. Pre produkciu lesného reprodukčného materiálu kategórie „testovaný" je uznaných 9 klonov a pre kategóriu „kvalifikovaný" 4 klony. Klonový archív topoľov je umiestnený na Výskumnej stanici Juh v Gabčíkove. Čo sa týka zdrojov reprodukčného materiálu topoľových klonov, najrozsiahlejšia prevádzková matečnica topoľových klonov sa nachádza v Škôlkarskom stredisku Trstice Lesov SR, š. p. Obsahuje kompletnú sadu klonov zahrnutých do Národného registra zdrojov lesného reprodukčného materiálu. Po istom období stagnácie sa v posledných rokoch podarilo oživiť aktivity v oblasti selekcie a testovania topoľov (do veľkej miery vďaka záujmu o ich využitie v energetických porastoch s krátkou produkčnou dobou).

Kompletný zborník referátov v elektronickej podobe možno nájsť na webovej adrese NLC: http://www.nlcsk.sk/nlc_sk/publikacie_spravy/zborniky/rok-2016.aspx.

V rámci konferencie sa uskutočnila exkurzia na ploche s výsadbou rôznych druhov jedlí u súkromného pestovateľa v lokalite Halča - Šingľová a v Lesníckom arboréte Kysihýbel.

Na základe bohatej diskusie počas konferencie boli sformulované a prijaté nasledovné závery:

- Účastníci konferencie konštatujú pretrvávanie zhoršovania zdravotného stavu lesných porastov na Slovensku, čím je uplatňovanie prírode bližších pestovných systémov významne limitované. Frekvencia výskytu kalamitných javov vyplývajúcich z globálnych klimatických zmien (vietor, sucho, častejší výskyt extrémnych klimatických javov), masívne poškodzovanie lesných porastov biotickými škodcami a hlavne zverou, ako aj nedostatok zdrojov financovania na pestovnú činnosť začína veľmi výrazne znižovať ich stabilitu.
- Cieľavedomé a desaťročiami overené odborné postupy lesníkov a obhospodarovateľov lesa pri likvidácii následkov kalamít sú znemožňované, resp. často bagatelizované rôznymi záujmovými skupinami, ktorých názory sa dnes medializujú a akceptujú viacej ako odporúčania odborníkov. Následkom toho je práca lesníkov často nepriaznivo vnímaná zo strany neobjektívne informovanej verejnosti.
- Na základe analýzy súčasného stavu v zakladaní a pestovaní lesa, v kontexte so strategickým cieľom 1 „Zabezpečenie dodávok dreva v meniacich sa prírodných a spoločenských podmienkach aktívnym trvalo udržateľným obhospodarovaním lesov" vládou schváleného Akčného plánu Národného programu využitia potenciálu dreva (APNPVPD) navrhujeme:
  - Vyčleniť zdroje financovania na realizáciu prioritných opatrení v lesoch na ich adaptáciu na klimatickú zmenu (kapitola 8.5.2 Stratégie adaptácie Slovenskej republiky na nepriaznivé dôsledky zmeny klímy).
  - Prioritne riešiť problematiku škôd zverou – prijať a urýchlene realizovať také legislatívne opatrenia, ktoré budú viesť k zníženiu stavov raticovej zveri na Slovensku.
  - Vytvoriť finančný nástroj na podporu vykonávania predovšetkým ochranných, ale aj obranných opatrení proti škodám spôsobeným kalamitnými hmyzími škodcami a zverou (ide zároveň o opatrenie 1.5.2 v rámci APNPVPD).
  - Vytvoriť finančné zdroje na podporu stabilizácie lesných porastov postihnutých prírodnými kalamitami (obdoba v minulosti zrušeného Štátneho fondu zveľaďovania lesa).

- Uchádzať sa o projektové zdroje financovania výskumu na rozšírenie existujúcich a získanie nových poznatkov o introdukovaných drevinách na Slovensku v podmienkach klimatickej zmeny, s perspektívou ich využitia na udržanie produkčného potenciálu našich hospodárskych lesov.
- Skúsenosti z lesníckej praxe potvrdzujú, že súčasný systém zabezpečovania pestovných prác dodávateľsky prostredníctvom verejného obstarávania sa neosvedčil a podľa doterajších skúseností ide na úkor kvality a fyziologickej stability založených lesných porastov. V záujme zachovania kvality pestovných prác účastníci konferencie odporúčajú lesníckym subjektom v širšej miere zvážiť možnosť vytvárania robotníckych pracovných pozícií pre tieto činnosti.

Pozitívne ohlasy účastníkov konferencie na jej odborný program i exkurziu sú pre nás veľkým ocenením a povzbudením pre organizovanie ďalších ročníkov tohto podujatia určeného pre širokú verejnosť lesníckej vedy, pedagogiky a najmä praxe.

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CHRONICLE

Prof. Ing. Pavel Hrubík, DrSc. – 75-ročný

Dňa 16. marca 2016 sme si pripomenuli významné životné jubileum 75 rokov prof. Ing. Pavla Hrubíka, DrSc. Narodil sa v Sennom okres Veľký Krtíš. Po absolvovaní Strednej lesníckej technickej školy v Banskej Štiavnici (1955–1959) pokračoval v štúdiu na Vysokej škole lesníckej a drevárskej vo Zvolene (1959–1964). Z odborných predmetov ho zaujali predovšetkým entomológia, dendrológia a ochrana lesov a toto zameranie mu ostalo ako celoživotná záľuba spojená s prácou. Jeho prvým pracoviskom (od 1. júla 1964) sa stal Lesný závod Nitra, polesie Horné Lefantovce, kde pôsobil ako technik polesia. Tam sa stretol prvýkrát s vedeckými pracovníkmi z Arboréta Mlyňany SAV (pri výskume gaštana jedlého), a problematika výskumu ho natoľko zaujala, že po roku praxe (od 1. septembra 1965) prešiel na nové pracovisko Arborétum Mlyňany SAV, kde pokračoval v štúdiu svojich obľúbených predmetov v pracovnej skupine ochrany drevín. V Arboréte Mlyňany - Ústav dendrobiológie SAV, pracoval do roku 1993 a po delimitácii pracoviska pokračoval v Ústave ekológie lesa SAV, od 1. 1. 1994 Pobočka biológie drevín v Nitre. Po roku pôsobenia v Ústave ekológie SAV Zvolen, odchádza (od 1. 9. 1995) na Slovenskú poľnohospodársku univerzitu na Fakultu záhradníctva a krajinného inžinierstva, kde pracoval do roku 2009 (31. 8. 2009) a potom dva roky v práci pokračoval v Botanickej záhrade Slovenskej poľnohospodárskej univerzity v Nitre, ako zodpovedný riešiteľ projektu KEGA: „Budovanie zbierok kultúrnych rastlín okrasného charakteru s využitím pre edukačné účely v Botanickej záhrade Slovenskej poľnohospodárskej univerzity v Nitre".

Jeho pracovná problematika spočívala zo začiatku (od 1. 9. 1965) v inventarizácii a sledovaní biotických škodcov v Arboréte Mlyňany a neskôr sa zamerala na štúdium biológie a ekológie hmyzích škodcov vo vzťahu k introdukovaným drevinám. V roku 1967 ho prijali na externú ašpirantúru v študijnom odbore 41-03-9 „Poľnohospodárska a lesnícka fytopatológia a ochrana rastlín". Kandidátsku dizertačnú prácu na tému „Húsenice niektorých *Lepidopter* ako potenciálni škodcovia introdukovaných drevín" ukončil v máji 1972, súhlas k obhajobe získal až v septembri roku 1983. Jeho pracovné zameranie sa v osemdesiatych rokoch rozšírilo o aktuálnu problematiku živočíšnych škodcov drevín mestskej zelene v rôznych ekologických podmienkach Slovenska. Výsledkami práce prispel k prehĺbeniu poznatkov komplexného štúdia introdukovaných i domácich drevín mestskej zelene, so zameraním na kvalitatívnu a kvantitatívnu štruktúru a biologicko-ekologickú analýzu. Počas pôsobenia v Arboréte Mlyňany SAV sa zúčastnil a viedol dve dendrologické expedície do Kórey (KĽDR, 1983, 1985). V rokoch 1990–1993 bol zástupcom riaditeľa a predsedom vedeckej rady (1990–1992).

V roku 1995 (1. 9. 1995), po 30 rokoch na pracoviskách SAV, odchádza pracovať na novovznikajúcu Fakultu záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre, kde pokračoval vo výskume a pedagogickej činnosti v problematike dendrológie a ochrany drevín. Svoje vynikajúce znalosti dendrológie využil pri výučbe predmetu Sadovnícka dendrológia ihličnaté, vždyzelené a listnaté dreviny a nového predmetu ochrana okrasných drevín Vo februári roku 1996 sa habilitoval za docenta pre vedný odbor „Záhradníctvo". V roku 1997 úspešne obhájil doktorskú dizertačnú prácu na tému „Škodlivá entomofauna cudzokrajných drevín na Slovensku" a získal vedeckú hodnosť „DrSc."– doktor poľnohospodársko-lesníckych vied, vedný odbor 41-97-9 „Ochrana rastlín", SAV Bratislava; následne s priznaním vedeckého kvalifikačného stupňa I.– vedúci vedecký pracovník. V roku 1999 bol prezidentom SR menovaný za univerzitného profesora, vedný odbor 41-42-9 „Záhradníctvo."

Počas svojej dlhoročnej praxe významne prispel k rozšíreniu poznatkov o entomofaune domácich a cudzokrajných drevín vo verejnej zeleni a vo významných dendrologických objektoch Slovenska. Opísal výskyt viacej druhov hmyzích škodcov, ktoré sa na Slovensku zaznamenali prvý raz na introdukovaných drevinách (vrátane ďalších živočíšnych druhov, najmä novointrodukovanej čínskej dendroflóry). Počas pracovného pôsobenia v Arboréte Mlyňany - Ústave dendrobiológie SAV a následne v delimitovanom pracovisku Ústave ekológie lesa SAV vo Zvolene, Pobočka biológie drevín v Nitre, jubilant intenzívne spolupracoval so spolupracovníkmi z Lesníckeho výskumného ústavu Zvolen, z oddelenia ochrany lesov (teraz Národné lesnícke centrum - Lesnícky výskumný ústav Zvolen) a s kolegami z Katedry ochrany lesov a poľovníctva, Lesníckej fakulty Technickej univerzity vo Zvolene. Bol členom Vedeckej rady a členom Redakčnej rady časopisu v Ústave ekológie lesa SAV vo Zvolene.

Jeho práce v oblasti entomológie, kde publikoval množstvo poznatkov o nových, introdukovaných škodcoch výrazne ovplyvnili aj bádanie v oblasti ochrany lesa. Viacero nebezpečných a lesnícky významných druhov, ktoré popísal v oblasti okrasného záhradníctva sa neskôr objavili aj v našich lesoch. Spomeňme aspoň druhy *Cameraria ohridella*, *Obolodiplosis robiniae* alebo *Leptoglossus occidentalis*, ktorým sa venoval vo svojich prácach. A tak napriek tomu, že väčšina entomologických prác prof. Ing. Pavla Hrubíka, DrSc. sa venovala škodcom drevín v mestskej zeleni, stali sa tieto práce studnicou poznania aj pre oblasť ochrany lesa.

Svoje bohaté vedecké poznatky publikoval v monografiách(12), v pôvodných vedeckých publikáciách doma (173) a v zahraničí (25). Prednášal na domácich i zahraničných konferenciách. Publikoval aj v odborných časopisoch (133). Celkove uverejnil 372 prác. Bohatá publikačná činnosť mala značný citačný ohlas: citácie SCI (31), citácie mimo SCI (451), citácie v karentovaných časopisoch (54), citácie v nekarentovaných časopisoch (428), iné zahraničné ohlasy na vytvorené dielo (2). Ako pedagóg na Fakulte záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre, bol školiteľom bakalárskych prác (12 ZAKA, 24 BPKU), diplomových prác (68) a doktorandských dizertačných prác (10, z toho 5-KI a 2/ZAKA). Bol garantom študijného odboru Záhradná a krajinná architektúra, spolugarant študijného odboru Krajinná a záhradná architektúra, študijného programu Biotechnika parkových a krajinných úprav a gestorom predmetov Listnaté dreviny v sadovníckej tvorbe, Ihličnaté a vždyzelené dreviny v sadovníckej tvorbe, Hodnotenie biotických prvkov, Dreviny v záhradno-architektonickej tvorbe a Ochrana okrasných rastlín. Všetky uvedené predmety zabezpečil odbornou literatúrou vydaním skrípt. Svoje odborné skúsenosti využil ako člen vedeckej rady (Fakulta krajinárstva a záhradného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre, Ústav ekológie lesa SAV vo Zvolene) ako člen poradného zboru Chránenej krajinnej oblasti Ponitrie, člen redakčnej rady časopisu Folia oecologica, medzinárodného časopisu Plant Protection Science pri Československej akadémii zemědělskej v Prahe, člen akreditačnej komisie SAV, člen komisie pre obhajoby doktorských dizertačných prác pre vedný odbor Záhradníctvo, Ochrana rastlín, člen spoločnej komisie pre vedný odbor Záhradná a krajinná architektúra Fakultu záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre v Nitre, Záhradníckej fakulte Mendelovej zemědělskej a lesníckej univerzity v Brne so sídlom v Lednici na Morave. Bol riešiteľom, spoluriešiteľom a vedúcim grantových projektov VEGA, KEGA, zúčastnil sa riešenia medzinárodného programu COST: Multidisciplinárny výskum gaštana jedlého v Európe a COST projektu: Mestské lesy (záverečné správy výskumu 18; projekty 8; zahraničné 2). Na Fakulte záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre pôsobil v rokoch 1995–2009 aj ako vedúci katedry; predseda Akademického senátu fakulty; prodekan a štatutárny zástupca dekana.

Po odchode do dôchodku v roku 2009 sa venoval výskumu kultúrneho rozšírenia ginka dvojlaločného (*Ginkgo biloba* L.) na Slovensku (2010–2011; 2014–2015), pričom so svojou dcérou (doc. Ing. Katarína Ražná, PhD.), rozšírili aplikáciu genetických metód a markérov, pri determinácii biologických vlastností stromov, pomocou DNA. So spolupracovníkmi vydal z riešenej problematiky vedeckú monografiu (2014). Súčasťou dlhodobého výskumu jubilanta, bolo i hodnotenie klimatických podmienok a základných meteorologických prvkov v Arboréte Mlyňany SAV, čo uverejnil vo viacerých príspevkoch. Posledne pri príležitosti jeho životného jubilea (2011) uverejnil svoju personálnu bibliografiu a knihu Kvalitatívna inventarizácia, klasifikácia a hodnotenie zdravotného stavu drevín pre účely záhradno-architektonickej a krajinárskej tvorby (v spolupráci s ďalšími autormi).

Profesor Pavel Hrubík svojou húževnatosťou, vytrvalosťou a vysokou odbornosťou prispel k rozšíreniu poznatkov vo viacerých vedných odboroch (entomológia, dendrológia, ochrana drevín). Nemenej významná je jeho dlhoročná pedagogická činnosť v rokoch 1995–2009, kde odovzdal svoje vedomosti získané vo výskumnej činnosti na pracoviskách SAV v Arboréte Mlyňany - Ústave dendrobiológie SAV a v Ústave ekológie lesa SAV Zvolen, Pobočka biológie drevín Nitra. Spolupráca s týmito pracoviskami pretrváva doteraz. Bol členom riešiteľských kolektívov vedeckých grantových projektov VEGA a APVV, KEGA.

Za vykonanú prácu dostal celý rad vyznamenaní. Tak napríklad za mimoriadnu odborno-popularizačnú činnosť, mu Predsedníctvo SAV v roku 1985 udelilo „Cenu SAV za popularizáciu vedy“. V roku 1998 získal Zlatú Jánskeho plaketu, za viacnásobné darcovstvo krvi. Za aktívnu činnosť pri rozvoji Slovenskej poľnohospodárskej univerzity v Nitre dostal Pamätnú medaila rektora uvedenej univerzity (2001), Pamätnú bronzovú medailu Fakulty záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre (2001), pri príležitosti 60. výročia jeho narodenia, Pamätnú plaketu Lesníckeho výskumného ústavu vo Zvolene, k životnému jubileu – 60 rokov, za spoluprácu s Lesníckym výskumným ústavom Zvolen pri riešení vedecko-technických projektov (2001), Striebornú medailu Fakulty záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity v Nitre, za pomoc pri rozvoji fakulty (2002). Menovaný je čestným členom Slovenskej spoločnosti pre poľnohospodárske, lesnícke, potravinárske a veterinárske vedy pri SAV (2002). Uvedená Spoločnosť mu v roku 2009 udelila Medailu Juraja Fándlyho, za významné vedecké výsledky v týchto vedách a za rozvoj vedeckej spoločnosti. V posledných rokoch pri príležitosti jeho 70. ako aj 75. narodenín dostal celý rad ďalší vyznamenaní a ocenení, ktoré ešte viac zvýraznili zásluhy jeho tvorivej činnosti.

Do ďalších rokov života, jubilantovi všetci prajeme veľa zdravia, naplnenie všetkých životných predsavzatí, ešte veľa nových inšpirácií pre ochranu a tvorbu životného prostredia.

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