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ORIGINAL PAPER

Ozone phytotoxicity in the Western Carpathian Mountains in Slovakia

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Abstract

In this work, the response of temperate coniferous forests to ozone air pollution (O_3) in the mountain environment of the High Tatra Mts. (Western Carpathians) was analyzed. The modelling of stomatal O_3 flux is a complex method for the estimation of phytotoxicity of O_3 pollution to forest vegetation. Stomatal flux-based critical levels (*CLef*) for effects of O_3 on radial growth take into account the varying influences of O_3 concentration, meteorological variables, soil properties, and phenology. The application of the model DO_3SE (Deposition of Ozone for Stomatal Exchange) at five experimental plots with altitudes varying from 810 to 1,778 m a.s.l. along vertical and spatial profile in the High Tatra Mts. revealed the high phytotoxic potential of O_3 on spruce forests during the growing season 2014. The accumulated stomatal O_3 flux above a threshold of Y (1 nmol m^{-2} s^{-1}), i.e. POD_1 (Phytotoxic Ozone Dose) ranged from 13.6 mmol m^{-2} at the Kolové pleso site (1,570 m a.s.l.) to 16.2 mmol m^{-2} at Skalnaté Pleso site (1,778 m a.s.l.). *CLef* for POD_1 (8 mmol m^{-2}) recommended for the protection of spruce forests were exceeded at all experimental plots from early July. Similarly, AOT40 index suggests vulnerability of mountain forests to O_3 pollution. AOT40 values increased with altitude and reached values varying from 6.2 ppm h in Stará Lesná (810 m a.s.l.) to 10.7 ppm h at Skalnaté Pleso close to the timber line (1,778 m a.s.l.). Concentration-based critical level (*CLec*) of 5,000 ppb h was exceeded from June to August and was different for each experimental site.

Key words: mountain forests; Phytotoxic Ozone Dose$_Y$; DO_3SE model; stomatal conductance; stomatal ozone flux

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1. Introduction

Ozone levels in Europe are rather high to jeopardize human health and vital growth of vegetation (WHO 2008; Paoletti 2014; Monks et al. 2015). Relevant reduction of O_3-precursors emissions in Europe (Vestreng et al. 2004) tends to decrease O_3 maxima and increase annual averages at both urban and rural sites (Paoletti et al. 2014) due to less O_3 titration by reduced NO_x emissions. The ozone levels are increasing in cities and decreasing at Mediterranean remote sites (Sicard et al. 2013). However, cumulative indices such as SOMO35 and AOT40, i.e. 5,000 ppb h (Directive 2008/50/EC) indicate that rural highland sites of Europe are more vulnerable to health and environmental risks associated with perpetual O_3 exposure than urban lowland areas (Bičárová et al. 2013). Concentration-based critical level (*CLec*) of AOT40 for forest ecosystems is regularly exceeded in almost whole territory of Slovakia (Pavlendová 2008) as well as in the Czech Republic (Hůnová & Schreiberová 2012; Hůnová et al. 2016). At high-altitude stations, the background O_3 levels (chronic exposure) are higher, and higher O_3 concentrations are observed at night (Sicard et al. 2009). Acute exposures are characterized by high O_3 concentrations for a relatively short time period, within hours or days that lead to visible foliar injury (Schaub et al. 2010; Sicard et al. 2011). Chronic exposures involve lower concentrations that persist or recur over a period of weeks or months (Grulke et al. 2007). Mountains can act as cold-traps for long-range transport of atmospheric pollutants. The mechanism of transport of pollutants through the atmosphere and accumulation in the mountain environment were well described in literature (Steinbacher et al. 2004; Sicard et al. 2009, 2011; Monks et al. 2015). For example, there is evidence of accumulation of persistant organic pollutants (POPs) in the mountainous environment (Hageman et al. 2015). The highest deposition fluxes of organochlorine compounds (OCs) were found at high-altitude European sites, especially at Skalnaté Pleso in the High Tatra Mts. (Arellano et al. 2015).

Tropospheric ozone acts as a phytotoxin which produces an oxidative stress in plants. The phytotoxic nature of O_3 can impair forest productivity by both favouring stomatal closure and impairing stomatal control. High O_3 concentrations reduce carbon assimilation in trees while this reduction is more related to stomatal O_3 deposition than to O_3 concentration (Fares et al. 2013). The scientific community is moving toward an evaluation of the ozone risk based on stomatal O_3 fluxes (Matyssek et al. 2007; UN-ECE 2010; Mills et al. 2011; Büker et al. 2012). Tracking of stomatal O_3 uptake by vegetation required more comprehensive methods than the evaluation of O_3 concentration data alone. Multiplicative models of stomatal conductance, such as the DO_3SE (Deposition of Ozone and Stomatal Exchange), have been suggested as a basis for calculating the hourly O_3 flux resulted to the Phytotoxic Ozone Dose (POD_Y) (Emberson et al. 2000). For forest trees, stomatal flux-based critical levels (*CLef*) of POD_Y were derived for effects on changes in annual increments in the whole tree biomass. These critical levels can be used to refer adverse health effects of O_3 on

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**Corresponding author. Zuzana Sitková, e-mail: sitkova@nlcsk.org, phone: +421 5314 158* relevant ecosystem services provided by forest trees, e.g. production of roundwood, C sequestration, soil stability and flood prevention (Mills et al. 2011). Main problem is that present exposure-based standards for protecting vegetation from ozone (O_3) do not reflect the actual field conditions. Recent knowledge resulting from epidemiological assessment of forest responses to O_3 showed that a risk assessment based on POD_Y and on real plant symptoms is more appropriate than the concentration-based method and developed the new flux-based critical levels *CLef* for forest protection against visible O_3 injury (Sicard et al. 2016).

Previous studies concerning the problems of air quality pointed to the high level of ozone air pollution in the Western Carpathian Mts. that is comparable with the most polluted regions in Europe (Bytnerowitz et al. 2004; Bičárová et al. 2013; Hůnová et al. 2016). Formation of O_3 in mountain regions of Slovakia is substantially influenced by long-range transport of O_3 precursors and their interaction with local components from both antropogenic and biogenic sources (Bičárová et al. 2005). It can be expected that high chronic O_3 exposure and O_3 uptake by vegetation may impair the vitality of forests, especially in wet and cold climate conditions of highland areas.

The aim of this work is to quantify phytotoxical ozone dose for coniferous forest species, especially Norway spruce (*Picea abies* L. Karst) in the mountain environment of the High Tatra Mts. (Slovakia). Stomatal O_3 fluxes and POD_1 are calculated by DO_3SE model for five experimental sites situated along spatial and vertical profiles from 810 to 1,778 m a.s.l. during the vegetation season 2014. The results are intend to support new complex approach in research of adverse impact of O_3 pollution on forest vegetation based on modelling of stomatal O_3 flux. This new approach may improve still prevalently used O_3 concentration based method associated with AOT40 indicator for the protection of vegetation and forests. Presented research can provide many results useful for the wide scientific community (in environmental and forest science, physiological and biological research, ecological modelling etc.). Research activities and field measurements are part of the ongoing project MapPOD (Mapping of Phytotoxic Ozone Dose in the Forest Environment of the High Tatra Mts.) which focuses on assessment of potential O_3 risk to mountain forests in Slovakia.

2. Material and methods

2.1. Study area

The High Tatra Mts. are located in the northern part of Slovakia on the border with Poland (Fig. 1). Region of interest represents the highest part in the whole Carpathian Mountains. The elevation of the main mountain chain of the High Tatra Mts. varies from about 2,000 m a.s.l. (saddles) to 2,654 m a.s.l. (the highest peak). Temperate coniferous forest with Norway spruce (*Picea abies* L. Karst.) is the dominant vegetation type up to 1,500 m a.s.l. From the other tree species occur European larch (*Larix decidua* Mill.), Scots pine (*Pinus sylvestris* L.) and Grey alder (*Alnus incana* L. Moench). The higher part of the valley (subalpine) is almost completely covered by Dwarf pine (*Pinus mugo* Turra).

In order to model O_3 fluxes, the O_3 concentrations, meteorological and environmental parameters were measured at 3 experimental sites situated in the south aspect: Stará Lesná – SL, Štart – STA, Skalnaté Pleso – SP (Table 1, Fig. 1). On the north side of the High Tatra Mts., in the vicinity of Tatranská Javorina municipality, the other 2 experimental sites (Podmuráň – PDM and Kolové pleso – KP) are located. On the south side, the massive rocky branches separate numerous glacial valleys including Skalnatá dolina area. Due to strong rain-shadow effect the climate of south-facing Skalnatá dolina area is slightly warmer and significantly drier

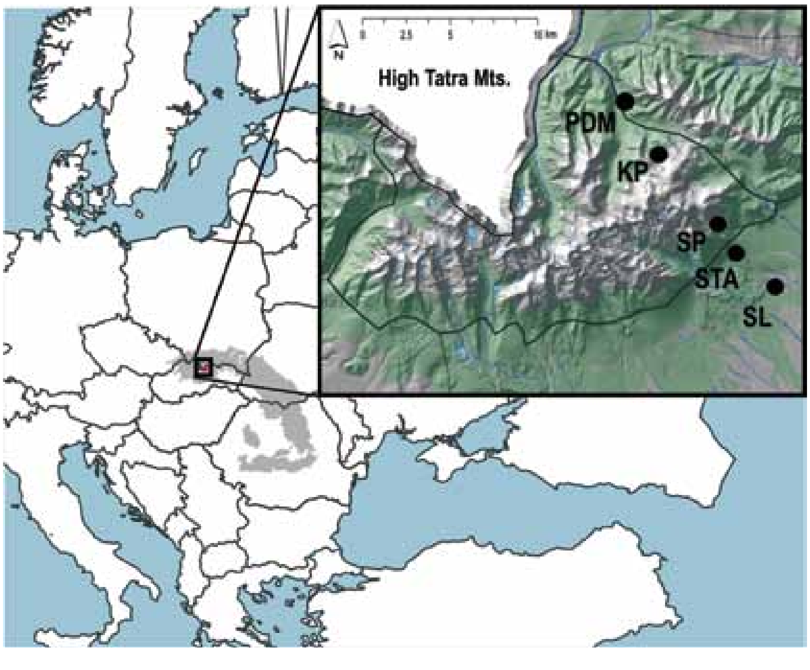

Fig. 1. The geographical position of the High Tatra Mts. in the Carpathian Montane Forests and location of the experimental sites (SL – Stará Lesná, STA – Štart, SP – Skalnaté Pleso, KP – Kolové pleso, PDM – Podmuráň).

Table 1. Experimental sites description (CODES used in relation to Fig. 1).

Transect Aspect	Experimental site CODE	GPS Latitude Longitude	Altitude m asl	Vegetation zone	Group of forest type	Tree species composition	Geological subbase	Soil type	Soil texture	AT$_{1961–90}$ °C	P$_{1961–90}$ mm
South transect Skalnatá valley area	Stará Lesná SL	49°09’08” N 20°17’19” E	810	Fir–beech (5th)	*Pineto-Piceetum*	Norway spruce, Birch, Scots pine, European larch, Grey alder	Fluvioglacial	Gleyic Cambisols	Silt loam medium coarse	5.4	740
	Štart STA	49°10’30”N 20°14’48” E	1,150	Spruce–Fir–Beech (6th)	*Sorbeto Piceetum* *Lariceto piceetum*	spruce, larch, pine, fir, maple	Granodiorite	Cambic Podzols	Sandy loam coarse	4.0	981
	Skalnaté Pleso SP	49°11’21” N 20°14’02” E	1,778	Mountain pine (8th)	*Mugethum acidifilum*	Mountain pine	GranodioriteGranite	Skeli-Dystric Leptosols	Sandy loam coarse	0.8	1,220
North transect Tatr. Javorina area	Podmuráň PDM	49°15’00” N 20°09’25” E	1,100	Spruce (7th)	*Sorbeto Piceetum* *Acereto Piceetum*	spruce, fir, rowan, beech, maple	Granodiorite Fluvioglacial	Cambic Podzols	Loam medium	3.8	1,250
	Kolové pleso KP	49°13’22” N 20°11’27” E	1,570	Mountain pine (8th)	*Mugethum acidifilum*	Mountain and swiss pine, spruce	Granodiorite	Skeli-Dystric Leptosols	Silt loam medium coarse	2.0	1,493

Used data sources:
1 – forestry databases of National Forest Centre in Zvolen (soil, geological and typological maps, Forestry GIS-databases).
2 – climate data provided by Slovak Hydrometeorological Institute for the reference period 1961–1990 and Climate Atlas of Slovakia (SHMI 2015).
3 – soil units according to WRB Soil Classification System (WRB 2015, FAO).
4 – forest typology and edaphic-trophic units based on Zlatník’s geobiocenological school (Zlatník 1976).
Abbreviations: AT – air temperature; P – precipitation.

compared to north part of the High Tatra Mts. (Table 1). On the contrary, the climate of the north-facing Tatranská Javorina area is cold and very wet with long-term mean annual temperatures around 3.8 °C and rainfall total of 1,250 mm at the altitude of 1,100 m a.s.l. The meteorological observation during the last two decades revealed moderate warming and increasing rainfall amounts (SHMI 2015).

In recent decades, the area of interest was affected by large-scale disturbances in connection with the adverse effects of climate change. The extreme weather conditions more frequently observed in the recent years (drought, heat waves, snow cover decline etc.) contributed to the massive bark beetle outbreaks (*Ips typographus*) in forest stands weakened by abiotic destructive factors as windstorm, fire, flooding, long-range transport of air pollutants etc. (Mezei et al. 2014; Nikolov et al. 2014).

2.2. Meteorological and ozone data

The basic meteorological variables (such as air temperature, relative humidity, wind speed, wind direction, solar radiation and precipitation) were continuously monitored at all experimental sites using automatic weather stations (EMS Brno CZ; Physicus, s. r. o. SK). The measuring interval of meteorological data was set on variable time step (starting from 10 seconds up to 5–10 minutes) and average data were consequently stored every 10 to 30 minutes into the central datalogger of the weather station.

Ozone concentration data were measured at five experimental sites using the ozone analyzers based on the well established technique of absorption of UV light at 254 nm. At three experimental forest sites (Stará Lesná – SL, Skalnaté Pleso – SP, Podmuráň – PDM), the analyzers manufactured by Horiba (APOA360 Ambient Ozone Monitor) and Thermo Electron Environmental (49C Ozone Analyzer) were used. The more remote experimental sites where the electricity was unavailable (Štart – STA, Kolové pleso – KP) were equipped by Ozone Analyzer Monitor M106-L (2B Technologies, Inc.) and powered by solar energy. The ozone data in default ppb units were measured in 6–10 second interval and hourly averages were stored into the datalogger. For purposes of this study, the hourly meteorological and O_3 concentration data from the period of April to October of the year 2014 were processed and analysed.

2.3. DO$_3$SE model

The multiplicative deposition DO$_3$SE model has been developed to estimate the risk of O_3 damage to the European vegetation and it is capable of providing flux-modelling estimates according to UN-ECE LRTAP methodologies for effects-based risk assessment (Pihl-Karlsson et al. 2004; Emberson et al. 2007; Karlsson et al. 2007; Tuovinen et al. 2007).

Meteorological data, O_3 concentration and plant-specific characteristics (e.g. physiological and phenological) are three basic groups of input data that enter into the model for the estimation of O_3 flux to the vegetated surfaces (Büker et al. 2012). The stomatal conductance (G_{sto}) is one of the most important and key parameters of the DO_3SE model. The detailed description of the algorithm of G_{sto} calculation is given in the manual for modelling and mapping of the critical level exceedance (UN-ECE 2004).

The stomatal flux of O_3 (*Fst*) is modeled using an algorithm incorporating the effects of meteorological conditions (air temperature, vapour pressure deficit, light); soil and plant water (soil water potential, available water content); plant phenology and O_3 concentration on the maximum stomatal conductance measured under the optimal conditions. *Fst* is the instantaneous flux of O_3 through the stomata pores per unit projected leaf area (PLA) and refers specifically to the sunlight leaves at the top of the canopy. As there is strong biological support for the use of a threshold to represent the detoxification capacity of the trees (Karlsson et al. 2007), the expert judgement was used to set Y to 1 nmol m^{-2} PLA s^{-1} for the forest trees (Mills et al. 2011). The model calculation of the stomatal flux is based on the assumption that the concentration of O_3 (nmol m^{-3}) at the top of the canopy c (z1) measured in the tree height (z1) represents a reasonable estimate of O_3 concentration at upper surface of the laminar layer. Stomatal O_3 flux *Fst* (nmol m^{-2} PLA s^{-1}) is given by (UN-ECE 2004):

$$Fst = c(z1) * Gsto * (rc / (rb + rc)) \qquad [1]$$

where *Gsto* is the stomatal conductance for O_3 (m s^{-1}), *rb* and *rc* are the quasi-laminar resistance and the leaf surface resistance (s m^{-1}), respectively. *PLA* is the abbreviation of Projected Leaf Area.

The stomatal conductance can be calculated as:

$$G_{sto} = g_{max} * f_{phen} * f_{light} * max\,\{f_{min}, (f_{temp} * f_{VPD} * f_{SWP})\} \qquad [2]$$

where g_{max} is the species-specific maximum stomatal conductance (mmol O_3 m^{-2} PLA s^{-1}), f(phen, light, min, temp, VPD, SWP) are the parameters determining the effect of the environment and phenophase on the stomatal conductance. The detailed description of the algorithm and derivation of the physical relationships for the final calculation is given in the manual for modelling and mapping of *CLef* level exceedance (Mills et al. 2011).

The phytotoxic ozone doses (POD_Y) is the accumulated value of the stomatal fluxes that exceed the threshold Y nmol m^{-2} s^{-1} during the vegetation season. It is calculated according to the formula:

$$POD_Y = \Sigma(1; n)\,[Fst - Y] \qquad [3]$$

for $Fst \geq Y$ with the accumulation of the hourly stomatal O_3 flux during the whole vegetation season (defined for the tree species and year of the assessment). *Fst* is the hourly mean stomatal O_3 flux (nmol m^{-2} s^{-1}) and *n* is the number of hours within the accumulation period. The threshold Y is defined as species-specific, the actual value for forest trees is proposed to 1 nmol m^{-2} PLA s^{-1}, the *CLef* of POD_Y is proposed to be 8 mmol m^{-2} PLA for spruce (evergreen coniferous) with expected biomass increment reduction of 4 and 2% respectively (Mills et al. 2011).

Besides POD_Y, the exceedance of *CLec* of exposition index AOT40 was calculated for all experimental sites. The AOT40 for forests is the accumulated excess of the hourly ozone concentrations above 80 µg m^{-3} between 8:00 and 20:00 CET over the period April–September (Directive 2008/50/EC). This indicator quantifies only the ozone exposure, i.e. not the effective ozone uptake by (and therefore the damage caused to) vegetation. In this study, AOT is the sum of the concentrations over the threshold value *X* calculated for the daily hours during the vegetation season according to the equation:

$$AOTX = \Sigma\,(1; n)\,[C - X] \qquad [4]$$

for $C \geq X$, where *C* is the hourly mean O_3 concentration (ppb), *n* is the number of daily hours in the accumulation period, and *X* is the threshold value for forest ecosystems being 40 ppb. *CLec* of AOT40 was set to 5,000 ppb h (Directive 2008/50/EC). In the past, the value 10,000 ppb h was used. The exceedances of *CLef* for POD_1 and *CLec* for AOT40 are calculated for the main tree species Norway spruce (*Picea abies* L. Karst.).

The parameterisation of DO_3SE model reflects the recommendations in different scientific papers, the generic values are also given in manual ICP Modelling and Mapping (UN-ECE 2010), for some of them it is possible to assess by field measurement to be species specific and also site specific. More specific and detail information about model parametrisation is included in the Appendix.

3. Results

3.1. Meteorological data and weather conditions

Information on the development of meteorological parameters is important not only for the interpretation of the measured ozone data but also as key input into the model of stomatal ozone fluxes. In the High Tatra Mts., growing season 2014 (GS 2014) started after the snowmelt (March/April) and depending on the altitude continued until the late autumn (October/November). The statistical characteristics of the hourly weather data measured at the selected field sites in the High Tatra Mts. from April to October 2014 are included in the Table 2. The mean air temperature varied in interval from 7.5 to 12.0 °C and reached maxima up to 30 °C. Values were in line with the normal course of climate data (Fig. 2). The calculated values of the vapour pressure deficit (VPD) were under the limit level (VPD_min, 3.00 kPa) for the minimal stomatal conductance (Fig. 2) that illustrates the favourable air humid conditions for the stomatal flux. The precipitation sums varied between 918 and 1,370 mm depending on the altitude of the site (Table 2). During the given GS period, the extraordinary weather events occurred. In May there was intensive heavy rain for two days and there fell about 100–200 mm. The windstorm at high altitudes (the maximum observed gust has achieved value of 42 m s^{-1}) resulted in flooding and forest windfall, especially in the NW area above the Podmuráň experimental site (PDM). On the other hand, the SE foothill area was affected by an exceptional long dry event in June. A rainless or light rain period lasted 38 days from 22th May to 28th June with a very low precipitation sum of 19 mm at the Stará Lesná experimental site. The next wet event started on 29th June and continued for the next 34 days. During this period, the total amount of precipitation reached a high value of 295 mm. July was a very wet month with a mean monthly temperature slightly above normal in the High Tatra Mts. as well as in whole territory of Slovakia. The weather at the end of summer and during autumn was relatively normal without unusual events. Frequently, the mean hourly wind speed values were up to a level of 5 m s^{-1} (Fig. 2), median ranged from 0.7 to 1.9 m s^{-1} (Table 2). For GS period, the sums of global radiation varied between the values from 542 kWh m^{-2} measured in the NW area (Kolové pleso) to 848 kWh m^{-2} observed in the SE area (Stará Lesná). The mean air pressure varied from 82.3 to 92.4 kPa and corresponded to the altitudinal position of the experimental sites.

3.2. Ozone data

The mean O_3 values at the study sites aggregated over GS 2014 fluctuated from 30.9 to 44.1 ppb (Table 3). Prevailing humid weather in the summer of 2014 influenced the O_3 formations in the atmospheric boundary layer, therefore the O_3 concentrations for GS 2014 was relatively low. According to data from the Slovak air quality monitoring network (SHMI and ME SR 2015), the mean O_3 concentrations for GS 2014 were lower then those in GS 2003 when the summer O_3 event occurred (Bičárová et al. 2005) likely due to the heatwave and extraordinary drought in Europe (Fiala et al. 2003). Generally, by many physiological studies it was approved that the light causes plant stomata to open and darkness to close. At the sites under the altitude of 1,600 m a.s.l., the mean O_3 concentrations during the hours of sunlight (i.e. between 07–17 h, when global radiation >50 W m^{-2}) were higher about 30–90% than O_3 mean concentrations during the night and weak sunlight hours (18–06 h). These results suggest relevant stomatal O_3 uptake into forest vegetation during daylight hours. On the contrary, at the high altitude site of Skalnaté Pleso (1,778 m a.s.l.) the values of ozone concentrations were higher by approximately 1.7 ppb during the nights in comparison to the sunlight part of day. Nevertheless, the mean O_3 values for both sunlight and night part of day at this site exceeded a level of 40 ppb. Maximal hourly O_3 concentrations occurred at sites on the northern slope (75.7 – 88.0 ppb) were higher in comparison with sites on the southern slope (70.5 – 78.1 ppb). Lower O_3 maxima on south-facing slope may be associated with large deforestration and reduction of biogenic O_3 precursors after wind disaster (Bičárová et al. 2015).

3.3. Plant-specific parameters and POD_1

The descriptive statistics of *Gsto* data estimated by DO_3SE model for all 5 experimental sites in the High Tatra Mts. during GS 2014 are included in Table 4. The modeled *Gsto* values reached maxima up to 115 mmol m^{-2} s^{-1}. Over the GS 2014, *Gsto* mean ranged between 21 and 28 mmol m^{-2} s^{-1}, during the sunlight hours (07–17 h) mean values were nearly twice higher. Night-time mean *Gsto* did not exceed level of 10 mmol m^{-2} s^{-1}. As the growing season of 2014 was mostly humid the impact of water stress on plant stomatal conductance was minimal with the exception of June at the foothills represented by the Stará Lesná site. Generally, the stomatal conductance gradually increases as the temperature increases reaching a peak and then gradually declines as the temperature increases beyond the optimum, whilst the stomatal conductance increases rapidly as light levels increase, reaching a maximum at relatively low light levels and maintaining that maximum as light level increase further (UN-ECE 2004).

DO_3SE model estimation of *Fst* for the experimental sites in the High Tatra Mts. (Table 5) showed that the mean *Fst* values for GS 2014 were over the threshold value Y of 1 nmol m^{-2} PLA s^{-1}. Nearly twice higher mean *Fst* calculated for the sunlight part of a day (07–17 h) suggests intensive stomatal O_3 uptake to the forest vegetation during the photosynthetic process. The elevation profile of mean values of O_3, *Gsto* and *Fst* (Fig. 3) illustrates great increase of O_3 concentration with altitude that is in contrast to slightly decrease of *Gsto* and nearly unchanged *Fst*.

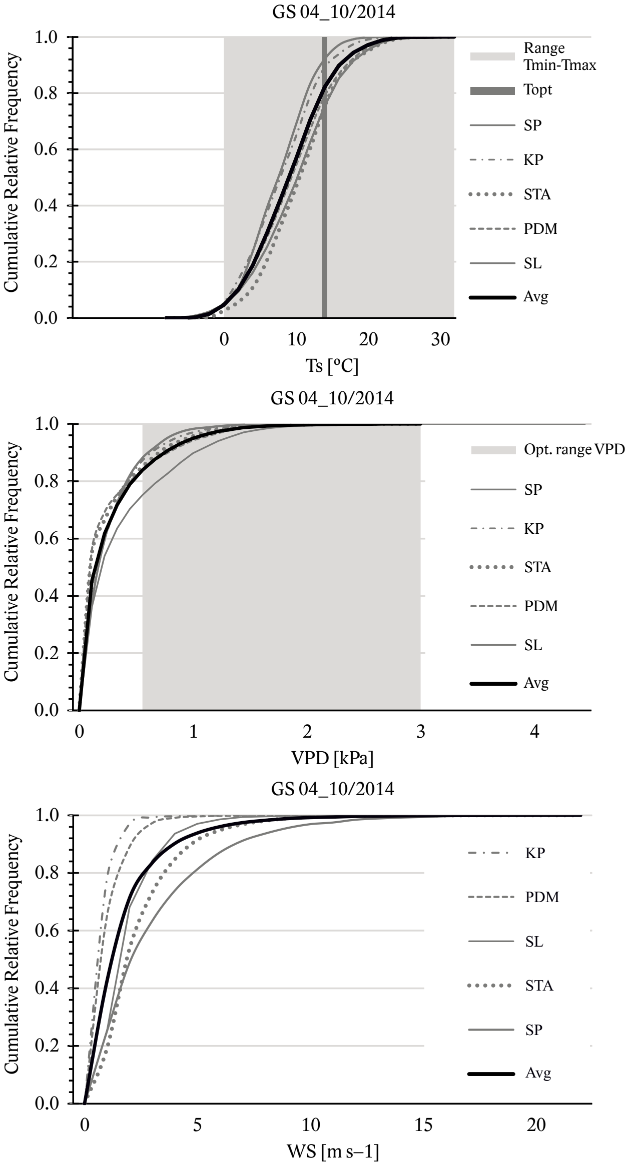

Fig. 2. Cumulative frequency distribution of hourly mean air temperature (Ts), vapour pressure deficit (VPD) and wind speed (WS).

Table 2. Statistics of hourly meteorological data measured at experimental sites for growing season (GS), April – October 2014.

Experimental plot	SL	STA	SP	PDM	KP
Altitude	810 m asl	1,150 m asl	1,778 m asl	1,100 m asl	1,570 m asl
Meteorological variables					
Air temperature – Ts [°C]					
Minimum	−2.9	−3.6	−5.6	−4.0	−3.5
Maximum	28.4	27.2	21.8	26.5	24.9
Median	12.2	10.5	7.6	9.5	7.8
Mean	12.0	10.5	7.5	9.4	7.9
Standard deviation	5.8	5.3	4.6	5.8	5.0
Vapour Pressure Deficit – VPD [kPa]					
Maximum	2.536	2.153	1.560	2.466	2.217
Median	0.174	0.071	0.151	0.079	0.140
Mean	0.342	0.209	0.228	0.232	0.231
Standard deviation	0.386	0.302	0.227	0.327	0.262
Precipitation – P [mm]					
Sum for GS period	749.1	917.6	1,286.0	1,337.0	1,370.6
Median	342.7	377.2	624.2	779.3	760.2
Mean	382.5	438.9	643.5	717.6	696.0
Standard deviation	252.5	306.4	427.2	437.6	460.5
Wind speed – WS [m s^{-1}]					
Maximum	13.7	16.1	20.6	8.6	6.0
Median	1.5	1.9	2.0	0.7	0.7
Mean	1.9	2.4	3.0	1.0	0.8
Standard deviation	1.3	1.9	2.8	0.8	0.5
Global radiation – R [kW m^{-2}]					
Sum for GS period	848	552	744	657	542
Monthly maximum	156	100	140	119	106
Median	120	78	117	95	77
Mean	121	79	106	94	77
Standard deviation	35	22	28	22	21
Air Pressure – Pa [kPa]					
Minimum	90.9	87.1	80.8	87.7	82.8
Maximum	93.8	90.1	83.6	90.6	85.3
Median	92.4	88.7	82.4	89.1	84.1
Mean	92.4	88.7	82.3	89.2	84.1
Standard deviation	0.5	0.5	0.5	0.5	0.4

Table 3. Statistics of hourly O_3 data for growing season (GS), April – October 2014.

Experimental site	SL	STA	SP	PDM	KP
Altitude	810 m asl	1,150 m asl	1,778 m asl	1,100 m asl	1,570 m asl
O_3 concentration (0–23 h) [ppb]					
Minimum	4.4	3.2	10.6	2.0	5.9
Maximum	77.1	70.5	78.1	88.0	75.7
Median	30.5	31.1	44.3	29.5	33.0
Mean	30.9	31.7	44.1	29.5	33.7
Standard deviation	12.8	11.5	8.2	15.8	11.1
Sunlight daily (07–17 h)					
Minimum	6.1	7.1	14.9	4.4	10.1
Maximum	77.1	70.5	78.1	88.0	75.7
Median	38.0	37.1	43.5	40.2	39.1
Mean	37.4	36.6	43.2	39.1	39.5
Standard deviation	10.8	10.8	8.4	13.0	9.6
Night and weak sunlight hours (18–06 h)					
Minimum	4.4	3.2	10.6	2.0	5.9
Maximum	65.6	62.6	70.8	73.4	63.6
Median	23.5	26.5	45.1	17.4	27.7
Mean	25.3	27.5	44.9	21.4	28.8
Standard deviation	11.8	10.4	8.0	13.2	9.8

Table 4. Statistics of stomatal conductance G_{sto} data estimated by DO_3SE model for growing season (GS), April – October 2014.

Experimental site Altitude	SL 810 m asl	STA 1,150 m asl	SP 1,778 m asl	PDM 1,100 m asl	KP 1,570 m asl
Stomatal Conductance G_{sto} [mmol m^{-2} s^{-1}]					
All daily hours (0–23 h)					
Maximum	115	114	114	115	112
Median	0	0	0	0	0
Mean	28	22	23	24	21
Standard deviation	35	32	34	34	32
Sunlight daily hours (07–17 h)					
Maximum	115	114	114	115	112
Median	59	43	44	50	40
Mean	53	44	45	49	43
Standard deviation	34	34	38	35	36
Night and weak sunlight hours (18–06 h)					
Maximum	99	82	83	79	76
Median	0	0	0	0	0
Mean	7	4	6	4	4
Standard deviation	16	12	15	11	10

Table 5. Descriptive statistics of stomatal *Fst* flux of O_3 estimated by DO_3SE model for growing season (GS), April – October 2014.

Experimental site Altitude	SL 810 m asl	STA 1,150 m asl	SP 1,778 m asl	PDM 1,100 m asl	KP 1,570 m asl
		Stomatal O_3 flux *Fst* (nmol m^{-2} PLA s^{-1})			
All daily hours (0–23 h)					
Maximum	5.80	5.78	6.42	6.83	6.06
Median	0.00	0.00	0.00	0.00	0.00
Mean	1.30	1.18	1.29	1.25	1.14
Standard deviation	1.56	1.55	1.72	1.69	1.58
Sunlight daily hours (07–17 h)					
Maximum	5.80	5.69	6.42	6.83	6.06
Median	2.80	2.55	2.62	2.94	2.49
Mean	2.45	2.26	2.35	2.53	2.24
Standard deviation	1.43	1.55	1.76	1.70	1.68
Night and weak sunlight hours (18–06 h)					
Maximum	5.42	5.78	5.69	4.55	4.75
Median	0.00	0.00	0.00	0.00	0.00
Mean	0.32	0.27	0.39	0.17	0.21
Standard deviation	0.81	0.78	1.04	0.50	0.59

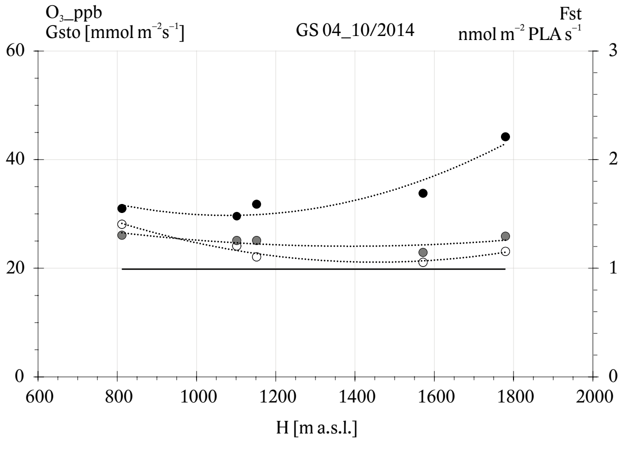

Fig. 3. Altitudinal relation of O_3 concentration (ppb), stomatal conductance (Gsto_mmol m^{-2} s^{-1}) and stomatal flux (Fst_nmol m^{-2} s^{-1}) in the High Tatra Mts. averaged for GS 2014 (0–23 hours).

The model estimates for both AOT40 (Fig. 4) and POD_1 (Fig. 5) for Norway spruce (*Picea abies* L. Karst) indicate the exceedance of *CLec* as well as *CLef* at all experimental sites in the High Tatra Mts. during GS 2014. Index AOT40 was increasing with the altitude and reached the values from 6.2 ppm h in Stará Lesná (810 m a.s.l.) to 10.7 ppm h at Skalnaté Pleso near the timber line (1,778 m a.s.l.). The critical threshold (*CLec* of 5,000 ppb h) was exceeded at each considered sites in different date. First it was at the Skalnaté Pleso site in the first half of June due to a generally higher O_3 concentration for the higher altitude position. At the beginning of August, index AOT40 was above *CLec* at all sites. POD_1 reached values from 13.6 mmol m^{-2} PLA at site Kolové pleso (1,570 m a.s.l.) to 16.2 mmol m^{-2} PLA at Skalnaté Pleso (1,778 m a.s.l.). The critical level *CLef* of 8 mmol m^{-2} PLA recommended for the spruce protection was exceeded at all experimental plots during July, in around half of the growing season 2014.

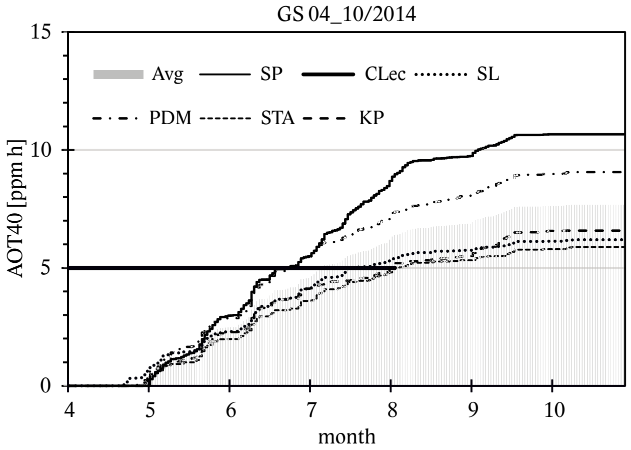

Fig. 4. Accummulated ozone exposure index AOT40 [ppm h] and the concentration-based critical level (*CLec*) for effects of ozone on forests at experimental sites in the High Tatra Mts. during GS 2014.

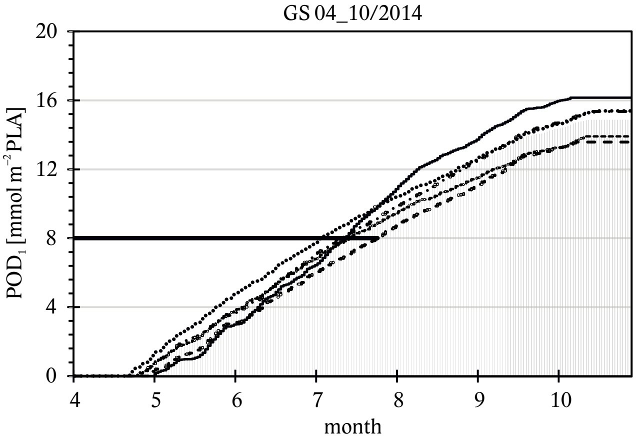

Fig. 5. Cumulative stomatal flux of ozone POD_1 [mmol m^{-2} PLA] and stomatal flux-based critical level (*CLef*) for effects of ozone on forests at experimental sites in the High Tatra Mts. during GS 2014.

4. Discussion

Phytotoxic effects of O_3 on forest vegetation are hardly distinguishable by direct methods. Based on recent epidemiological studies, Norway spruce is not clearly affected by visible O_3 injury (chlorotic mottling on the needles) and may be classified as an O_3-tolerant species (Nunn et al. 2002; Sicard et al. 2016). Critical levels of ozone concentrations could be described in different ways including concentration-based *CLec* for AOT40 and stomatal flux-based *CLef* for POD_Y that considers the stomatal conductance as the main control driver of O_3 uptake by plants. Stomatal flux-based approach has not been applied yet in assessment of O_3 impact on forest vegetation in Slovakia, mainly due to the extensive requirement of direct measurements and model input data. The presented results of pilot O_3 measurements and model outputs of POD_1 and AOT40 in the High Tatra Mts. achieved for the growing season of 2014 indicate vulnerability of forest vegetation to chronic and long-term exposure of O_3 pollution in the Western Carpathian Mts. Our results are consistent with the findings of many previous research studies conducted in surrounding countries. For example, in the medium altitudes of forested mountains in Central Europe (in the Jizerské hory Mts.), the O_3 exposure is also relatively high and comparable with the polluted sites in Southern Europe and in the higher altitudes (Hůnová et al. 2016). On the contrary, some areas of the Carpathian Mountains, in Romania and parts of Poland, as well as the Šumava and Brdy Mountains in the Czech Republic are characterized by low European background O_3 concentrations (summer season means of 30 ppb). Other parts of the Carpathians, particularly the western part of the range (Slovakia, the Czech Republic and Poland), some of the Eastern (Ukraine) and Southern (Romania) Carpathians and the Jizerske Mountains have high O_3 levels with the peak values >100 ppb and seasonal means of 50 ppb (Bytnerowicz et al. 2004). In the Czech Republic, the O_3 flux over a Norway spruce forest was measured by the gradient method and the results showed that the total deposition and stomatal uptake of O_3 significantly decreased the net ecosystem production (Zapletal et al. 2011).

As shown in our results, mean O_3 concentrations are high enough to effective O_3 uptake through stomata of coniferous trees supported by colder and wetter mountain climate favourable for open stomata processes. Both, simple concentration-based AOT40 and complex stomatal flux-based POD_1 values exceeded critical levels during growing season. AOT40 more reflects increase of O_3 concentration with altitude while POD_1 in relation to *Gsto* and *Fst* takes into account meteorological conditions. The main difference between AOT40 and POD_1 was found in the date (month) of exceedance of critical levels, particularly at site Skalnaté Pleso where the *CLec* value was exceeded in June (at the earliest date) and the *CLef* value was exceeded later in July 2014.

As confirmed by many researches, the high mountain regions are especially susceptible to the deposition of many industrial and agricultural pollutants undergoing atmospheric transport, through a process called orographic cold trapping (Hageman et al. 2015; Arellano et al. 2015). The influence of long-range transport of air pollutants on O_3 concentration in the High Tatra Mts. was noticed e.g. during unusual drought and heatwave event in summer 2003 (Bičárová et al. 2005), when the values of O_3 were significant higher then those observed within this study in wet GS 2014. The accumulated stomatal O_3 uptakes calculated by model DO_3SE exceeded *CLef* during the growing season 2014 (April-October) and indicate the risk of O_3 injury to spruce forest in the High Tatra Mts. Based on our results, the application of DO_3SE model in the High Tatra Mts. seems to be appropriate tool for monitoring of chronic O_3 exposure, O_3 deposition and stomatal O_3 uptake to forest vegetation.

Innovative epidemiological assessment of forest responses to O_3 reflecting flux-effect relationships includes species-specific *CLef* for forest protection against visible O_3 injury (Sicard et al. 2016). New *CLef* for the forest protection against the visible O_3 injury was calculated for O_3 highly sensitive conifer *Pinus cembra*. In this case, the proposed value of *CLef* 19 mmol m^{-2} represents the value POD_0 accumulated for hours with a non-null global radiation (Sicard et al. 2016). However, visible injuries on the needles of many conifer species, like Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), are rare and cannot yet be reliably associated with O_3 in the field (Günthardt-Goerg 2001).

Currently the main tree species of interest in our research are Norway spruce (*Picea abies* L. Karst.), mainly for its economic relevance in the model area as well as the Mountain pine (*Pinus mugo* Turra), creating a timberline in the High Tatra Mts. Another ecologically valuable and endemic tree in the Tatra Mountains is Swiss stone pine (*Pinus cembra* L.) that occupies specific, relatively small areas close to the alpine tree line and is highly protected in the whole Tatra National Park. Therefore, in the next years the research priorities linking to study of O_3 effect on forest vegetation in the High Tatra Mts. will be focused on biomonitoring of conifer pine species, particularly *Pinus cembra* and *Pinus mugo*.

5. Conclusions

In recent decades, the considerably and progressive deterioration of forest health status in the Tatra National Park in Slovakia was observed. Synergy of biotic and abiotic disturbances has caused the degradation of the living forest, disruption of ecological relations and other functions of the forest environment. This study presents the results of the phytotoxic ozone doses (POD_1) modeling for Norway spruce forests in the High Tatra Mts. – the highest part of Western Carpathians. The DO_3SE model outputs for the growing season 2014 indicate an excessive stomatal O_3 uptake by spruce forests at five experimental sites distributed in the altitudinal range from 810 to 1,778 m a.s.l. along the vertical and spatial profile in the High Tatra Mts. Accumulated stomatal O_3 flux i. e. POD_1 exceeded *CLef* at all considered sites during July 2014, approximately in the middle of considering growing season. Potential detrimental effect of O_3 is shown also by AOT40 index that exceeded *CLec* differently for each experimental site from the half of June to the end of August 2014. Both POD_1 and AOT40 show a high phytotoxic potential of O_3 pollution in the forest environment of the highest part of Carpathian Mountains. The deposition models such as DO_3SE that simulate the total and stomatal O_3 fluxes was in our study approved as an appropriate tool for the assessment of critical O_3 level exceedance and risk of secondary air pollution for the mountain forest ecosystems.

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Appendix – Supplementary Information to paper

Details to section: Material and methods

Model parametrisation of input variables is performed by creation of DO$_3$SE model project. For each experimental site, creation of new project is needed e.g. Appendix 1 includes input parameters for Norway spruce forest in Stará Lesná. The structure of model project consists of ten items explained in next paragraphs.

[1] **The model introduction** is related to the opening of a new or selected project that could be modified according to the location properties, vegetation type, environmental interactions, growing season, and phenology.

[2] The input dataset format processed the CSV data file, including the hourly values of **O$_3$ concentration and meteorological variables** as specified in the Table 1 and with respect to the required units. The Vapour Pressure Deficit (VPD, kPa) was calculated from the air temperature and relative humidity measurements. Where O$_3$ and meteorological data were missing for periods of several hours, data gaps were filled using a linear interpolation between adjacent data points.

[3] **The location properties** cover the geographical coordinates and typical soil texture (Appendix 1): silt loam (medium coarse), sandy loam (coarse) and loam (medium) where the soil resistance term to water vapour flow (*Rsoil*) is 200 s m^{-1}. *Rsoil* is a complex function of the vertical soil water distribution. An important feature of evaporation from soil is a fast reduction due to the drying of the uppermost soil layer after rainfall. For a fully wet soil *Rsoil* value is equal to 100 s m^{-1} (Grünhage & Haenel 2008).

[4] **Measured data** were optimised and recalculated for individual heights of O$_3$ and wind speed measurements. For forests, O$_3$ concentrations must often be derived from measurements made over grassy areas or other land-cover types. O$_3$ measured at variable heights over land-use were used to estimate the O$_3$ concentration at a referenced height by application of the gradient profile appropriate for the desired land use (UN-ECE 2004). Soil water measurement depth (d, 0.5 m) allows the model to calculate soil water data for a particular depth which can then be compared to the real-world data.

[5] **Vegetation characteristics** were linked to the following parameters: Canopy height (h, 20 m); Rooth depth (dr, 1 m); Leaf dimension (Lm, 0.05m); Albedo (0.12); Species specific maximum stomatal conductance (gmax, 125 mmol O$_3$ m^{-2} PLA s^{-1}); Sun/shade factor (1); Receptor specific value (fmin, 0.16); External plant cuticule resistance (Rext, 2,500 s m^{-1}); Threshold Y for POD$_Y$ (1.0 nmol m^{-2} s^{-1}); Closed stomata conductance (Gsto0, 30,000 µmol m^{-2} s^{-1}); Species-specific sensitivity to An (m, 16.83); Maximum catalytic rate at 25 °C (Vcmax, 30 µmol m^{-2} s^{-1}); Maximum rate of electron transport at 25 °C (Jmax 60, µmol m^{-2} s^{-1}).

[6] **The environmental response** includes: A parameter related to the function f$_{light}$ and the photosynthetic photon density (ligh_a, 0.010); Minimum temperature (T_min, 0 °C); Optimum temperature (T_opt, 14 °C); Maximum temperature (T_max, 35 °C); Vapour Pressure Deficit for maximal stomatal conductance (VPD_max, 0.50 kPa); Vapour Pressure Deficit for minimal stomatal conductance (VPD_min, 3.00 kPa); Critical daily VPD sum (VPD_crit, 1,000 kPa); Soil water potential for minimal stomatal conductance (SWP_min, –0.50 MPa); Soil water potential for maximal stomatal conductance (SWP_max, –0.05 MPa).

[7] **The model option** allows an alternate choice of different methods for calculating the same factors. For the simulation in this work, the following ones were selected: Multiplicative stomatal conductance model; Estimated leaf temperature; Not used the fO$_3$ method in the calculation of leaf Gsto; Linear (SWP_min, SWP_max) fSWP calculation; Use of supporting interface fSWP for calculating the effect of soil water availability on stomatal conductance; Steady-state method of Leaf Water Potential calculation – the steady state model controls water flux on an hourly time-step using an estimation of LWP based on the daily SWP and plant transpiration of the previous hours (Büker et al. 2012).

[8] **The season** was set on the duration of Growing Season (GS). Duration of GS from the start (SGS) to the end (EGS) estimated according to the latitude function with respect to the forest vegetation. Leaf Area Index at SGS (LAI_a, 3.5 m^2 m^{-2}); First mid-season LAI (LAI_b, 4.0 m^2 m^{-2}); Second mid-season LAI (LAI_c, 3.8 m^2 m^{-2}); Leaf Area Index at EGS (LAI_d, 3.5 m^2 m^{-2}); Period from LAI_a to LAI_b (LAI_1, 25 days); Period from LAI_c to LAI_d (LAI_2, 30 days); Stem Area Index calculation for forest.

[9] **Phenology** is focused on the configuration of the *Fphen* function. For the forests species, the *fphen* parameterisation is based on data describing the increase and reduction in *Gsto* with the onset and end of the physiological activity (CLRTAP 2004). We assumed that *fphen* was 1 throughout the growing season, i.e. the POD$_Y$ accumulation period. *Fphen* at SGS (fphen_a, 0.0); First mid-season *Fphen* (fphen_b, 1.0); Second mid-season *Fphen* (fphen_c, 1.0); Third mid-season Fphen (fphen_d, 1.0); *Fphen* at EGS (fphen_e, 0.0); Period from fphen_a to fphen_b (fphen1, 0 days); Parameters of SWP limitation are set to 0, the model reverts to a simpler version.

[10] **Leaf phenology** (*Leaf fphen*): the calculation is the same as of *Fphen*.

Appendix 1. Input parameters using for model calculation of POD$_1$ for Norway spruce forest at Stará Lesná experimental site during growing season 2014.

DO$_3$SE model: INPUT parameters			
Location properties		Measurement data	
Latitude	49.15	O$_3$ measurement height-recalculated [m]	20
Longitude	20.28	O$_3$ measurement canopy height [m]	20
Elevation [m a.s.l.]	810	Wind speed measurement height- recalcul. [m]	20
Soil texture	Silt loam (medium coarse)	Wind speed measurement canopy height [m]	20
Rsoil [s/m]	200	Soil water measurement depth ([m]	0.5
Environmental response		Vegetation characteristics	
light_a	0.01	Canopy height [h, m]	20.00
T_min °C	0.00	Root depth (root, m)	1.00
T_opt °C	14.00	Leaf dimension [Lm, m]	0.08
T_max °C	35.00	Albedo (fraction)	0.12
VPD for max.g [VPD_max, kPA]	0.50	gmax [mmol O$_3$/m^2 PLA/s]	125.00
VPD for min.g [VPD_min, kPA]	3.00	Sun/shade factor (fraction)	1.00
SWP for min.g [SWP_min, Mpa]	−0.50	fmin (fraction)	0.16
SWP for max.g [SWP_max, Mpa]	−0.05	External plant cuticule resistance [Rext, s/m]	2500.00
Model options		Threshold Y for PODy [nmol/m^2/s]	1.00
Stomatal conductance model	Multiplicative	Closed stomata conductance [Gsto0, umol/m^2/s]	30000.00
Leaf temperature calculation	Estimate	Species-specific sensitivity to An [m, dimensionless]	16.83
fO$_3$calculation	Not used (f3=1)	Maximum catalytic rate at 25 °C [Vcmax, umol/m^2/s]	30.00
Soil water influence on Gsto	Use fSWP	Maximum rate of electron transport at 251C [Jmax, umol/m^2/s]	60.00
LWP calculation	steady-state	fphen	
fSWP calculation	Linear	fphen_a	0.0
Season		fphen_b	1.0
SGS/EGS method	Latitude function	fphen_c	1.0
Star of growing season SGS	112	fphen_d	1.0
End of growing season EGS	291	fphen_e	0.0
LAI at SGS [LAI_a, m^2/m^2]	3.5	fphen_1	0
First mid-season [LAI_b, m^2/m^2]	4.0	fphen_limA	0
Second mid-season LAI [LAI_c, m^2/m^2]	3.8	fphen_2	200
LAI at EGS [LAI_d, m^2/m^2]	3.5	Fphen 3	200
Period from LAI_a to LAI_b [LAI_1, days]	25	fphen_limB	0
Period from LAI_c to LAI_d [LAI_1, days]	30	fphen_4	0
SAI calculation	Forest	Leaf fphen calculation	Same as Fphen

Explanatory note:

DO$_3$SE model parametrisation for interfaced version (DO3SE_INTv3.0.5) developed by the Stockholm Environment Institute, Available at: www.sei-international.org/do3se.

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ORIGINAL PAPER

Forest management economics based on forest typology

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Abstract

In forest management, natural conditions have long been systemized by groups of forest habitat types (GFHT). Based on them, appropriate economic measures can be taken and economic efficiency of silviculture calculated. Management intensity, the term related only to timber production in the past, has recently been defined more broadly within the sustainable, close-to-nature forest management concept. It includes economic-ecological and efficient management, and reflects potential production as well as ecological effects of forest stands. Nature and natural development are preferred where artificial interventions are unnecessary (Plíva 2000). This concept uses a specific GFHT as the elementary unit as it allows to exactly identify ecological and economic potential, management measures, quantification and monetary expression of elementary components of economic efficiency. Such optimization of management measures and their economic projections analysis can be considered a comprehensive biological-ecological-economic analysis.

Key words: Groups of forest habitat types; management intensity; ecological potential; economic potential

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1. Introduction

Sustainable and site-befitting forest management means “the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions that do not cause damage to other ecosystems” (Second Ministerial Conference, Helsinki 1993, Anonymus 2003).

Analyses of forestry production conditions distinguish among different natural conditions, conditions of workplaces, technologies, management, human factors etc. Natural conditions express general production features of forests and site characteristic that – to a large extent – go along with forest typological classification. Differences in natural conditions are reflected in different tree species, quality and age structures of forest stands and, consequently, in different assortment structures and allowable total cuts (Kupčák 2006).

Natural conditions of forests in the Czech Republic (CR) vary considerably. In forest typology, the elementary unit of growth conditions differentiation is the forest habitat type (FHT). The contemporary approach to FHT is basically identical with Zlatník’s classical definition (1956): “Forest habitat type is an aggregate of natural geobiocoenosis and all geobiocoenoses originating from it, from the viewpoint of development, and partly geobiocoenoses changed to a certain extent, including development stages.”

Forest habitat types associate in groups of forest habitat types (GFHT) in accordance with their ecological relation expressed by important economic features of the site. At present, these typological units are subject to Regulation No. 83/1996 (Ministry of Agriculture) on regional plans of forest development and management units. Moreover, FHT serves as a criterion for forest land prices (see Regulation No. 3/2008 to Act No. 151/1997 on property evaluation[1]).

The GFHT approach is based on Plíva (1971, 1980, 1998, 2000) who elaborated a methodology for GFHT utilization for forest management differentiation in accordance with the concept of sustainability and efficiency. The author draws on his previous works and adjusts the data to the concept of sustainable management (SM), particularizes them for selected GFHT and adds more information to support a multipurpose utilization. He associates GFHT by intensity and targets of management.

According to Plíva (2000), “management intensity” in the concept of SM and close-to-nature management acquires broader sense than in the original approach supporting timber production and rationalisation and intensification (or, maybe, together with labour and means investment). Plíva supports economic-ecological and, last but not least, efficient management. He reflects not only the value of potential production but also ecological effects of forest stands which affect – and limit – the management intensity. His approach leaves more up to the nature and natural development where artificial intervention is unnecessary.

The stands are actively influencing their surroundings, and the effect is expressed by their ecological functions, i.e. positive effects of forest on its environs. Their overall influence in GFHT is, therefore, ecological potential (EP), and simultaneously, production potential (PP) of a GFHT is determined by the production function (value of production). Quantitative markers EP and PP influence manage-

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[1] GFHT are units of the typological system associating forest habitat types by its ecological relation expressed by important economic features of the site (Appendix No. 24 to Regulation No. 3/2008).

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ment intensity (MI). Both potentials influence MI reversely as well (increasing ecological function makes MI decrease down to protection forest intensity; reversely in case of production function), therefore their comparison in GFHT determines appropriate MI. In fact, both potentials are of comparable extent as they comprise the full scale of potential alternatives of all GFHT (Pulkrab et al. 2009).

The article investigates management measures and methods of GFHT-based economic features calculations. These issues represent the introductory part of the National Agency for Agricultural Research project called "Differentiation of the Management Intensities and Methods to Ensure Forest Biodiversity and Economic Sustainability of Forestry" (hereinafter referred to as the project). One of the project's principle objectives is to define appropriate management measures of silviculture and harvest, and to calculate economic efficiency of forestry in an easy-to-use system based on typology.

2. Methods

The methodological approach of the project is based on the essential structure of GFHT – in relation to ecological and production (timber production) forest function.

Forest types as elementary units of differentiation of forest growth conditions (growth of trees, their production and silviculture) are grouped by their ecological (soil and climatic) affinity expressed by phytocoenosis (association) or manifest features (characteristics) of the site into GFHT. Inductively created GFHT, systemized into an ecological (edaphoclimatic) network constituted a solid framework with a feedback and a deductive procedure expressed by the following definition (Amendment No. 4 to Regulation No. 83/1996): "GFHT are determined by forest altitudinal zone (FAZ) and edaphic category." The definition is tempting to schematically fill in the network on one hand, but on the other, it lets us adjust the system more clearly to facilitate practical application. As mentioned above, the ecological forest functions (active influence of stands on forest environs) are generally called ecological potential (EP) and the production function, expressed by the value of potential production, is called production potential (PP).

We distinguish EP by the importance of cardinal functions, i.e.:

1. Infiltration – infiltration of precipitation into the soil, its retention, retardation and accumulation; loss control by interception.
2. Erosion control (slopes of 40% and steeper; or milder in case of erosion risk) – prevention of surface outflow and soil erosion; facilitation of high retention and infiltration.
3. Suction – forest stands absorb water and drain superfluous water to let the soil accumulate precipitation and slow down the drainage.
4. Precipitation supporting (climatic) function (complementary function 1, 2, 3 in the 7th and 8th FAZ) – zones of frequent mists in mountain zones improving water balance by supporting precipitation.

Other ecological functions of stands occurring only in some localities (parts) of GFHT:

- water protecting – lanes of shore stands (mostly within L and U categories)
- mesoclimatic – protection from negative mesoclimatic effects, especially in frost hollows,
- other soil protection functions (deflation, landslides, avalanches, banks controlling functions) considered when evaluating the erosion control function,
- (forest) protection – self-preservation function of forest ecosystems in extreme conditions limiting the forest existence.

2.1. Economic parameters of production potential evaluation

The calculation is based on the following prerequisites:

1) potentional forest production yields calculation was based on yield tables (Černý et al. 1996);
2) sorting was based on assortment tables for Norway spruce, Scots pine, beech and oak stands in "N" quality – healthy, undamaged, straight stems (Pařez 1987a, b);
3) considering main collections in each girth class (6+ to 1), currently traded in CR and evaluated in market prices published by the Czech Statistical Office for year 2013;
4) the elementary space unit for evaluation was GFHT;
5) the principal synthetic indicator of evaluation effect was the gross yield of forest production (GYFP);
6) the calculation of direct silviculture and harvest operation costs is based on performance standards (Nouza, Nouzová 2003) considering the following: adding a 15% mean flat surcharge to the basic norm; accepting the flat wage rate of CZK 65.00/standard hour in silvicultural operations and CZK 80.00/standard hour in harvesting operations (the estimated republic's average the value of which might vary in different regions); adding the flat rate of social and health insurance (34% to labour costs); adding flat substitutes (39% to labour costs).
   Calculations cover also reasonable indirect costs of 35% to direct costs; roads and slope roads maintenance are not included in the costs.

Five grades of MI are defined by comparison of PP with the ecological functions importance grade of an ecosystem (EP), and, within the five grades, several types of target management are set (in accordance with the character of natural conditions and the main target tree species). These two broadly set units serve to make general principles clear, but do not substitute GFHT nor management units. MI by GFHT is presented in the ecological network of the typological system (where PP and EP grades are also mentioned) and is scaled A–E, see Table 1.

Table 1. Differentiation of management intensity.

	Management Intensity	Relation PP ↔ EP
A	Highly intensive management	PP highly exceeds EP
B	Intensive management	PP (considerably) exceeds EP
C	Standard management	PP mildly exceeds EP
D	Limited management	EP exceeds PP
E	Protection forests management	EP highly exceeds PP

Gross yield of forest production is presented in Table 2.

Table 2. The gross yield of forest production value by target management (thous. CZK).

	Group of forest habitat types																							
	transitional			extreme			exposed			acid				nutritious			gleyed				waterlogged			alluvia	
	W	C	X	Z	Y	J	A	F	N	M	K	I	S	B	H	D	V	O	P	Q	T	G	R	L	U
9 dwarf pine																									
8 spruce				NS 0.8	NS 1.2		NS 2.6	NS 3.1	NS 3.1	NS 2.3	NS 2.7		NS 2.7				NS 3.1			NS 2.8	NS 2.1	NS 4.6	NS 2.1		
7 beech-spruce				NS 1.0	NS 1.2			NS 3.9	NS 2.9	NS 2.2	NS 3.0		NS 3.2	NS 3.3			NS 5.1	NS 4.0	NS 3.8	NS 3.1	NS 3.3	NS 4.8	NS 3.3		
6 spruce-beech					NS 1.1		NS 4.3 EB 1.3	NS 4.4 EB 1.8	NS 3.0 EB 0.8	EB 0.6 NS 2.2	EB 2.3 NS 3.2	EB 1.1 NS 3.3	NS 5.1 EB 1.9	EB 2.5 NS 5.8	EB 2.1 NS 5.2	EB 2.5 NS 5.9	EB 2.2 NS 5.7	NS 4.4	NS 3.0	NS 2.7		NS 4.8	NS 4.8		
5 fir-beech	NS 4.5 EB 1.6	EB 1.6			NS 0.9	EB 0.6	NS 5.3 EB 1.4	NS 4.4 EB 1.9	NS 3.2 EB 0.9	EB 0.6	EB 1.2 NS 3.3	EB 1.2 NS 3.3	NS 5.3 BK 2.3	NS 5.8	EB 2.3 NS 3.0	EB 2.5 NS 5.8	EB 2.2 NS 5.8	NS 4.4	NS 3.7	NS 2.7 SP 2.0		NS 5.4	NS 2.8		NS 4.9
4 beech	EB 1.6	EB 1.1 SP 1.5			SP 0.7		NS 4.9 EB 1.3	NS 4.6 EB 1.7	SP 2.2 NS 3.4 EB 1.0	SP 0.5 OA 0.5	NS 3.3 EB 1.3	EB 1.3 NS 3.3	EB 1.9 NS 4.1	EB 2.3 NS 5.4	EB 2.3 NS 5.4	EB 2.5 NS 6.1	NS 6.1 EB 2.2 OA 4.1	NS 5.1 OA 4.1	NS 3.6 OA 1.3	SP 0.8		NS 5.4	NS 5.1		
3 oak-beech	EB 1.8	EB 1.3 SP 0.9			SP 0.6	EB 0.01	NS 4.3 EB 1.2	NS 3.8 EB 1.6	SP 1.1 NS 3.4 EB 0.9	SP 0.2 OA 0.3	SP 0.8 EB 2.5	SP 0.7 NS 3.4 EB 2.5	EB 2.1 NS 4.0	EB 2.3 NS 5.4	EB 2.3 NS 5.5	EB 2.1 NS 4.6	NS 6.0 EB 2.2 OA 4.0	NS 4.0 EB 1.7 OA 4.8				NS 5.0		AL 2.4	NS 6.7
2 beech-oak	OA 1.2	EB 0.6 OA 0.8		OA 0.4			OA 2.0		SP 0.7 OA 0.8	SP 0.2 OA 0.3	SP 0.7 OA 0.7	SP 0.9 OA 1.0	SP 1.9 OA 1.4	OA 2.6	OA 3.6	OA 1.7	OA 2.2	OA 3.0	SP 1.1	SP 0.8				OA 4.6	
1 oak		SP 0.6 OA 0.5	OA 0.4	OA 0.4		OA 0.5	OA 0.8		SP 0.6 OA 0.6	SP 1.3	SP 0.2 OA 0.4	SP 0.7 OA 0.7	SP 1.1 OA 2.5	OA 1.9	OA 1.2	OA 1.7	OA 2.2	OA 2.6	SP 1.3	SP 0.8				OA 3.8	OA 4.4
0 pine		SP 1.5		SP 0.3	SP 0.3				SP 0.9	SP 0.2	SP 0.8							SP 2.4	SP 2.4	SP 0.4	SP 2.0	SP 2.4	SP 0.6		

Explanatory notes: NS – Norway spruce, SP – Scots pine, OA – oak, EB – European beech, LA – larch, FI – fir, AL – alder.

3. Results and discussion

Table 3 presents groups of forest habitat types and their representation in CR. The following forest site complexes are among the most frequent GFHT: 5K (*Abieto-Fagetum acidophilum*), 6K (*Piceeto-Fagetum acidophilum*), 3K (*Querceto-Fagetum acidophilum*), 2K (*Fageto-Quercetum acidophilum*), 5S (*Abieto-Fagetum oligo-mesotrophicum*), 5B (*Abieto-Fagetum mesotrophicum*), 3H (*Querceto-Fagetum illimerosum mesotrophicum*) (Kupčák & Pulkrab 2012).

The output of the project and its methodology is identification and quantification of economic parameters of management in relation to management measures. The calculations respect ecological limits implied by the CR typological system and legislation. The analysis considered the recommended tree species representation, the share of soil improving species, rotation period and target management (Norway spruce, Scots pine, oak and beech).

Types of target managements by Plíva (2000) are defined by framework units with the same target management, and the same essential tree species of the target composition which mark the type of the management, set management intensity and the forest management system.

In given natural conditions, the target composition defines the optimal PP when the forest ecosystem keeps stable (ecological stability, or acceptable instability), therefore the related management system is optimal as well. Production of alternative managements systems cannot be higher, but can possibly improve ecological forest functions.

Target managements open the way for setting framework principles in specific MI but their presence also provides ample information on management prerequisites and targets in broader areas.

3.1. Alternatives of target management

The following tables enumerate the ecologically acceptable alternatives of target management (Norway spruce, Scots pine, oak and beech) by GFHT. Tree composition (in %) by GFHT for Norway spruce and Scots pine target management in the ecological network of typological system is shown in Table 4, tree composition for oak and beech target management is presented in Table 5.

It is in accordance with the Czech typological system that in some GFHT, only one target management is acceptable; in most GFHT, though, the owner can choose from two or three alternatives of target management. The following list (based on Tables 4 and 5) shows us areas of acceptable target managements from the total 2,659,832 ha of Czech forests:

- 420,254 ha – Norway spruce target management only,
- 1,321,939 ha – Norway spruce target management or another, usually beech,
- 154,271 ha – Scots pine target management only,
- 37,238 ha – Scots pine target management or another, usually oak,
- 170,230 ha – oak target management only,
- 308,541 ha – oak target management or another, usually Scots pine,
- 79,795 + 10,639 ha – beech target management only,
- 127,672 ha – beech target management or another, usually Norway spruce.

3.2. Management intensities

Table 6 presents a survey of management intensities in the ecological network of the typological system. Presented data do not reflect the contemporary forest stand state and composition but anticipate the results on the basis of maximum PP of target composition and site characteristics (potential). PP was defined on the basis of gross yield of forest production (GYFP). In the table, alternatives of target managements with maximum production potential, i.e. gross yield of forest production, were opted for. The grade of production potential is provided with each GFHT (top left) based on the value scale (see Table 2); on the bottom left, there is the grade of ecological potential based on cited Plíva's works; in the middle, there is the target management with the highest GYFP in the particular GFHT and it also presents the grade of MI as the difference between ecological and economic potential.

The table shows GFHT with the highest PP: 2L (*Fraxineto-Quercetum alluvialis*), 3U (*Acereto-Fraxinetum vallidosum*), 3B (*Querceto-Fagetum mesotrophicum*), 3H (*Querceto-Fagetum illimerosum mesotrophicum*), 3V (*Querceto-Fagetum fraxinosum humidum*), 4B (*Fagetum mesotrophicum*), 4H (*Fagetum illimerosum mesotrophicum*), 4D (*Fagetum acerosum deluvium*), 4V (*Fagetum fraxinosum humidum*), 5B (*Abieto-Fagetum mesotrophicum*), 5D (*Abieto-Fagetum acerosum deluvium*), 5V (*Abieto-Fagetum fraxinosum humidum*), 5S (*Abieto-Fagetum oligo-mesotrophicum*), 6B (*Piceeto-Fagetum mesotrophicum*), 6D (*Piceeto-Fagetum acerosum deluvium*), 6H (*Piceeto-Fagetum illimerosum mesotrophicum*), 6V (*Piceeto-Fagetum fraxinosum humidum*) and 7V (*Fageto-Piceetum acerosum humidum*). GFHT with the highest EP are the following: 7R (*Piceetum turfosum acidophilum*), 7Z (*Fageto-Piceetum humilis*), 8A (*Aceri-Piceetum lapidosum*), 8F (*Piceetum lapidosum mesotrophicum*), 8N (*Piceetum lapidosum acidophilum*), 8R (*Piceetum turfosum [montanum]*), 8Y (*Piceetum saxatile*) and 8Z (*Sorbeto-Piceetum [humilis]*).

Management intensity, originally encompassing only timber production and rationalization and intensification, has adopted a broader sense in the concept of sustainable management. Management intensity is used to define concrete management measures, which can support some of the principles of sustainable management, e.g.:

- diversity of species and its aiming at natural character (lower MI), or, possibly, closer links to target species (higher MI),
- nature-friendly management approach – preferring natural processes where artificial intervention is unnecessary,
- e.g. rotation period – the higher the intensity, the closer to target assortments; the lower the intensity, the more inherent the ecological aspect; when the ecological functions prevail, the rotation period prolongs, even up to the physical age limits, in extreme cases,
- in Table 6 the comparison was based on the target management alternatives with the highest PP (as apparent from the title of the table).

Table 3. Representation of groups of forest habitat types in Czech Republic [%].

No.	GFHT	%	MI	No.	GFHT	%	MI	No.	GFHT	%	MI	No.	GFHT	%	MI
1	0X	+	E	44	3I	1.7	C	87	5B	2.8	A	130	4O	0.9	B
2	1X	0.1	E	45	4I	0.1	B	88	6B	0.1	A	131	5O	1.3	B
3	2X	+	E	46	5I	0.6	B	89	7B	+	B	132	6O	0.7	B
4	3X	+	E	47	6I	0.1	B	90	2W	0.1	C	133	7O	0.2	B
5	4X	+	E	48	0N	0.4	D	91	3W	0.3	C	134	0P	0.2	D
6	0Z	+	E	49	1N	+	D	92	4W	0.1	C	135	1P	0.3	C
7	1Z	0.3	E	50	2N	0.1	D	93	5W	+	C	136	2P	0.4	C
8	2Z	0.1	E	51	3N	0.3	D	94	1D	0.2	B	137	4P	1.5	C
9	3Z	+	E	52	4N	0.1	D	95	2D	0.2	B	138	5P	1.0	B
10	4Z	+	E	53	5N	0.7	D	96	3D	0.7	B	139	6P	1.2	B(C)
11	5Z	+	E	54	6N	0.7	D	97	4D	0.7	A	140	7P	0.2	C
12	6Z	+	E	55	7N	0.2	D	98	5D	1.1	A	141	0Q	0.3	D
13	7Z	0.1	E	56	8N	0.1	D-E	99	6D	0.1	A	142	1Q	0.2	D
14	8Z	0.3	E	57	1S	0.4	C	100	1A	+	D	143	2Q	0.1	D
15	9Z	0.1	E	58	2S	0.8	C	101	2A	0.2	D	144	4Q	0.5	D
16	0Y	+	D-E	59	3S	3.2	B	102	3A	0.5	D	145	5Q	0.2	C
17	3Y	0.1	E	60	4S	1.5	B	103	4A	0.2	D	146	6Q	0.1	C
18	4Y	+	D-E	61	5S	5.7	A	104	5A	0.7	C	147	7Q	+	D
19	5Y	0.1	D-E	62	6S	2.1	A	105	6A	0.3	C	148	8Q	0.1	D
20	6Y	0.2	D-E	63	7S	0.5	C	106	7A	+	D	149	0T	0.1	D-E
21	7Y	+	E	64	8S	0.2	C	107	8A	+	D-E	150	1T	+	D
22	8Y	+	E	65	0C	0.1	D-E	108	1J	0.1	E	151	3T	+	D
23	0M	0.8	D	66	1C	0.5	D	109	3J	0.2	E	152	5T	+	D
24	1M	0.6	C	67	2C	0.7	D	110	5J	0.2	D-E	153	7T	0.1	D
25	2M	0.9	D	68	3C	0.2	D	111	1L	1.0	A	154	8T	+	E
26	3M	1.1	D	69	4C	0.1	D	112	2L	0.2	A	155	0G	0.3	C
27	4M	0.1	D	70	5C	+	D	113	3L	0.4	C	156	1G	0.2	D
28	5M	2.2	D	71	3F	0.1	C	114	6L	+	D-E	157	3G	+	C
29	6M	0.4	C	72	4F	0.1	C	115	1U	0.1	A	158	4G	0.2	C
30	7M	0.1	C	73	5F	0.5	C	116	3U	0.2	B	159	5G	0.2	C
31	8M	0.2	D	74	6F	0.1	C	117	5U	0.2	C	160	6G	0.4	C
32	0K	1.3	C	75	7F	+	D	118	1V	0.2	B	161	7G	0.5	C
33	1K	0.8	C	76	8F	+	D-E	119	2V	0.1	B	162	8G	0.3	D
34	2K	4.0	C	77	1H	0.1	B	120	3V	0.2	A	163	0R	0.1	E
35	3K	4.6	C	78	2H	1.1	B	121	4V	0.1	A	164	3R	+	D
36	4K	1.5	B	79	3H	2.4	A	122	5V	0.7	A	165	4R	0.1	C
37	5K	9.7	B	80	4H	0.3	A	123	6V	0.8	A	166	5R	0.1	D
38	6K	6.0	C	81	5H	0.9	A	124	7V	0.1	C	167	6R	0.1	C
39	7K	2.2	C	82	6H	0.1	A	125	8V	+	D	168	7R	0.2	D
40	8K	0.6	C	83	1B	0.7	B	126	0O	+	C	169	8R	0.2	E
41	9K	+	E	84	2B	0.7	B	127	1O	0.7	B	170	9R	0.1	E
42	1I	0.7	C	85	3B	1.7	A	128	2O	0.3	B				
43	2I	1.8	C	86	4B	0.7	A	129	3O	1.0	B				

(Source: Plíva 2000)
Explanatory notes: No. = number, GFHT = groups of forest habitat types, MI = management intensity.

Table 4. Tree species share (in %) by GFHT for Norway spruce and Scots pine target management in the ecologic network of the typology system.

Line	Group of forest habitat types																								
			extreme				exposed			acid				nutritious					gleyed				waterglogged		alluvial
faz[1]/cat[2]	X	Z	Y	J	A	C	F	N	M	K	I	S	B	H	D	W	V	O	P	Q	T	G	R	L	U
9 dwarf pine																									
8 spruce		NS 90 EB 10	NS 90 EB 10		NS 90 EB 10		NS 90 EB 10	NS 90 EB 10	NS 90 EB 10	NS 85 EB 7 LA 4 FI 4		NS 85 EB 7 FI 4 AL 4					NS 90 EB 10			NS 90 EB 10	NS 90 EB 10	NS 90 EB 10	NS 90 EB 10		
7 beech-spruce		NS 90 EB 10	NS 90 EB 10				NS 90 EB 10	NS 90 EB 10	NS 85 EB7 FI 4 AL 4	NS 85 EB 7 FI 4 AL 4		NS 85 EB 7 FI 4 AL 4	NS 70 EB 20 LA 5 FI 5				NS 85 EB 7 LA 4 FI 4	NS 70 EB 20 LA 5 FI 5		NS 90 EB 10	NS 90 EB 10	NS 85 EB 7 FI 4 AL 4	NS 90 EB 10		
6 spruce-beech			NS 70 EB 25 FI 5		NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5		NS70 EB20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA5 FI 5		NS 85 EB 7 FI 4 AL 4	NS 85 EB 7 FI 4 AL 4		
5 fir-beech			NS 70 EB 25 FI 5		NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5		NS70 EB20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI5/ SP 80 OA 20		NS 85 EB 7 FI 4 AL 4	NS 90 EB 10		NS 50 EB 30 FI 20
4 beech			SP 95 OA 5		NS 70 EB 20 LA 5 FI 5	SP 70 OA 30	NS 70 EB 20 LA 5 FI 5	SP 70 OA 30 / NS 70 EB 20 LA 5 FI 5	SP 70 OA 30	NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA5 FI 5	NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	SP 80 OA 20		NS 85 EB 7 FI 4 AL 4	NS 85 EB 7 FI 4 AL 4		
3 oak-beech			SP 95 OA 5		NS 70 EB 20 LA 5 FI 5	SP 70 OA 30	NS 70 EB 20 LA 5 FI 5	SP 70 OA 30 / NS 70 EB 20 LA 5 FI 5	SP 70 OA 30	SP 70 OA 20 LA 5 FI 5	SP 70 OA 20 LA 5 FI 5 / NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA5 FI 5	NS 70 EB 20 LA 5 FI 5		NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5	NS 70 EB 20 LA 5 FI 5			NS 85 EB 7 FI 4 AL 4			NS 50 EB 30 FI 20
2 beech-oak						SP 70 OA 30		SP 70 OA 30	SP 70 OA 30	SP 70 OA10 LA 5 FI 5	SP 70 OA 20 LA 5 FI 5	SP 70 OA 20 LA 5 FI 5							SP 70 OA 20 LA 5 FI 5	SP 80 OA 20					
1 oak						SP 70 OA 30		SP 70 OA 30	SP 85 OA 10 LA 5	SP 70 OA20 LA 5 FI 5	SP 70 OA20 LA 5 FI 5	SP 70 OA 20 LA 5 FI 5							SP 70 OA 20 LA 5 FI 5	SP 80 OA 20					
0 pine		SP 95 OA 5	SP 95 OA 5			SP 95 OA 5		SP 85 OA 10 LA 5	SP 85 OA 10 LA 5	SP 85 OA10 LA 5								SP 85 OA 10 LA 5	SP 70 OA 20 FI 10	SP 85 OA 10 LA 5	SP 95 OA 5	SP 95 OA 5	SP 95 OA 5		

Explanatory notes: [1] faz = forest altitudinal zone, [2] cat. = category, NS – Norway spruce, SP – Scots pine, OA – oak, EB – European beech, LA – larch, FI – fir, AL – alder.

Table 5. Tree species share (in %) by GFHT for oak and beech target management in the ecological network of the typological system.

	Group of forest habitat types																								
Line	extreme				exposed				acid			nutritious					gleyed				water logged			alluvial	
faz[1]/cat.[2]	X	Z	Y	J	A	C	F	N	M	K	I	S	B	H	D	W	V	O	P	Q	T	G	R	L	U
9 dwarf pine																									
8 spruce																									
7 beech-spruce																									
6 spruce-beech					EB 70 OA 10 LA 20		EB 70 OA 10 LA 20	EB 80 OA 10 LA 10	EB 70 OA 10 LA 10	EB 70 OA 10 LA 20	EB60 NS 20 OA 20	EB 60 OA 20 NS 20		EB 60 OA 20 NS 20	EB 60 OA 20 NS 20		EB 60 NS 20 OA 20								
5 fir-beech				EB 60 NS 20 FI 20	EB 70 OA 10 LA 20	EB 80 OA 10 LA 10	EB 70 OA 10 LA 20	EB 80 OA 10 LA 10	EB 80 OA 10 LA 10	EB 60 NS 20 OA 20	EB 60 NS 20 OA 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	OA70 EB10 LA 20	EB 60 NS 20 OA 20								
4 beech					EB 80 OA 10 LA 10	EB 80 OA 10 LA 10	EB 70 OA 10 LA 20	EB 80 OA 10 LA 10	OA 80 EB 10 LA 10	EB 60 NS 20 OA 20	EB 60 NS 20 OA 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	OA70 EB10 LA 20	EB 60 NS 20 OA 20 / OA 90 LA 10	OA 90 LA 10	OA70 EB 10 LA 20						
3 oak-beech				EB 80 LA 10 FI 10	EB 80 OA 10 LA 10	EB 80 OA 10 LA 10		EB 80 OA 10 LA 10	OA 80 EB 10 LA 10	EB 70 OA 10 LA 20	EB 70 OA10 LA 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	EB 60 OA 20 NS 20	OA70 EB10 LA 20	EB 60 NS 20 OA 20 / OA 90 LA 10	EB 60 NS 20 OA 20 / OA 90 LA 10						AL 60 NS 20 EB 20	
2 beech-oak		OA 60 SP 30 EB 10			OA 60 SP 20 EB 10 LA 10	OA 80 EB 10 LA 10		OA 80 EB 10 LA 10	OA 80 EB 10 LA 10	OA 70 EB-10LA 20	EB 70 OA10 LA 20	EB 70 OA10 LA 20	OA 90 LA 10	OA 90 LA 10	OA 90 LA 10	OA70 EB10 LA 20	OA 90 LA 10	OA 90 LA 10						OA 100	
1 oak		OA 70 SP 30		OA 80 EB 20	OA 80 EB 10 LA 10	OA 80 EB 10 LA 10		OA 80 EB 10 LA 10		OA 70 EB 10 LA 20	EB 70 OA10 LA 20	EB 70 OA10 LA 20	OA 90 LA 10	OA 90 LA 10	OA 90 LA 10		OA 90 LA 10	OA 90 LA 10						OA 100	OA 100
0 pine	OA 100																								

Explanatory notes: [1] faz = forest altitudinal zone, [2] cat. = category, NS – Norway spruce, SP – Scots pine, OA – oak, EB – European beech, LA – larch, FI – fir, AL – alder.

Table 6. Management intensities in the ecologic network of the typological system by maximal gross yield of forest production.

	Group of forest habitat types																								
		transitional			extreme			exposed			acid		nutritious									waterlogged		alluvial	
	W	C	X	Z	Y	J	A	F	N	M	K	I	S	B	H	D	V	O	P	Q	T	G	R	L	U
9 dwarf pine	MI A MI B	4.0 2.5	−5.0 −3.5																						
8 spruce	MI C MI D	0.5 −2.0	−2.0 −0.0	3 NS−2.5 5.5	4 NS −2 6		4 NS −1.5 5.5	4 NS −1.5 5.5	4 NS−1.5 5.5	3 NS 0.5 2.5	3 NS 0.5 2.5		3 NS 0.5 2.5				4 NS −0.5 4.5			3 NS −0.5 3.5	3 SP −1.5 4.5	5 NS 0.5 4.5	3 NS −2.5 5.5		
7 beech-spruce	MI E	−2.5	−5.0	3 NS −2.5 5.5	4 NS −1.5 5.5			5 NS 0.55 4.5	4 NS −0.5 4.5	3 NS 1.5 1.5	4 NS 2.5 1.5		4 NS 2.5 1.5	4 NS 2.5 1.5			6 NS 2.5 3.5	5 NS 3 2	4 NS 1.5 2.5	4 NS 1.5 2.5	3 SP −1.5 4.5	5 NS 1.5 3.5	4 NS −0.5 4.5		
6 spruce-beech					3 NS −2 5		5 NS 1 4	5 NS 1 4	4 NS 0 4	3 NS 2 1	4 NS 3 1	4 NS 3 1	5 NS 4 1	6 NS 5 1	6 NS 5 1	6 NS 4.5 1.5	6 NS 4 2	5 NS 3 2	3 NS 1 2	3 NS 1 2		5 NS 2 3	5 NS 2 3		
5 fir-beech	4 NS 1 3	2 EB −1 2			3 NS −2 5	2 EB −3 5	5 NS 1 4	5 NS 1 4	4 NS 0 4	1 EB 0 1	4 NS 3 1	4 NS 3 1	6 NS 5 1	6 NS 5 1	3 NS 2 1	6 NS 4.5 1.5	6 NS 4 2	5 NS 3 2	4 NS 2 2	3 NS 1 2		5 NS 2 3	3 NS 0 3		5
4 beech	2 EB −1 3	2 SP −1 3			2 SP −3 5		5 NS 1 4	5 NS 1 4	4 NS 0 4	1 OA 0 1	4 NS 3 1	4 NS 3 1	4 NS 3 1	6 NS 5 1	6 NS 5 1	6 NS 4.5 1.5	6 NS 4 2	5 NS 3 2	4 NS 2 2	1 SP −1 2		5 NS 2 3	5 NS 2 3		
3 oak-beech	2 EB −1 3	2 EB −2 4			2 SP −3 5	1 EB −4 5	4 NS 0 4	4 NS 0 4	4 NS 0 4	1 OA 0 1	4 EB 3 1	4 EB 3 1	4 NS 3 1	6 NS 5 1	6 NS 5 1	5 NS 3.5 1.5	6 NS 4 2	5 OA 3 2				5 NS 2 3		3 AL 0 3	6 NS 3
2 beech-oak	2 OA −1 3	1 OA −3 4		2 OA −3 5			3 OA −1 4		1 OA −3 4	1 SP 0 1	1 OA 0 1	1 OA 0 1	2 SP 1 1	4 OA 3 1	5 OA 4 1	3 OA 1.5 1.5	3 OA 1.5 1.5	4 OA 2.5 1.5	2 SP 0 2	1 SP −1 2				6 OA 4 2	
1 oak		1 SP −3 4	2 OA −3 5	1 OA −4 5		2 OA −3 5	1 OA −3 4		1 OA −3 4	2 SP 1 1	1 OA 0 1	1 OA 0 1	3 OA 2 1	3 OA 2 1	2 OA 1 1	3 OA 1.5 1.5	3 OA 1.5 1.5	4 OA 2.5 1.5	2 SP 0 2	1 SP −1 2				5 OA 3 2	5 OA 3 2
0 pine		2 SP −2 4	1 SP −4 5	1 SP −4 5				2 SP −2 4	1 SP 0 1	1 SP 0 1							3 SP 1 2	3 SP 1 2	1 SP−1 2	3 SP −0.5 3.5	3 SP 0 3	1 SP −4 5			

Explanatory notes: NS – Norway spruce, SP – Scots pine, OA – oak, EB – European beech, LA – larch, FI – fir, AL – alder, MI - Managment Intensity

A detailed definition of production potential based on all available data and legislation is the key output of our analysis. In relation to the production potential analysis we will also be able to particularize parameters of management intensity.

4. Conclusion

Economy of forest natural resources exploitation has a long tradition in Europe. The concept of sustainable management of forestry was articulated as early as at the beginning of XVIII century (Carlowitz 1713). The origin and development of this economic approach was documented by numerous authors. Nobel-winning economist P. A. Samuelson (1972) formulated the model of optimal sustainable forest natural resources exploitation (Holécy & Halaj 2015). EU administration supports sustainable forest management in resolutions signed at conferences on European forests protection, e.g.:

- Ministerial conference on the protection of forests in Europe (Lisbon 1998) – Resolution L2 Pan-European Criteria, Indicators and PEOLG for Sustainable Forest Management,
- Ministerial conference on the protection of forests in Europe (Vienna 2003) – Resolution V2 Enhancing Economic Viability of Sustainable Forest Management in Europe.

Our article presents a possible approach to the discussed issue – in the framework of the cited project "Differentiation of the Management Intensities and Methods to Ensure Forest Biodiversity and Economic Sustainability of Forestry". The authors ground their approach on essential natural characteristics of forests and conclude that GFHT is the only suitable unit for spatial valuation, Typological units allow us to quantify ecological limits and economic parameters of managements and compare alternative management systems.

The methodology of the concept respects Czech legislation on forest management, esp. Forest Act No. 289/1995 and Regulations No. 83/1996 and 84/1996.

The project reflects overall efficiency of investments in relation to the operational target and the whole set of management measures – from establishing the stand to its regeneration. Careful differentiation of site conditions and appropriate management is usually sufficient for cutting the budget while not limiting the management target nor changing the ecosystem condition to an extent preventing us to increase management intensity in relation to target production, if need be. Therefore, cost-saving measures include limiting unnecessary input costs, i.e. supporting lower management intensity and leaving enough space for self-regulation within natural processes. Considering the fact that all calculations are closely related to expert findings in forest typology, appropriate management measures and their economic impact analyses, our methodology can be presented as a complex biological-ecological-economic analysis of sustainable, site-befitting forest management.

- Apart from the above-mentioned outputs of the project – esp. for forest owners – the results can also be used for:
- expressing framework economic characteristics in regional forest development plans (RFDP) and other materials of forest management,
- evaluating efficiency of money input from public budgets (subsidies and benefits for forest management),
- applying environmental accountancy in forest management.

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ORIGINAL PAPER

Wood quality and value production in mixed fir-spruce-beech stands: long-term research in the Western Carpathians

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Abstract
Stem quality and damage was evaluated in mixed spruce-fir-beech stands. Moreover, an assortments structure was determined with their financial value. Results were compared with pure spruce (*Picea abies* [L.] Karst.), fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.) stands. Repeated measurements on 31 long-term research plots, stand assortment models, assortment yield models and value yield models were used. Stem quality of fir and spruce was only slightly lower in mixed stands compared to pure stands but beech stem quality was considerably worse in mixed stands. Fir and spruce had slightly lower proportions of better IIIA quality logs and higher proportions of IIIB quality in mixed stands. Beech had worse assortment structure than spruce and fir, in general. Pure beech stands had higher proportions of better I–IIIA quality assortments than mixed stands by 1–7%. Fir and spruce average value production (€ m^{-3}) culminated at about 56 and 62 cm mean diameters. Almost the same value production was found in pure stands. In these stands it culminated at the mean diameter of 58 and 60 cm. Beech produced substantially less value on the same sites. In mixed stands, its value production culminated at the mean diameter of 40 cm. In pure stands, it culminated at the mean diameter of 36 cm. Although the production was found to be similar in both mixed and pure forests, higher damage intensity and less stem quality in mixed forests suggest that the pure forests can be more profitable.

Key words: silver fir; Norway spruce; European beech; mixed stands; assortments production

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1. Introduction

Mixed stands are usually expected to have higher production, which has repeatedly been proven (Pretzsch 2009; Forrester 2014). Mixed stands can be more productive than pure stands, however this depends on the site conditions, stand age and how the species interact.

A lot of mixed-stand studies quantify growth or yield of individual tree species by height or diameter growth (Künstle 1962; Monserud & Sterba 1996; Knoke et al. 2008; Petráš et al. 2014a), as well as by their production volume and increments (Kennel 1966; Prudič 1971; Míchal 1969; Hink 1972; Pretzsch 1992; Pretzsch & Schütze 2009; Lebourgeois et al. 2014; Petráš et al. 2014b). For Central Europe, these were mainly based on measurements on simultaneous plots in pure or mixed parts of the stand, and only few studies were based on long-term research plots in mixed stands. In the search for the causes of different growth and production in mixed stands, most authors focus on site, climate, tree species composition, the type of mixture and the stand age (Magin 1954; Kennel 1965, 1966; Hausser & Troeger 1967; Mitscherlich 1967; Hink 1972; Mettin 1985; Kramer et al. 1988; Pretzsch 2009; Pretzsch et al. 2010). Few authors provide detailed evaluation of the quality and value of wood produced in either pure forests (Karaszewski et al. 2013; Michalec et al. 2013) or mixed stands (Hausser & Troeger 1967; Kramer et al. 1988; Saha et al. 2012, 2014), and most of the above-mentioned authors agree that mixed stands have many advantages over pure stands, because the former more readily resist damage and have positive effects on soil properties. Mixed stands better utilize both above-ground and below-ground parts, especially when the tree species have different biological properties and requirements for light, water and nutrient availability. These factors explain why higher wood production is expected in mixed stands than in pure on some sites.

Knowledge on wood quality especially that of mixed-species stands, are essential for decision making in forestry. There is not only financial interest, but also in carbon management such as different wood products store carbon for different time periods. There is, however, a lack of knowledge on wood quality and value in mixed forests (Saha et al. 2012, 2014; Štefančík & Bošeľa 2014). Therefore, our aim is to fill the knowledge gap and go beyond the traditional quantitative production research by assessing assortment structure of mixed forests in Central Europe. We quantify differences in wood quality and financial yield between mono-specific and mixed-species forests. We also present an integrated methodological concept based on long-term experimental data and integrated models of wood quality and yield production.

The study particularly aims (i) to evaluate stem quality and damage in mixed forests in the Western Carpathians; (ii) to determine their assortment structures and financial value; and (iii) to compare results between mixed and single species forests of Norway spruce (*Picea abies* L. Karst), silver fir (*Abies alba* Mill.) and common beech (*Fagus sylvatica* L.)

Corresponding author. Michal Bošeľa, e-mail: ybosela@tuzvo.sk, phone: +420 5206 310 in similar growth conditions. We hypothesise that, although the quantitative production is supposed to be higher in mixed forests, species-pure forests might produce higher value production because less-quality wood is expected to be produced.

2. Material and methods

2.1 Research plots

Empirical material included repeated measurements from 31 long-term research plots (LTPs). These plots were established in the Western Carpathians (Fig. 1) in the 1960's and 1970's to study the growth and production of pure and mixed forest stands (Table 1). The plots were situated in the western and eastern parts of the Slovenské Rudohorie Mountains; the western parts in the Hriňová region and the eastern ones in the Spiš and Hnilecká dolina valley. The altitude ranged between 480 and 970 m a.s.l. The prevailing climatic-geographic subtype is a cold mountain climate, which gradually changes to mild and slightly warm mountain climate (Lapin et al. 2002). Plots were established in and represent the following forest types: beech-fir fertile forests; fir-beech forests on eutrophic to moderately oligotrophic soils; beech-fir forests with spruce on oligotrophic soils and beech-fir forests with sessile oak (*Quercus petraea* Matt.) on oligotrophic soils. The tree species mixture differed between LTP; with all three species being present on 16 LTPs; spruce with fir on 13 LTPs; and fir with beech and spruce with beech each on one LTP. Fir had the highest proportion on the LTPs, followed by spruce, and then beech. Stand age at the time of LTP establishment varied from 32 to 159 years. All research plots were repeatedly measured and tended with negative thinning from below; most often at regular 5-year intervals. The same thinning method was applied in all the LTPs; both established in mixed and pure forests. The majority of the plots were measured four to eight times. The rectangle-shaped LTP area ranged from 0.2 to 1 ha, with all trees numbered and the place of diameter measurement marked. The height of all trees in the plots was only measured at the first and last measurements, while a sample of trees were selected for height measurement throughout the entire period. These sample trees were selected from the entire DBH range to enable developing the height-diameter model. The model was then used to estimate the height of the all remaining trees.

2.2. Assessment of stem quality and damage

Using the Kraft classification system (Kraft, 1884) (predominant, dominant, co-dominant, intermediate, suppressed/overtopped), trees were classified into 1–5 tree classes, and their stem quality and damage were assessed. Stem quality was determined in the following three classes at each inventory prior to 1990: (1) best quality stems, straight and without technical defects; (2) average-quality stems with small technical defects and (3) lowest quality stems with large technical defects. This grading had been applied without consideration of the timber end-use, and more appropriate stem-quality classification was introduced in 1991 as new assortment models were developed in Slovakia (Petráš & Nociar 1991). Stems were then categorized in A (High quality stems, almost without knots (only healthy knots under 1 cm in diameter at the base), twisting (spiral growing), and without other technical defects.), B (Average quality stems, with small technical defects. In the case of hardwood species all of the healthy or unhealthy knots with diameters under 4 cm are allowed. For spruce and fir healthy or unhealthy knots under 4 cm and for

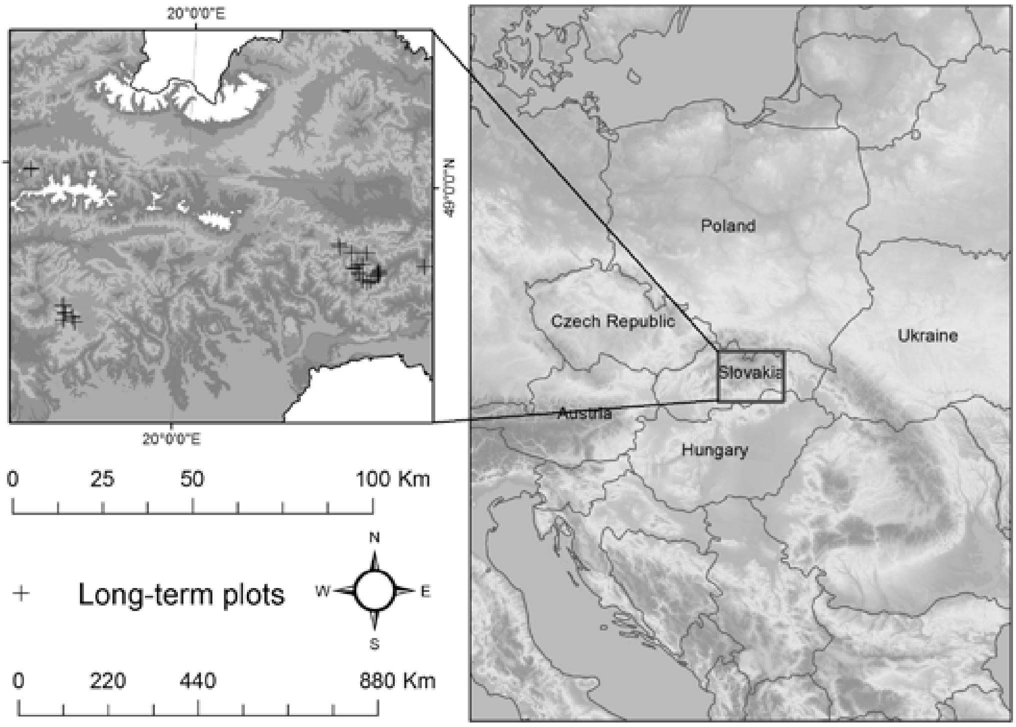

Fig. 1. Location of study sites in the Western Carpathians.

Table 1. Basic information on surveyed LTPs: t_0 is the age at plot establishment, t_n is the age at last measurement and *G* denotes stand basal area.

LTP	Area [ha]	Altitude [m]	Proportion [% of G]			Site index [1 m]			Age	
			fir	spruce	beech	fir	spruce	beech	t_0	t_n
15	0.40	480	81.5	6.3	12.2	31	32	27	65	108
44	0.36	760	68.3	4.2	27.5	30	28	30	77	120
45	0.49	730	65.1	16.6	18.3	35	36	30	82	123
46	0.49	560	94.1	5.9		29	29		104	145
47	0.48	650	84.0	10.7	5.3	30	32	21	94	135
50	1.00	724	69.2		30.8	27		23	159	202
51	0.30	588	92.3	7.7		31	33		47	88
52	0.43	775	81.7	9.5	8.8	22	23	16	141	185
53	0.66	865	82.9	17.1		30	32		110	152
54	0.28	740	77.4	22.6		31	31		52	93
56	0.49	968	92.4	7.6		29	31		121	162
60	0.44	885	12.5	87.5		33	33		73	114
61	0.65	890	7.2	89.3	3.5	32	33	29	83	124
63	1.00	686	63.8	31.3	4.9	26	26	19	140	184
79	0.24	600	89.6	10.4		31	32		53	96
80	0.42	900	66.5	23.7	9.8	29	30	24	74	114
81	0.40	640	91.1	8.9		31	31		47	88
82	0.30	690	84.8	15.2		35	37		32	73
83	0.20	790	94.4	5.6		30	37		36	79
89	0.23	630	83.6	16.4		29	33		40	80
91	0.67	700	64.5	15.1	20.4	31	32	27	88	124
93	0.56	560	40.1	9.2	50.7	27	26	25	80	122
94	0.64	770	33.0	47.8	19.2	29	32	29	81	111
107	1.00	717	83.4	7.8	8.8	34	38	17	142	181
110	0.81	820	90.7	9.3		34	35		140	166
111	0.49	670		70.0	30.0		38	32	69	110
112	1.00	839	18.0	36.8	45.2	37	39	28	95	134
114	0.96	770	61.0	5.7	33.3	36	39	27	103	144
115	0.60	818	9.9	69.5	20.6	38	38	27	89	115
118	0.35	705	45.3	52.2	2.5	34	34	14	99	125
119	0.54	705	31.5	68.5		36	39		95	136

Note: *G* – stand basal area, t_0 – age at establishment, t_n – age at the last measurement.

Scots pine less than 6 cm are allowed.), C (Low quality stems with large technical defects, with high frequency of branches (densely branched trees), twisting up to 4% of straight length axis. Healthy knots without limit for the size (diameter) are allowed, unhealthy knots up to a diameter of 6 cm in the case of softwood species, and up to 8 cm for hardwood species.) and D (Poor quality stems with unhealthy knots over 6 cm for softwood species and over 8 cm for hardwood species, which are also affected by rot. The stems are only utilized as fuelwood.) classes, dependent on quality assessment of their lower third portion. For this study, the new classification was only used in order not to affect results and interpretations.

Damaged stems (visually assessed on standing trees) significantly predict inside-wood defects such as rot, and the red heart often found in beech trees. Therefore buttress and surface roots were evaluated in addition to surface stem damage; with damage presence only recorded, disregarding its size, intensity and position.

The proportions of A–D classes and damaged stems were calculated for each inventory after 1990; with average percentages and standard deviations determined for each tree species. The same variables were calculated for pure fir, spruce and beech stands by assortment yield models (Petráš & Mecko 1995; Petráš et al. 1996). The proportion of the *A–D* stem quality classes is a function of *q* site index (Equation 1). Here, site index is the mean stand height at 100 years standard age, derived from height growth models developed for Slovakian yield models (Halaj & Petráš 1998). The proportion of damaged stems, *p%*, is a function of stand age *t*.

$$A, B, C, D\% = f(q) \quad [1] \qquad p\% = f(t) \quad [2]$$

As follows from the models the stands with higher site index produce a higher proportion of better quality stems, and the proportion of damaged stems increases with the stand age.

2.3. Estimation of assortment structure

Assortment structure was estimated for each LTP and tree species using stand assortment models (Petráš & Nociar 1991; Petráš 1992). These models provide assortment proportions *S%* for each tree species as a function of the following factors: mean diameter d_v; proportion of stem quality classes *kv%*; proportion of damaged stems *p%;* and for beech trees also as a function of stand age *t*.

$$S\% = f(dv, kv\%, p\%, t) \quad [3]$$

Individual assortments represent log classes based on log quality and diameter. The proportion of the following classes results from Equation 3:

Class	*End-use*
I	cut veneer, special sports and technical equipment,
II	plywood, matches and sports equipment,
III(A, B)	saw logs (better quality – IIIA, worse quality – IIIB), building timber and sleepers,
V	pulpwood, chemical and mechanical processing for cellulose and wood-based panels production,
VI	fuel-wood.

I–IIIB classes are split into 1–6+ diameter classes in the stand assortment model.

The assortment structure of fir, spruce and beech single species stands was derived from assortment yield models (Petráš & Mecko 1995; Petráš et al. 1996), where assortment proportions $S\%$ is a function of stand age t and site index q.

2.4. Defining the assortments value

Assortment value was calculated as the product of assortments volume and wood prices for each log quality and diameter class (Fig. 2). Wood prices were taken from the price list published by Slovak state forest enterprise in 2013.

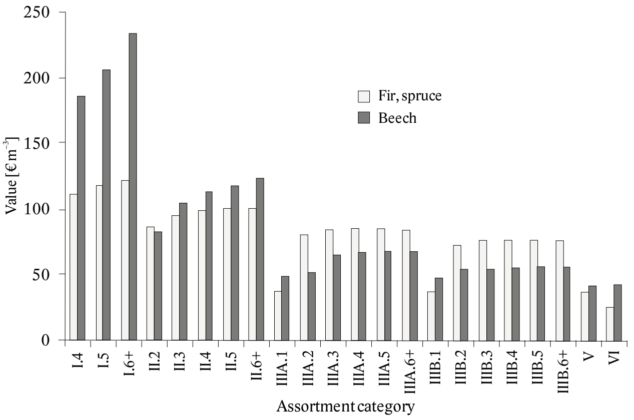

Fig. 2. Wood prices (€ m^{-3}) by I–VI qualitative classes, and by 1–6+ diameter classes of fir, spruce and beech.

Structure and production value were calculated in the following two variants to evaluate the mixed stand production. These variants were chosen with regard to input data source for each variant:

Variant	*Source of input data (stem quality and damage, mean diameter)*
1	All input data emanates from LTP measurements.
2	All input data comes from the models developed for pure stands.

3. Results

3.1. Stem quality and damage

The proportions of stem quality classes on LTPs in mixed stands indicate that B class dominates in fir and spruce with 62 to 66% (Fig. 3). The beech stem quality decreased during the study period and the highest proportion of approximately 57% was found in class C. This percentage was higher than both the average quality B class and the highest quality A class. In addition, the 2% of poor quality D class increased overall worst quality of beech in the mixed stands. Standard deviations suggested that fir had the lowest between-plot variability in the all quality classes, followed by spruce, with the highest variability in beech. The coefficients of variation for their most represented B class were 11% for fir and 26% for spruce, with 30% for C class beech.

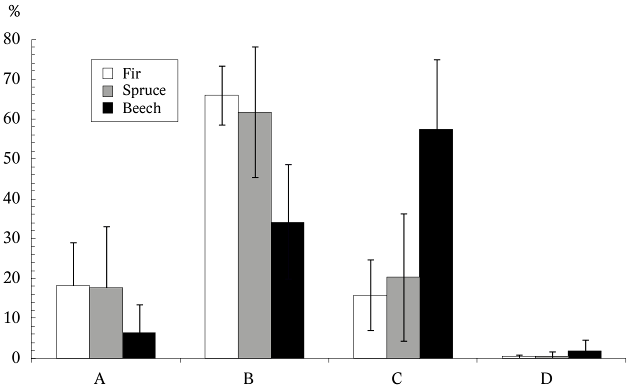

Fig. 3. Proportion of A–D stem quality classes by tree species in mixed stands. The whiskers denots 95% confidence intervals.

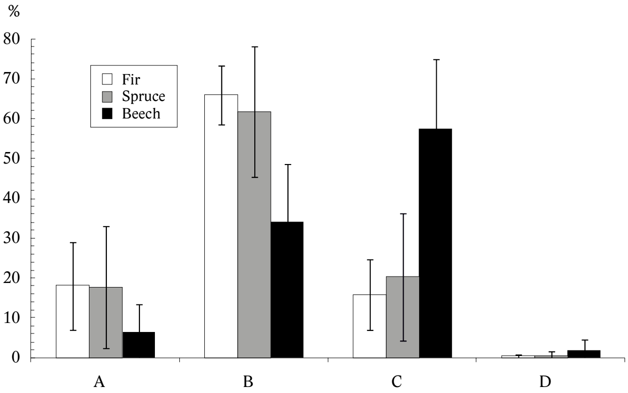

Fig. 4. Differences in A-D stem quality classes between mixed and pure stands.

In comparison to the quality of pure stands growing on the same sites (Fig. 4), fir and spruce had higher proportions of both best A stem quality class by 4–5% and C class by 9–13%. In contrast, the proportion of average B quality class was lower by 14–17%. In addition, beech had 24% less best A quality class stems in mixed than pure stands as well as 13% less B class quality. This 37% sum leaves higher proportions of poor quality C class stems. We can clearly conclude that conifers in mixed stands produced more stems of both best and worst quality than pure stands, and the average-quality stems diminished. In contrast, the opposite was found for beech. Beech mixed with fir and spruce had a lower proportion of average quality stems by 13%, but the proportion of the best quality stems was even 24% lower compared to pure beech forests.

Stem damage (e.g. after logging, debarking by a deer species, etc.) substantially reduces the wood quality. The proportion of damaged stems was between 49 and 53% for all the LTPs and all the tree species (Fig. 5). In the pure stands (as simulated by the models) the proportions were different. Spruce had the highest proportion of damaged stems (61%), followed by fir (46%) and beech (23%).

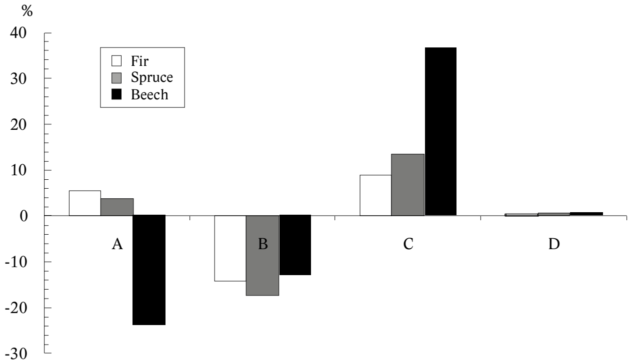

Fig. 5. Damaged stem proportions in mixed and pure stands.

3.2. Assortment structure

Fir and spruce exhibited very similar assortment structure, where IIIA and IIIB saw-log classes prevailed with 30–50% (Fig. 6). These were followed by pulpwood assortments in V class with 10–15% and the most valuable assortments of I and II class with 3–5% and then fuel-wood amounting approximately to 1%. Differences in assortment structure between the variants were far smaller. For both species, the proportions of the highest quality assortments (I and II) in mixed forests (1st variant) were only a few tenths of percent higher than in pure stands (2nd variant). Saw logs, however, had contrasting proportions. Mixed stands had a slightly lower proportion of IIIA assortment and higher proportion of worse quality IIIB assortment than pure stands.

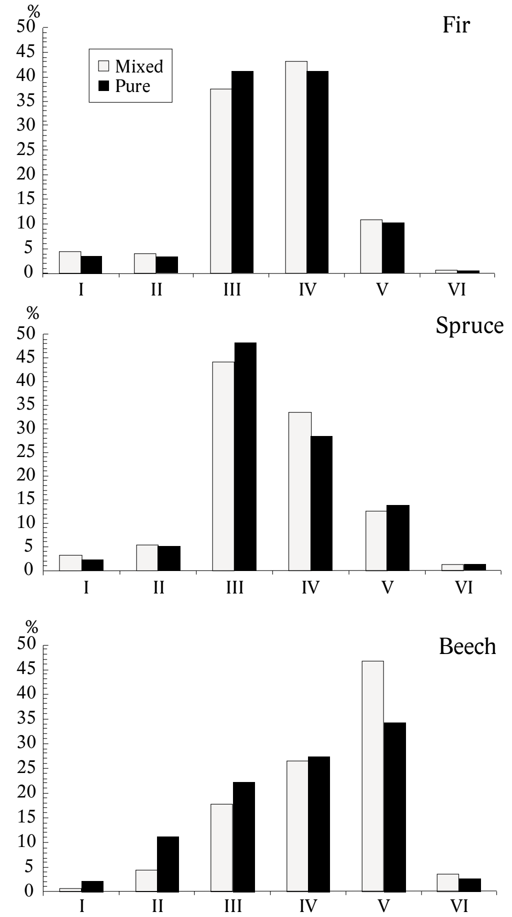

Fig. 6. Volume proportions of I–VI quality class logs in mixed and pure fir, spruce and beech stands.

The assortment structure of beech was worse than that of both spruce and fir. While timber volumes increased steadily between I and V assortment category, pure stands had simultaneously higher proportions of better quality assortments (I–IIIA category) than mixed stands by approximately 1–7%, but this situation was reversed for lower quality IIIB–VI classes.

3.3. Assortment and value production

Value of assortment and timber production is additionally influenced by actual prices. We found that the proportions of the assortments of I–IIIA class calculated from the prices (Fig. 7) were higher than the proportions derived from their volumes (Fig. 6). Fir was found to have a higher proportion by 1–3%, spruce by 2–5% and beech by 2–8%. In contrast, lower proportions were found for IIIB–VI assortment classes; fir by 1–5%, spruce by 1–7% and beech by 1–10%.

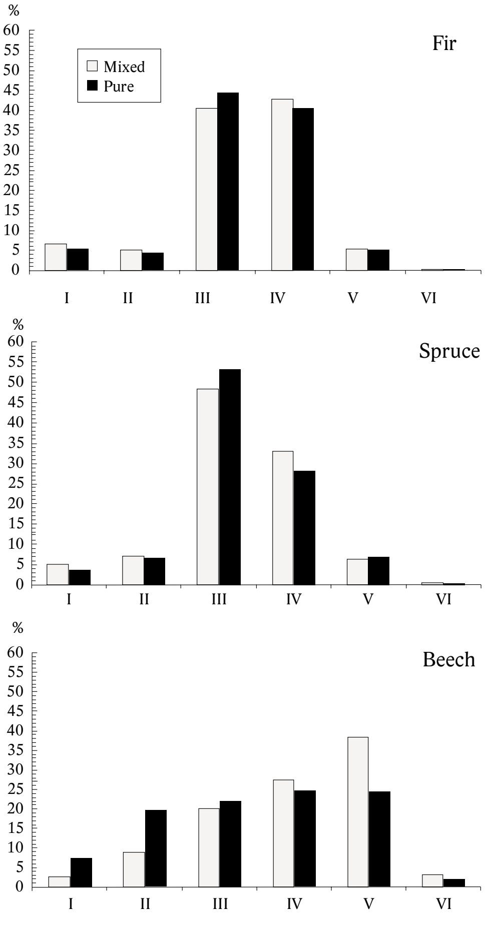

Fig. 7. Value proportions of I–VI quality classes logs in mixed and pure fir, spruce and beech stands.

The value of wood production in mixed forests is not only influenced by assortment structure and prices, but also by the different timber volume of individual tree species. The average production value (€ m^{-3}) was calculated for each tree species and each variant to compare tree species production (Fig. 8, 9), and these were assessed as a function of mean diameter and site index. The value production pattern of fir and spruce followed a very similar course and culminated at

56 and 62 cm in mixed stands, at approximately 79 € m^{-3}. Simulations by the Slovakian yield models showed almost the same production in pure stands, where it culminated at mean diameters of 58 and 60 cm with approximately 79 and 78 € m^{-3}. In contrast, beech produced significantly less on the same site index; where mixed stand production culminated at 40 cm mean diameter and just below 54 € m^{-3}. It culminated earlier in pure stands at 36 cm mean diameter and by 10 € m^{-3} higher value.

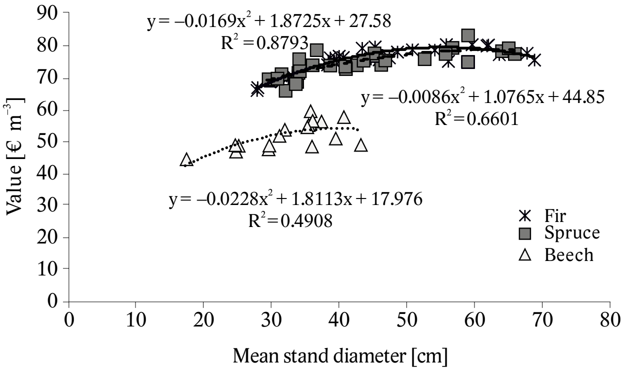

Fig. 8. Average value of fir, spruce and beech wood (€ m^{-3}) produced in mixed stands.

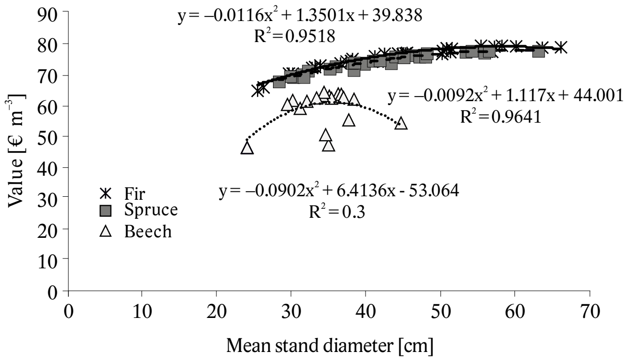

Fig. 9. Average value of fir, spruce and beech timber (€ m^{-3}) produced in pure stands.

4. Discussion

Spruce, fir and beech are ecologically and economically the most important tree species in the Western Carpathians and these naturally form both pure and mixed stands.

Our results indicated slightly worse stem quality in mixed forests for all the species. Wiedemann (1951) suggested this was due to vertical and horizontal structure of mixed forests where less dense crown canopy enables longer survival and consequent branch roughening than in pure stands with their more concentrated single-layer canopy. Furthermore, strong heliotropism negatively influences beech lengthwise and crosswise shape and also its spiral grain (Krammer et al. 1988; Pretzsch & Schütze 2009). Mechanical stem damage introduces a secondary factor; caused mainly by inappropriate technology in logging and by red deer bark-stripping and peeling. Beech stems generally have harder wood, but stem damage increases the probability of red heart (Petráš 1996a, b). Although overall stem damage was higher in pure stands, our results highlight that fir and especially beech suffered less damage in pure than in the mixed stands compared to spruce which had a higher damage in pure forests. This was probably because bark of spruce is one of the natural food sources in winter (Fiňdo & Petráš 2011).

Stem quality and damage is reflected in assortment structure. Fir and spruce had very similar assortment proportions in both mixed and pure stands. Thicker stem branches in mixed stands led to a slightly lower proportion of higher quality IIIA class logs and a higher proportion of IIIB. However, beech reached essentially lower timber quality in mixed forests. Wiedemann (1951) and Krammer et al. (1988) also suggested that beech usually has higher potential for best quality assortment in pure stands than in mixed. For this reason, Wiedemann (1951) and Prudič (1971) suggested that maximum beech proportion in mixed stands is usually limited to 20–30%.

Financial values comprehensively reflected the production capabilities of these stands. Our results confirmed that fir and spruce are the major value producers in mixed stands, with beech significantly lagging in this respect (Wiedemann 1951; Prudič 1971) and also performing worse in pure stands. Hauser & Troeger (1967) reported that fir produces 9% greater value than spruce in mixed spruce-fir stands because of their greater diameter. Here, it is important to realize that assortment tables do not consider stem quality and damage; these rely solely on dimensions for production value calculation.

5. Conclusions

This study suggested that conifers had only slightly worse stem quality in mixed than pure stands. However, beech had considerably lower stem quality in mixed forests. While the proportion of damaged stems in mixed stands was high for all the tree species, fir and especially beech stems experienced less damage in pure stands. Spruce trees, in contrast, suffered higher damage in pure stands In mixed forests, beech was found to have overall worse assortment structure than spruce and fir.

This study suggested that wood quality and assortment structure was considerably lower in mixed forests only for beech, while almost no differences were found for conifers. This thus encourage forestry practice to prefer mixed-species forests, especially when static stability and resistance to climate change should be taken into account.

Acknowledgements

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ORIGINAL PAPER

Perceptions of natural disturbance in Tatra National Park, Poland

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Abstract

Since the last decades, natural disturbances in forests including protected areas have intensified. They have the potential to impact visual quality and safety of visitors as well as spread beyond protected area boundaries. While economic and ecological impacts are well studied, there is still a lack of work focused on human dimensions and social aspects. This study examines visitor perceptions towards bark beetle infestation in Tatra National Park, Poland. The findings, based on visitor surveys collected during the summer of 2014, indicate the significance of different factors influencing visitor attitudes towards the bark beetle. Age of visitors and importance of the bark beetle issue for them (based on subjective ratings of importance of bark beetle issue for respondents) are the most prominent variables. Also place of origin and environmental worldview were recognized as significantly important variables in accordance with similar studies. Results suggest management implications for park authorities including public relations and environmental education in order to increase knowledge and support for natural disturbance and ecological integrity policies in the national park.

Key words: visitor perception; protected areas; human dimensions; bark beetle; forest

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1. Introduction

The shift to an ecosystem management framework during the last decades has also brought a paradigm shift in perception of the role of ecological disturbance in natural resources management, so that they are now seen not as negative events but as more value-neutral from an ecological point of view (being part of healthy and dynamic ecosystems). On the other hand, from a human dimensions standpoint, they are rarely seen as value-neutral events (conflicts on political and societal levels). While ecological and biophysical parameters of forest disturbances by insects are relatively well studied, human dimensions (societal impacts and implications) are still neglected (Flint et al. 2009).

Natural disturbances (abiotic or biotic) are fundamental to the development of structure and function of forest ecosystems (Attiwill 1994). However, forest disturbance regimes may heavily affect forest functions as well as forest management (Seidl et al. 2008). Damage from natural disturbances in European forests seems to be increasing in the future (Schelhaas et al. 2003). Windstorms are among the most severe disturbances that affect mountain forests in central Europe, including the High Tatras Mountains (Zielonka & Malcher 2009; Mezei et al. 2014). Many authors have analyzed the frequency and severity of disturbances and their effects on tree recruitment (Szewczyk et al. 2011) including different management strategies. Forest insect infestations, usually followed by windstorms, are considered one of the most pervasive and important agents of disturbances in forests. All aspects of insect outbreak behavior will intensify as the climate warms (Logan et al. 2003). Some studies are focused on particular agents; Wermelinger (2004), for example, summarizes the ecology and management of the spruce bark beetle (*Ips typographus* (Linnaeus, 1758)) in forests. Ecological disturbances of forests by insects have a complex array of associated human dimensions presenting complications for natural resource decision-making. As examples we can mention visual-quality impacts at the landscape level (Sheppard & Picard 2006), increased fire hazard and potential fire behavior (Jenkins et al. 2008) or relationships between stakeholders and managers (Flint et al. 2009).

Visitors represent an important stakeholder in the management of natural disturbances in protected areas (Müller & Job 2009). A primary objective of category II protected areas (national parks) is to protect natural biodiversity and to promote education and recreation. Extractive use is not considered consistent with this objective (Dudley 2008). This means that they are mandated to protect ecosystems from human interference and make them accessible for recreational activities (Müller et al. 2008). Areas designated as core zones prohibit any management intervention in natural forest dynamics. The goal of the present study is to identify what visitor attitudes towards bark beetle infestation and management are. Park administration can use the obtained results as contribution for development of management strategies which might be applied in Tatra National Park.

2. Study area and methodology

Tatra National Park, founded in 1955, is located in the southern part of Poland along the Slovakia border (Fig. 1).

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The area is also designated as a UNESCO biosphere reserve and, along with the Slovak side, an EU Natura 2000 site. The national park comprises an area of 21 197 hectares of which 82% is publicly owned land. Forest ecosystems account for 72% of the area of which about 58% is natural or semi-natural forests. The core zone of the park makes up about 60% of the total land area, the other parts include a buffer and a transition zone. While 92% of the forest area now consists of spruce (*Picea abies* L.), silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.) are expected to increase to 20% and 13%, respectively, resulting in a decrease in spruce areas, according to forest management plans (this will be a result of forestry; natural processes would take a much longer time to change tree composition). The national park is an important tourist attraction for the region; current annual ticket purchases by accessing the park number about 3 million. The national park administration implements and monitors visitor management policy – e.g. restriction of access to certain areas (Getzner 2010).

An intensive bark beetle (mainly *Ips typographus*, rarely also *Ips cembrae* (Heer, 1836)) outbreak occurred between 1993 and 1998 and again between 2009 and 2013 in the Tatra Mountains of Slovakia and Poland. In Poland, the outbreak was primarily located in reserve areas where pest management or other activities were prohibited. The size of affected areas with dead stands increased from 180 ha in 2009 to 590 ha in 2012. Glades (clearings covered by deadwood or without trees) increased in same time from 50 ha to 70 ha and new growth (regrowth or young generation) from 10 to 30 ha. The biggest augmentation in above mentioned categories of affected areas in forest were registered in 2013 in Gąsienicowa Valley.

Fig. 1. Location of the park in central Europe and position of study area in the network of national parks in Poland © Tatra National Park, Poland.

To understand visitor perceptions, face to face on-site interviews were carried out by park volunteers during two weeks in the summer of 2014 (25.08.–07.09.2014). Respondents were enquired on Morskie Oko road which is the highest visited area in the park with 12 500 visitors per day during vacation. The research design chosen replicated a similar survey conducted in Germany (Bavarian Forest National Park). Independent variables were hypothesized as predictors for tourist attitude towards the bark beetle (see Müller & Job 2009) and 511 valid questionnaires were collected (79 refused). With recent visitation obtained sample size was sufficient to reach a confidence level with interval of 95±5%[1]. Data were collected in software IBM SPSS 19 and analyzed with multivariate linear regression model.

3. Results

Demographic characteristics of visitors are ranked by frequency of cases – 51.8% of respondents were male, the average age was 34.48 years and 49% of the individuals sampled had a university degree. Respondents visited the study area an average 5.67 times, and they were predominantly from Poland (98.8%) and most (47.8%) live in a major city – see Table 1.

Table 1. Demographics of respondents and characteristics of visit used in survey.

Gender	
Female	48.2%
Male	51.8%
Age (mean)	34.48 years
Highest level of education	
Primary / Elementary school	1.6%
Secondary school	46.1%
University degree	49.0%
Other	3.3%
Number of visits in TPN (mean)	5.67
Country of visitors	
Poland	98.8%
Others (A, D, GB, SK)	1.2%
Origin of visitors	
Major city	47.8%
Provincial town	30.5%
Countryside	21.7%

Participants stayed an average of 3.23 nights in the region of the national park. Visitors could choose multiple options and named taking walks and hiking (79%), relaxation and spending time with family (25%), and enjoying nature (20%) as their primary motivations for their field trips to Tatra National Park. 62.7% of respondents stated that their expectations were fulfilled completely. A majority of respondents (87%) were impressed the most by landscape and nature, only a negligible percentage (9%) demonstrated an awareness of forest dieback and dead standing trees. 91.6% of visitors expressed their intention to spend their holidays in the park again.

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[1] http://www.surveysystem.com/sscalc.htm

We also tested the environmental worldview of visitors based on New Ecological Paradigm statements which describe the relationship between man and nature (as one of the predictors of later visitor attitudes towards bark beetle – see Müller & Job 2009). Respondents were asked to agree or disagree on a 5-point scale (5 = "fully agree" to 1 = "completely reject"). Generally we can see quite pro-ecological / positive attitudes – especially with the statement that ecological balance is very delicate and can be easily disrupted (4.40 points) – see Table 2. For most visitors, the existence of a national park influenced their decision to visit this region (very much – 28.3% and much – 24.9%).

Table 2. Descriptive statistics of statements describing relationship between man and nature based on New Ecological Paradigm statements (for comparison see Müller & Job 2009). "Respondents were asked to agree or disagree on a 5-point scale (5 = "fully agree" to 1 = "completely reject")".

Evaluative items	Min.	Max.	Mean	Std. Deviation
earth has enough natural resources, use them wisely	1	5	4.20	0.880
environment for satisfying demands of mankind	1	5	3.02	1.063
ecological balance is delicate and can be disrupted	1	5	4.40	0.741
human talent will make earth to be inhabitable	1	5	3.41	1.056
mankind overuses currently natural resources	1	5	4.09	0.960

The next part of the survey focused on natural disturbance in the forests. Nearly one third of respondents (30.3%) recognized dead trees during their walks and hikes in the national park. Further, 85.7% of visitors know that there are dead trees on a large scale in the national park area. As a source of information about dead trees, visitors responded that they saw them in the area for themselves (73%) and only a small part chose another option (e.g. TV – 9%). Respondents stated the reason for the large scale forest decline as bark beetle (26.2%), air or environmental pollution (20.2%), or natural reasons (18%). However, only a very limited number of respondents in the next question assessed their personal knowledge about bark beetles and their impact on the national park as good (5.2%) or very good (1.6%). When visitors were asked how important the bark beetle issue is in a national park for them personally according to a scale from 5 (very important) to 1 (completely insignificant), 41% of them selected option 4 (important).

In the final part of the survey, visitors were asked again to agree or disagree along a 5-point scale (1 = "strongly disagree" to 5 = "strongly agree") on their statements about the bark beetle in a national park. The first four statements (Table 3) described positive roles of the bark beetle for the forest. Generally we can see medium (neutral) preferences in the case of the statement that bark beetle should have a right to exist in a national park, positive preference was stated (3.64 points). The other four statements (Table 3) describing negative roles of the bark beetle for the forest were inverted (1 = "strongly agree" to 5 = "strongly disagree"). Again, we can see medium preferences but they mostly confirmed the statement that the bark beetle is a threat to biodiversity (2.50 points). 74.3% of respondents trust that areas of dead standing trees will develop in the future as young-growth forest after regeneration and natural rejuvenation.

Table 3. Descriptive statistics of statements describing positive (attd 1, 3, 5, 8) and negative (attd 2, 4, 6, 7) roles of bark beetle for forest along a 5-point scale (1="strongly disagree" to 5="strongly agree" resp. inverted for negative roles) (for comparison see Müller & Job 2009).

The bark beetle...	Min.	Max.	Mean	SD
...helps ensure that forests are healthy (attd 1)	1	5	2.49	1.045
...is important in rejuvenating the forest (attd 3)	1	5	2.95	1.082
...should have a right to exist in the park (attd 5)	1	5	3.64	1.004
...is more beneficial than harmful for the forest in the park (attd 8)	1	5	2.63	0.958
...is a threat to biodiversity in the park (attd 2)	1	5	2.50	0.997
...has a negative impact on tourism (attd 4)	1	5	3.45	1.177
...is an ecological disaster for the park (attd 6)	1	5	3.06	1.054
...should be controlled in the park (attd 7)	1	5	2.90	1.069

The arithmetic mean of eight attitudinal items was calculated using a Likert scale (Fig. 2) to evaluate the attitudes towards the bark beetle. For further analyses we used only 322 cases, those without any missing information, to analyze which predictors significantly influence visitor attitudes towards the bark beetle as dependent variable. Results demonstrate that younger respondents had better attitudes towards the bark beetle (Table 4). The importance of the bark beetle issue (based on subjective rating for respondent), place of origin (urban vs. urban rural areas) and environmental worldview are also significantly important.

Table 4. Multivariate linear regression model of mean bark beetle statements as a function of significant predictors (Adjusted R square = 0.189, n = 322).

Mean of bark beetle statements	Unstandardized Coefficients		Standardized Coefficients	t	P
Predictors	B	Std. Error	Beta		
(Constant)	3.631	0.363		10.002	0.000
Age (years)	−0.014	0.003	−0.249	−4.835	0.000
Importance of bark beetle issue	−0.192	0.042	−0.238	−4.577	0.000
Major city	0.190	0.072	0.135	2.651	0.008
Statements describing man and nature (earth and natural resources)	0.093	0.040	0.116	2.302	0.022
Activity...quietude, relaxation, winding down, spending time with family	−0.193	0.082	−0.120	−2.345	0.020
Filling of expectations	0.099	0.046	0.110	2.162	0.031
Statements describing man and nature (overuses of natural resources)	−0.077	0.037	−0.105	−2.064	0.040

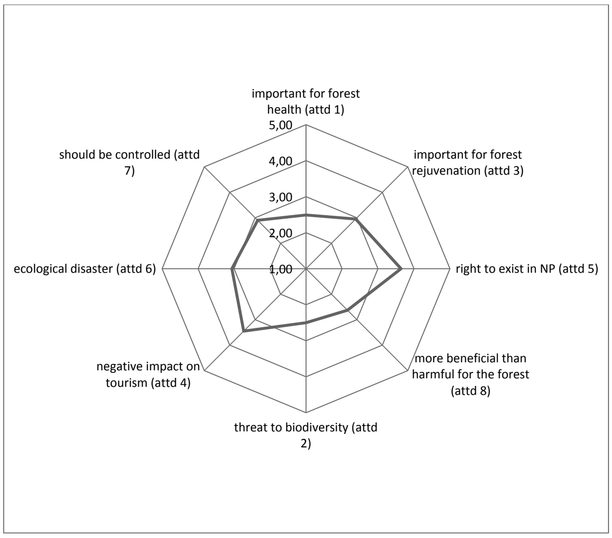

Fig. 2. The arithmetic mean of 4 positive and 4 negative attitudinal statements describing visitor attitudes towards the bark beetle in Tatra National Park on 5-point Likert scale (higher number means better attitude – see also Table 3).

4. Discussion

Existing literature (e.g. Flint et al. 2009) is underlying and focuses on agents, host trees, overall setting, and size of affected area. It is also important to understand different aspects or sectors of human dimensions of forest disturbances by insects. Economic impacts can especially be connected with commercial forestry: short-term increased forestry vs. long-term decreased timber supply. In regions oriented on tourism and recreation, effects on visitation can also be a concern (aesthetic and safety issues – e.g. falling trees). Social impact is connected mainly with aesthetic impacts (e.g. perception of dead wood – lying dead trees covered by visible green-up vs. standing dead trees), emotional response, high risk perceptions of fire, and temporal dynamic to public reaction. Management responses vary from salvage logging on commercial forest lands, preventative and fuel treatments in urban areas to no intervention in protected areas. The reaction of different stakeholders can also be very different – private landowners, local residents, tourists, and communities. The above mentioned examples of impacts and implications only underline the requirement of different strategies and good knowledge of local settings and conditions (including historical, regional and political context).

Comparing our findings with the results from the Bavarian Forest National Park (Müller et al. 2008), in general visitors in Germany exhibited a better attitude towards the bark beetle; several predictors (e.g. affinity of visitors towards the national park) were significant. On the other hand, our study confirmed the importance of age and urban residence towards attitude. Experiences from Canada (McFarlane et al. 2006) showed that proactive approaches in uninfested forests were generally not supported. Attitudes were the best predictors of support for no intervention in beetle infestations in Canada's national parks. McFarlane & Witson (2008) discovered that knowledge and residency were the most consistent predictors of risk judgments. Survey data were collected by both mail and onsite with park visitors. Visitors rated the ecological and visitor experience impacts as negative and unacceptable. Participants of the survey in Canada largely supported controlling future outbreaks with biological control (Chang et al. 2009). They generally agreed that ecologically sensitive areas and wildlife habitat were the top priorities that should be protected. Socio-demographic factors found to positively influence preferred control extent included level of knowledge, age, education, income, and work in the forest industry. Findings from Colorado (USA) suggest that respondents from lower amenity communities with more recent emphasis on resource extraction and higher tree mortality had significantly higher risk perceptions of mountain pine beetle impacts (Flint et al. 2012). Some studies from North America (Sheppard & Picard 2006) showed that informed respondents consider visual quality of affected scenes to be lower than do uninformed respondents, but this may reflect the way in which the information was delivered. Public stakeholder attitudes to pest and disease management can influence the decisions of forest managers and NGOs involved in responding (Fuller et al. 2016). Acceptance of management can also differ according to location and local context (e.g. managurement is less supported when it may impact wildlife).

Similar studies and methods used for investigation are often connected with the potential problems of the self-selection bias and of the representativeness of on-site survey. Social science research is used to support the formulation of natural resource management decisions with accurate and timely information (Czaja & Cottrell 2014). Managing protected areas requires information about the proportion of visitors attracted by the national park label and visitor attitudes towards protected area management (Arnberger et al. 2012). Changes in bio-physical and social systems due to large-scale forest disturbances have the potential to dramatically alter public participation in decision making processes (Smith 2013).

5. Conclusion

Results of this study can be used for further discussions of different economic and non-economic implications, strategies, community responses and capacities, and comparisons with similar case studies. Resource managers and decision makers should be able to respond to questions on the role of disturbances in ecosystems, how well they are accepted by visitors, what is the role of protected area settings, and how to manage natural disturbances in protected areas. We confirmed that some factors driving visitor attitudes could be influenced directly by the park management. For future research it would be advisable to test more predictors (e.g. income of visitors), develop different models to increase validity and test it for different stakeholder groups.

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ORIGNAL PAPER

Communities of tree vegetation and wood-destroying fungi in parks of the Kyiv city, Ukraine

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Abstract

Selected forestry parameters were investigated in the system of tree vegetation and wood-destroying fungi in parks of the Kyiv city along a gradient of recreational transformation. We investigated vitality, age structure and health conditions of woody plants (*Acer platanoides* L., *Aesculus hippocastanum* L., *Carpinus betulus* L., *Frangula alnus* Mill., *Pinus sylvestris* L., *Quercus robur* L., *Q. rubra* L., *Sambucus nigra* L., *Tilia cordata* Mill.), and species, systematic, trophic and spatial compositions of xylotrophic fungi (27 species of xylotrophs representing 22 genera, 16 families, 6 orders of divisions Basidiomycota; class Agaricomycetes). The results showed that the communities of tree vegetation and xylotrophic fungi in parks depend on the degree of recreational transformation of the environment. Vitality, age structure and health conditions of trees altered species composition of xylotrophs.

Key words: ecological links; parks; woody plants; xylotrophic fungi

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1. Introduction

Communities consisting of different biodiversity elements with their tight ecological links play a significant role in evolutionary ecology. In this context communities of tree vegetation and wood-destroying (xylotrophic) fungi are essential elements to study. These ecological objects represent an important basis for the modern indication and monitoring of the environment. Tree vegetation is an important element of forest ecosystems to preserve the landscape and especially biotic diversity of organisms.

Xylotrophic fungi are decomposers of organisms, and obligatory components of forest ecosystems. Wood-destroying fungi are essential functional elements of forest ecosystems, which are highly sensitive to environmental changes (Rypáček 1957; Stepanova & Mykhin 1979; Schmidt 2006; Yurchenko 2006; Terho et al. 2007; Dai et al. 2007; Schwarze 2008). In some cases, they are root and stem pathogens of trees, and hence, they negatively affect their health conditions. Numerous studies of the stated issues differ mostly in the methodological approaches and the depth of studies. The works often deal with only certain structural and functional components of forest ecosystems. They refer mostly to systematics and phytopathology of fungi. This leads to incomplete information, especially under the terms of biological objects being influenced by a complex of ecological factors of different origin, intensity and uncertainty.

The communities of tree vegetation and xylotrophic fungi as important bases for correct indication and monitoring the state of forest ecosystems, have not been sufficiently studied so far. This concerns the necessity of the complex analysis of evolutionarily established links between tree vegetation and xylotrophic fungi. The compositions of xylotrophic fungi and tree vegetation reflect artificial phytocoenoses' development and state (Blinkova & Ivanenko 2014). In urban conditions of parks, which are not durable for anthropogenic or natural reasons, the resistance of tree vegetation to negative influence is significantly diminished and in general, the attrition ofweakest plants and reformation of species composition and structures of parks increases (Terho et al. 2007; Schwarze 2008; Arefyev 2010; Glaeser & Smith 2010).

Due to the construction of park alleys, parkways, introduction of non-native crops and creation of new landscape components during the past decades, the parks in Kyiv have undergone an intensive recreational transformation, which is manifested in the break-down of structural and functional integrity of phytocoenoses' organisation. This in turn essentially affects the functioning of the communities of dominant woody species and xylotrophic fungi in urban ecosystems. It is also notable that there is no data on mycobiota of tree vegetation from the territory of the Kyiv parks. The literature survey and analyses of mycological collection of the National herbarium of Ukraine – Herbarium of M. G. Kholodny Institute of Botany NAS of Ukraine (KW-myc) showed that the investigation of wood-destroying fungi of Kyiv was localised in botanical gardens, in some objects of the nature reserve fund of Ukraine or natural landmarks. Fragmentary findings of xylotrophic fungi in artificial phytocoenoses were certified in herbarium: *Aurantiporus fissilis* (Berk. et M. A. Curtis) H. Jahn ex Ryvarden (as *Tyromyces fissilis* (Berk. et M. A. Curtis) Donk, KW 17867–17868; 1960), *Ganoderma lipsiense* (Batsch) G.F. Atk. (as *G. applanatum* (Pers.) Pat., KW 921; 1961), *Laetiporus sulphureus* (Bull.) Murrill (KW 17618, KW 17620; 1965, 1971), *Polyporus squamosus* (Huds.) Fr. (KW 18103; 1972) and *Trametes hirsuta* (Wulfen) Lloyd (KW 6; 1957).

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The hypothesis of our study is that the species, trophic, systematic and spatial compositions of xylotrophic fungi are closely associated with vitality, age structure and healths condition of stands in the Kyiv parks. The paper aim is to describe communities of tree vegetation and wood-destroying fungi of parks in urban conditions in relation to the level of recreational transformation of the environment.

2. Materials

2.1. Study site

The parks in the urban conditions of Kyiv were selected for the analyses since human impact is maximised in these objects. Kyiv is located on the right and left banks of the Dnipro river at the border between the Forest-Steppe zone and the Polissya of Ukraine following the geo-botanical division of Ukraine. The area of the city is 835.6 km², of which 43,600 ha are parks. The average annual temperature over the period 2013 – 2014 was 8.5 °C . The vegetation season (> 5 °C) lasted 204 days and started on April 10. The climate is of a semi-continental type for the Forest-Steppe zone. The geomorphologic structure of Kyiv belongs to 3 geomorphologic zones: South Polissya, Dnipro, Azov-Dnipro (Biluk 1977). Soddy-podzolic soils, gray forest soils and sod meadow soils are the main soil types in Kyiv (Gavriluk 1956). Kyiv is located at the border of two geobotanical zones: European broad-leaved forests, represented by the sub-province of mixed coniferous-broad-leaved forests of Polissya, and the European steppe region, represented by the Ukrainian forest-steppe sub-province of oak forests, steppificated meadows and meadow steppes (Biluk 1977).

In the survey conducted in September 15 – 30, 2014 we distinguished seven parks in the Kyiv city (Table 1).

2.2. Method

Within each studied park, the mapping of dominant tree vegetation was carried out at experimental plots EP1–EP7. The experimental plots represent the parks and were chosen by the reconnaissance method. Each experimental plot was established according to the detailed route-method (Dilis 1974; Vasilevich 1992; Mirkin 1998). The area of each experimental plot was 0.5 – 0.7 ha (Dilis 1974).

By taking into account basic characteristics of recreational changes of elements of structural and functional organisation of parks in Kyiv (the state of tree stratum, undergrowth, soil surface layer, herbaceous cover and leaf-litter) the level of recreational transformation rate was specified for each experimental plot ng from minimal to maximal consequences. The stages of the recreational transformation were assessed according to Rusin (2003) (Table 2).

Table 1. General characteristics of studied parks.

No	Name	GPS coordinates	Year Established	Affiliation to the nature reserve fund	Area [ha]	Dominant tree vegetation
1	Park "Syrets'kyy hay"	50°28'30'' N, 30°25'30'' E	1952	monument of landscape art of national significance	176,1	*Quercus robur* L., *Carpinus betulus* L., *Acer platanoides* L., *Tilia cordata* Mill., *Betula pendula* Roth, *Populus alba* L.
2	Holosshyivs'kyy Park name Maksyma Ryl's'koho	50°38'25'' N, 30°50'12'' E	1957	monument of landscape art of local significance	140,9	*Quercus robur* L., *Carpinus betulus* L., *Acer platanoides* L.
3	Park "Peremoha"	50°46'31'' N, 30°60'56'' E	1965	—	66,1	*Quercus robur* L., *Pinus sylvestris* L., *Fraxinus excelsior* L.
4	Park-monument of landscape art "Nyvky"	50°46'37'' N, 30°42'82'' E	1972	monument of landscape art of local significance	55,1	*Acer platanoides* L., *Acer saccharinum* L., *Quercus robur* L., *Aesculus hippocastanum* L., *Ulmus glabra* Huds., *Thuja. occidentalis* L., *Morus alba* L.
5	Park "Druzhby narodiv"	50°30'15'' N, 30°32'35'' E	1972	—	219.4	*Aesculus hippocastanum* L., *Acer platanoides* L., *A. tataricum* L., *Quercus rubra* L., *Tilia cordata* Mill., *Picea abies* [L.] H. Karst., *Salix alba* L.
6	Solom'yanskyy Landscape Park	50°42'55'' N, 30°48'45'' E	1973	—	29,6	*Quercus robur* L., *Q. rubra* L., *Tilia cordata* Mill., *Acer platanoides* L., *Fraxinus excelsior* L.
7	Forest Park "Urochyshche Sovky"	50°44'09'' N, 30°37'42'' E	1976	—	35,3	*Quercus robur* L., *Q. rubra* L., *Pinus sylvestris* L., *Betula pendula* Roth

Table 2. Stages of recreational transformation.

Degradation stage	State of		
	Herbaceous cover and leaf-litter	Tree stratum and undergrowth	Soil surface
1	full species composition of herbaceous plant community, plant projective cover is 90 – 100%, leaf-litter is not broken	trees are healthy, undergrowth is numerous and of different ages	I stage of degradation
2	appearance of ruderal or meadow herbaceous species, projective cover is 80 – 90%, leaf-litter begins to trample down	trees are weakened, undergrowth is numerous but not of different ages	II stage of degradation
3	share of ruderal or meadow herbaceous species is 5 – 10%, projective cover is 70 – 80%, leaf-litter is trampled down	trees are weakened or heavily weakened, undergrowth is limited	III stage of degradation
4	share of ruderal or meadow herbaceous species is 10 – 20%, projective cover is 50 – 70%, leaf-litter begins to deteriorate	trees are heavily weakened, low viability of undergrowth is located clumps	IV stage of degradation
5	ruderal or meadow herbaceous species are dominant species, projective cover is 0 – 50%, leaf-litter is completely absent	trees are heavily weakened or wilting with significant mechanical damage, undergrowth is absent	V stage of degradation

2.2.1 Assessment of tree health conditions and vitaly structure

Tree health condition (category of tree state) was assessed in accordance with the Sanitary Forest Regulation of Ukraine (1995). The stand state index was calculated as a sum of the values of the tree state index of the trees in a certain category, divided by the total number of the examined trees:

$$I_c = \frac{\Sigma k_i \cdot n_i}{N} \qquad [1]$$

k_i – category of tree state (I – VI); n_i – number of trees certain category of tree state; N – total number of trees.

The stands with the index values from the interval 1 – 1.5 are considered healthy (I), the weakened ones (II) have the values 1.51 – 2.50, heavily weakened (III) – 2.51 – 3.50, the wilting ones (IV) – 3.51 – 4.50, recently dead (V) – 4.51 – 5.50, old dead stands (VI) – 5.51 – 6.50.

In order to avoid the influence of the irregular intensity of silvicultural practice upon the index of stand state, the weighted average of Kraft classes (WAKC; vitality of tree vegetation) was calculated for each state category as a sum of the number of trees in each Kraft class multiplied by the stand state index (I – V), and divided by the total number trees in a certain state category:

$$WAKC = \frac{\Sigma k_{kc} \cdot I_c}{n_i} \qquad [2]$$

k_{kc} – number of trees in each Kraft class; Ic – stand state index; n_i – number of trees in a certain state category.

For this purpose, the trees in each category were divided into 5 Kraft classes. Classes V^a and V^b were combined into class V, since the trees of these categories were rarely found in the experimental plots. The WAKC depicts the damage zone in the tree stratum: the closer the WAKC is to I Kraft class, the higher is the degree of damage.

For each stand, forest mensuration parameters were derived: age (I); weighted average of diameters (D_{ave}), height (H_{ave}), diameter and height range ($D_{min} – D_{max}$; $H_{min} – H_{max}$) and standard deviation (S.D.), stand density (N), stand basal area as a sum of tree basal areas (G_n). The morpho-metric parameters were measured by an optical altimeter of Suunto PM-5 and Waldmeister 100alu callipers. Mechanically damaged woody plants were the trees and bushes with cutliving branches, injuries on the stem reaching cambium.

2.2.2 Soil surface layer assessment

The state of the soil surface layer was evaluated using the following categories of disturbance: 1 – undisturbed soil; 2 – weakened mulch (single passes); 3 – footpath in mulch; 4 – footpath or road without mulch; 5 – footpath or road with washaways; 6 – deposition and washaways made by recreants descending steep slopes.The degradation stages of soil surface layer were defined as follows: I – the 3rd, 4th, 5th and 6th categories of disturbance cover not more than 2% of the area of an experimental plot; II – from 2% to 10% of the plot area; III – from 10% to 25% of the area; IV – from 26% to 40% of the area; V – over 40% of the plot area (Polyakov 2009). Clogging of the soil's surface by solid waste was defined as the share clogged area from the total area of the experimental plot.

2.2.3 Herbaceous cover assessment

The taxa nomenclature was adopted from Cherepanov (1981) while taking into account the existing "International Code of Nomenclature for algae, fungi, and plants" (2011). We determined the species composition and the total projective cover of dominant herbaceous plants.

2.2.4 Data collection and determination of fungi

The ecological research was performed in each experimental plot at different diagnostic levels of xylotrophic fungal existence: organ, tree, population (species), biogroup (stratum) of phytocoenosis, phytocoenosis. According to Arefyev (2010), the measuring unit is a host tree, on which carpophores of certain fungi species were detected. The collection of factual evidence was carried out during the period of the visible growth and the formation of carpophores of xylotrophic fungi in the vegetation period. Every detected species was photographed in vivo by Nikon Coolpix L830 digital camera. The species that were easily identified "in oculo nudo" and did not require additional micro-morphological studies were not included in exsiccates. If required, the colour, smell, structure of carpophores were noted including the reaction of carpophores to mechanical damage (change of colour, sap ooze) and the substrate. The determination of fungi species was based on the methods of Eriksson et al. (1973 – 1988), Bondarceva & Parmasto (1986), Clémençon (2009), Bernicchia & Gorjón (2010) and Yurchenko (2010). The scientific names of fungi and their macrosystems are according to CORTBASE v. 2.1 (Parmasto et al. 2009) and MycoBank (Robert et al. 2005). Author's names of fungi species are according to Kirk & Ansell (1992).

2.2.5 Assessment of trophic and spatial compositions of fungi

The analysis of the trophic composition of fungi communities was based on the distribution of wood-destroying fungi on trees. We distinguished four trophic groups of xylotrophes: eurytrophes of I rank (communities of coniferous and deciduous trees), eurytrophes of II rank on coniferous trees, eurytrophes of II rank on deciduous trees and stenotrophes (communities composed of only one genus of woody plants). The dead substrate of the host trees of xylotrophic fungi was divided into three categories – deadwood, fallen wood (branches and stems) and stumps depending on the morpho-metric parameters. The analysis of the spatial composition of the communities of wood-destroying fungi was based on+ the distribution of wood-destroying fungi in myco-horizons: root, ground, stem base, stem and photosynthesising myco-horizons (Fig. 1).

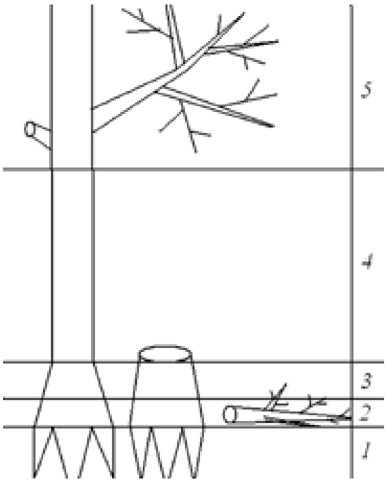

Fig. 1. Specification of myco-horizons: 1 – root, 2 – ground, 3 – stem base, 4 – stem, 5 – photosynthesising myco-horizons.

2.2.6 Statistical analyses

Menhinik's Index was usedto determine the species richness of wood-destroying fungi:

$$D_{Mn} = \frac{S}{\sqrt{N}} \quad [3]$$

S – number of species; *N* – number of findings.

Shannon's Index of diversity was used for the generalised assessment of wood destroying fungi diversity:

$$H = \Sigma p_i \log_{10} p_i \quad [4]$$

p_i – relative proportion of each species.

Pielou's Index was used for the generalised assessment of wood destroying fungi:

$$E_H = \frac{H}{H_{max}} \quad [5]$$

H – value of Shannon's Index of diversity, $H_{max} = lgN$, *lgN* – number of wood-destroying fungi species (Schmidt 1980).

The similarity of the formed associations "tree-wood-destroying fungi" was studied by cluster analysis (OriginPro 9) using the weighted average of quantitative and qualitative indicators of the investigated trees (vitality, age structure and health condition) and fungi (species, systematic, trophic and spatial composition) at each experimental plot. The standardised Euclidean distance was selected for the assessment of the distance. The detection of the diagnostic indicators for the assessment of the associations between tree vegetation and wood-destroying fungi along the gradient of recreational transformation in urban conditions of Kyiv was performed by the principal components analysis in order to reduce and interpret data sets with underlying linear structures (OriginPro 9).

3. Results

3.1 Assessment of the recreational transformation of city parks

The level of the recreational transformation of the city parks was determined. The studied parks were ranked on the base of the human impact and the stages of recreational transformation of territory (Fig. 2) from minimum to maximum degradation as follows: 1 – Park "Druzhby narodiv", 2 – Park "Peremoha", 3 – Holosshyivs'kyy Park name Maksyma Ryl's'koho, 4 – Park "Syrets'kyy hay", 5 – Solom'yanskyy Landscape Park, 6 – Forest Park "Urochyshche Sovky", 7 – Park-monument of landscape art "Nyvky".

Fig. 2. Location of study areas in Kyiv: 1 – Park "Druzhby narodiv", 2 – Park "Peremoha", 3 – Holosshyivs'kyy Park of Maksyma Ryl's'koho, 4 – Park "Syrets'kyy hay", 5 – Solom'yanskyy Landscape Park, 6 – Forest Park "Urochyshche Sovky", 7 – Park-monument of landscape art "Nyvky".

3.2. Summary results of mycological survey

Our mycological study detected altogether 27 species of macromycetes (166 findings of xylotrophic fungi), 22 genera, 16 families, 6 orders of Basidiomycota division (class Agaricomycetes) at all experimental plots together (Appendix 1). In general, 693 individuals (9 species) of woody plants were studied.

3.3. In-depth assessment of the city parks

3.3.1 Park "Druzhby narodiv"

The territory of the "Druzhby narodiv" park has the fewest signs of the recreational transformation of parks in Kiyv. EP1 (0.5 ha) was located on the island Muromets between the left and right banks of the river Dnipro. The stand was two-storeyed; the canopy cover was 0.7 – 0.8. The first storey was composed of *Acer platanoides* L. (A = 40 – 60; $G_n = 54.3\ m^2\,ha^{-1}$; N = 145 psc. ha^{-1}; $H_{ave} = 14.9$ m, $H_{min} = 13.7$ m, $H_{max} = 16.7$ m, S.D. = 1.45 m; $D_{ave} = 31.5$ cm; $D_{min} = 22.1$ cm, $D_{max} = 38.3$ cm, S.D. = 5.25 cm), *Tilia cordata* Mill.

(I = 1.79; A = 40 – 60; G_n = 47.1 m^2 ha^{-1}; N = 78 psc. ha^{-1}; H_{ave} = 14.6 m, H_{min} = 12.9 m, H_{max} = 16.1 m, S.D. = 1.32 m; D_{ave} = 29.7 cm; D_{min} = 20.7 cm, D_{max} = 35.1 cm, S.D. = 6.82 cm). The second storey was composed *Aesculus hippocastanum* L.(A = 20 – 40; G_n = 12.3 m^2 ha^{-1}; N = 25 psc. ha^{-1}; H_{ave} = 10.4 m, H_{min} = 8.7 m, H_{max} = 12.9 m, S.D. = 1.56 m; D_{ave} = 19.2 cm; D_{min} = 15.3 cm, D_{max} = 24.9 cm, S.D. = 5.95 cm). Mechanically damaged trees were not recorded.

The projected cover of the herbaceous storey was 94.5%. *Chelidónium május* L., *Ballota nigra* L., *Impatiens parviflora* L., *Stenactis annua* L., *Trifolium repens* L. dominated. The soil surface was in I stage of degradation: damaged areas occupied 1.9% of the total area, while 3rd, 4th, 5th and 6th were not detected. The clogging of the soil's surface was 0.01 – 0.03%. The overall stage of the recreational transformation was I.

At EP1 we detected 4 species of xylotrophs that represented 3 genera, 3 families, 2 orders on *Tilia cordata* Mill. and *Aesculus hippocastanum* L. 75% findings of xylotrophic fungi were eurytrophes of II rank on deciduous trees: *Fomes fomentarius* (L.) Fr., *Peniophora cinerea* (Pers.) Cooke and *Stereum hirsutum* (Willd.) Pers. Stenotrophes (25.0% of findings) were represented by only one species: *Peniophora rufomarginata* (Pers.) Bourdot et Galzin (Appendix 1). The shares of xylotrophic fungi in different substrate categories showed that all species were developed on trees of I – IV state categories.

The analysis of the vitality and health conditions of *Acer platanoides* L. revealed the absence of pathological processes: 67.1% of trees were healthy (I = 1.47), 25.3% were weakened (I = 2.34), and 7.6% were heavily weakened (I = 3.05). WAKC of healthy trees of *Acer platanoides* L. was 1.45 – 1.55. The analysis of the health conditions of *Tilia cordata* Mill. showed similar results as for *Acer platanoides* L.: 72.4% of trees were healthy (I = 1.40), 20.7% were weakened (I = 1.75), and 6.9% were heavily weakened (I = 2.77). WAKC of healthy trees of *Tilia cordata* Mill. was 1.40 – 1.45. 60.0% findings of *Peniophora rufomarginata* (Pers.) Bourdot et Galzin was observed on *Tilia cordata* Mill. of III state category, I Kraft class. The analysis of the vitality (WAKC of healthy trees =2.55 – 2.60) and health conditions (I = 1.51) of *Aesculus hippocastanum* L. revealed a small degree of damage and the absence of pathological processes in the system. 80.0% of findings of fungi (*Fomes fomentarius* (L.) Fr., *Peniophora cinerea* (Pers.) Cooke and *Stereum hirsutum* (Willd.) Pers.) occurred on heavily weakened trees (IV – V Kraft classes) of *Aesculus hippocastanum* L. (I = 3.15) in the photosynthesising myco-horizon (75.0%) and stem base myco-horizon (25.0%) (Appendix 2). We also observed *Peniophora cinerea* (Pers.) Cooke on fallen wood (branches, D_{ave} = 1.7 cm) of *Quercus rubra* L. (I Kraft class, II category of stand state).

3.3.2 Park "Peremoga"

EP2 (0.5 ha) was located in the Park "Peremoga" on the left bank of the river Dnipro. The stand was two-storeyed; the canopy cover 0.6 – 0.7. The first storey composed of *Pinus sylvestris* L. (A = 40 – 60), which had following stand inventory parameters: G_n = 108.1 m^2 ha^{-1}; N = 205 psc. ha^{-1}; H_{ave} = 17.6 m, H_{min} = 15.7 m, H_{max} = 20.7 m, S.D. = 1.45 m; D_{ave} = 31.5 cm; D_{min} = 22.1 cm, D_{max} = 38.3 cm, S.D. = 5.25 cm. The second storey composed *Quercus robur* L. (A = 40 – 60). Stand parameters of *Quercus robur* L.: G_n = 95.3 m^2 ha^{-1}; N = 107 psc. ha^{-1}; H_{ave} = 15.3 m, H_{min} = 12.2 m, H_{max} = 18.4 m, S.D. = 2.08 m; D_{ave} = 24.2 cm; D_{min} = 19.2 cm, D_{max} = 28.8 cm, S.D. = 3.48 cm. Mechanically damaged trees (2.2%, an average area of 53.2 cm^2) were observed at one place where fire occurred.

The projected cover of the herbaceous storey was 80.5%. The dominant species were*Achillea millefolium* L., *Artemísia vulgáris* L., *Calamagrostis epigeios* (L.) Roth., *Centaurea marschalliana* Spreng., *Lolium perenne* L., *Poa nemoralis* L., *Polygonum aviculare* L. and others. The leaf-litter has begun to be trampled down by people. Overall,the soil surface was in II stage of degradation: damaged areas occupied 9.1% out of which 5.3% were in 3rd, 4th, and 5th categories of soil surface degradation. The clogging of the soil's surface was 0.01 – 0.03%, similarly as at EP1. The park was assigned II stage of the recreational transformation.

We detected 3 species of xylotrophs presented by 3 genera, 3 families, 3 orders. 100% findings of xylotrophic fungi were eurytrophes of II rank on deciduous trees. All of them were detected on *Quercus robur* L. in the photosynthesising myco-horizon: *Cylindrobasidium evolvens* (Fr.) Jülich (one finding on undergrowth), *Peniophora quercina* (Pers.) Cooke (I – II Kraft classes, II – III state categories) and *Vuilleminia comedens* (Nees) Maire (I – II, IV Kraft classes, I – III state categories) (Appendix 1, 2). The analysis of the health conditions of *Quercus robur* L. showed that the trees in I (I = 1.38; 54.5%) and II (I = 2.15; 27.3%) state categories were most frequent at this EP. Only 4.3% of trees were wilting. The artificial plantings of *Pinus sylvestris* L., regardless of age, do not ensure the viable stand state: 21.5% of pine trees were healthy (I = 1.40), weakened ones – 27.1% (I = 2.35), heavily weakened – 40.9% (I = 2.90), wilting – 10.5% (I = 2.90). Recently dead stands and old dead-wood were absent. From the point of tree development, trees were their divided into individual categories as follows: 65.3% – I Kraft class trees, 22.2% – II Kraft class trees, 9.3% – III Kraft class trees, 2.8% – Kraft class trees. We did not detect xylotrophic fungi on *Pinus sylvestris* L.

3.3.3 Holosshyivs'kyy Park name Maksyma Ryl's'koho

EP3 (0.7 ha) was located in the Holosshyivs'kyy Park of Maksyma Ryl's'koho in the valley of the river Horikhuvatka. The relief was heavily dissected. The stand consisted of one storey of *Quercus robur* L. (A = 60 – 80). The canopy cover was 0.6 – 0.7, G_n = 240.4 m^2 ha^{-1}, N = 247 pcs. ha^{-1}; H_{ave} = 18.4 m, H_{min} = 15.1 m, H_{max} = 20.3 m, S.D. = 1.92 m; D_{ave} = 56.1 cm, D_{min} = 34.2 cm, D_{max} = 89.2 cm, S.D. = 10.11 cm. The mechanical damage (average area of 0.51 cm^2) was observed only on one tree. The undergrowth of *Quercus robur* L. was scare.

The projected cover of the herbaceous storey was 75.0% (*Ambrosia artemisiifolia* L., *Capsela bursa-pastoris* L., *Dactilis glomerata* L., *Elytrigia repens* L., *Poa annua* L. and others).

Thesoil surface was in III stage of degradation: damaged areas occupied 15.5% of the total area. 5th and 6th categories of the soil surface state were absent. The clogging of the soil's surface was about 0.025%. The overall stage of recreational transformation was III.

At EP3 we detected the maximum number of wood-destroying fungi in the studied parks: 11 species (51 findings) represented 10 genera, 9 families, 5 orders. 76.5% of findings of wood-destroying fungiytrophes of II rank on deciduous trees: *Basidioradulum radula* (Fr.) Nobles, *Cylindrobasidium evolvens* (Fr.) Jülich, *Hyphodontia sambuci* (Pers.) J. Erikss., *Peniophora quercina* (Pers.) Cooke, *Phellinus robustus* (P. Karst.) Bourdot et Galzin, *Radulomyces molaris* (Chaillet ex Fr.) Christ., *Trichaptum biforme* (Fr.) Ryvarden and *Vuilleminia comedens* (Nees) Maire; 23.5% – eurytrophes of I rank: *Corticium roseum* Pers., *Ganoderma lucidum* (Curtis) P. Karst. and *Phellinus ferruginosus* (Schad.) Pat. (Appendix 1). It is not easy to delimit the borders between biotrophy, necrotrophy, and saprotrophy for wood-destroying fungi (Urchenko 2006). We detected only one biotrophic species – *Phellinus robustus* (P. Karst.) Bourdot et Galzin. Their frequency at EP3 was 2.0% (in the cavities of living trees of III state category).

The shares of wood-destroying fungiin different substrate categories showed that an equal distribution of species and findings of fungi was detected on fallen woody debris (7 species, 29 findings) and on living trees in I – IV state categories (6 species, 21 findings). No wood-destroying fungi were detected on stumps (D_{ave} = 38.3 cm, H_{ave} = 0.1 m).

The analysis of the vitality of *Quercus robur* L. revealed that wood-destroying fungi occurred mainly on *Quercus robur* L. trees of I (57.4%, findings; 53.2%, trees) and II (29.8%, findings; 30.4% trees) Kraft classes. WAKC of healthy (I state category) and weakened (II state category) trees indicate that the number of trees in Kraft classes I–II increases when the trees are closer to roads and open landscape elements. The total proportion of heavily weakened trees was high (26.6%) as well as the number of trees in the weakened Kraft class III. Only 19.0% of *Quercus robur* L. trees at EP3 were healthy, the rest were weakened to different extent due to the recreational impact. The analysis of the health conditions of *Quercus robur* L. revealed that the maximum number of xylotrophs was recorded on *Quercus robur* L. trees of II (38.3%) and III (31.9%) state categories. No wood-destroying fungi were detected on trees of V state category. Approximately one half of the identified xylotrophic fungi (53.0%) occurred in the ground myco-horizon, and 39.2% in the photosynthesising myco-horizon of *Quercus robur* L. (Appendix 2).

3.3.4 Park "Syrets'kyy hay"

EP4 was located on the Park "Syrets'kyy hay". The stand was two-storeyed with the first storey composed of *Quercus robur* L. (A = 60 – 80), and the second storey composed of *Carpinus betulus* L. (A = 60 – 80), *Acer platanoides* L. (A = 40 – 60) and *Tilia cordata* Mill. (A = 60 – 80); the canopy cover was 0.5 – 0.6. The stand parameters of *Quercus robur* L. were: G_n = 94.4 m^2 ha^{-1}; N = 125 psc. ha^{-1}; H_{ave} = 23.2 m, H_{min} = 21.9 m, H_{max} = 25.7 m, S.D. = 1.98 m; D_{ave} = 71.3 cm; D_{min} = 62.5 cm, D_{max} = 82.1 cm, S.D. = 6.23 cm. The stand parameters of *Carpinus betulus* L. were: G_n = 86.5 m^2 ha^{-1}; N = 265 psc. ha^{-1}; H_{ave} = 18.1 m, H_{min} = 16.2 m, H_{max} = 20.3 m S.D. = 1.34 m; D_{ave} = 36.0 cm; D_{min} = 30.1 cm, D_{max} = 43.5 cm, S.D. = 3.89 cm. *Acer platanoides* L.: G_n = 21.8 m^2 ha^{-1}; N = 76 psc. ha^{-1}; H_{ave} = 16.9 m, H_{min} = 13.7 m, H_{max} = 19.2 m, S.D. = 1.74 m; D_{ave} = 19.5 cm; D_{min} = 16.3 cm, D_{max} = 24.7 cm, S.D. = 2.51 cm. Biogroups of *Tilia cordata* Mill. were scattered and had the following inventory parameters: G_n = 11.1 m^2 ha^{-1}; N = 28 psc. ha^{-1}; H_{ave} = 19.0 m, H_{min} = 16.4 m, H_{max} = 22.8 m, S.D. = 1.92 m; D_{ave} = 45.3 cm; D_{min} = 40.1 cm, D_{max} = 52.0 cm, S.D. = 3.70 cm. Mechanically damaged trees (5.5%, an average area of 95.6 cm^2) were recorded at EP4. The undergrowth was composed only of *Acer platanoides* L.

The recreational transformation was more intense at EP4 in comparison with the previous experimental plots EP1 – EP3. The projected cover of the herbaceous storey was 73.0%. The dominant species at EP4 were *Galinsoga ciliata* (Raf.) Blake, *Geum urbanum* L., *Impatiens parviflora* L., *Solidágo virgáurea* L., *Urtica dioica* L., *Geranium sylvaticum* L.

The soil surface was in III stage of degradation: damaged areas occupied 21.3%, while 16.5% of the damaged areas were in 3th and 4th state categories of the soil surface degradation. The clogging of the soil's surface was about 0.05%. Overall, the plots was assigned III stage of the recreational transformation.

Altogether 9 species (25, findings) of macromycetes were found at EP4, the fruiting of which occurs autumn. These fungi species represented 8 genera, 8 families, 5 orders. 48.0% of findings of xylotrophic fungi were eurytrophes of II rank on deciduous trees: *Peniophora quercina* (Pers.) Cooke, *Phellinus robustus* (P. Karst.) Bourdot et Galzin, *Phlebia radiata* Fr., *Stereum hirsutum* (Willd.) Pers. and *Vuilleminia comedens* (Nees) Maire. The same percentage, i.e 48.0% of findings of xylotrophic fungi were eurytrophes of I rank: *Hypholoma fasciculare* (Huds.) P. Kumm., *Schizopora paradoxa* (Schrad.) Donk and *Schizophyllum commune* Fr. Stenotrophes (4.0%, findings) were represented by *Peniophora rufomarginata* (Pers.) Bourdot et Galzin (Appendix 1). The frequency of biotrophic species *Phellinus robustus* (P. Karst.) Bourdot et Galzin at EP4 was 2.5%.

It is also clear that the composition and distribution of xylotrophic fungi is tightly connected not only with vitality and health conditions of tree stands, but also with the myco-horizons and the substrate type. From this point of view, the greatest number of the identified xylotrophic fungi (60.0%) was found in the photosynthesising myco-horizon and 20.0% in the stem myco-horizon. 16.0% of wood-destroying fungi were in the ground myco-horizon, 4.0% in the stem base myco-horizon (Appendix 2). On *Quercus robur* L., we detected 4 species (8 findings) of xylotrophic fungi. *Phellinus robustus* (P. Karst.) Bourdot et Galzin (37.5% of findings) preferred broken bark and branches. The occurrence of *Peniophora quercina* (Pers.) Cooke (25.0%) and *Vuilleminia comedens* (Nees) Maire (25.0%) was mostly limited to the top of branches in the canopy (D_{min} = 0.8 cm, D_{max} = 5.5 cm). *Schizophyllum commune* Fr. was the saprotroph occurring on fallen branches (12.5%, D = 15.5 cm).

The analysis of the vitality of *Quercus robur* L. revealed thatwood-destroying fungi were observed mainly on trees of I Kraft class (77.5% findings), while their proportion on tress of II Kraft class was lower (12.5%). The trees of III (4.7%) and IV (5.3%) Kraft classes did not have a mycological component. Such a distribution of trees in Kraft classes is caused by the age structure of *Quercus robur* L. The analysis of the health conditions of *Quercus robur* L. and the species composition of xylotrophic fungi showed that the greatest number of xylotrophs (87.5%) was observed on the trees of II state category (78.6%, I = 1.56). The smallest number of xylotrophs (12.5%) was recorded on the trees of I state category (7.1%, I = 1.46). No wood-destroying fungi were observed on the heavily weakened (7.1%) and the wilting trees (7.1%).

On *Carpinus betulus* L. we detected 5 species (13 findings) of xylotrophic fungi: *Schizopora paradoxa* (Schrad.) Donk (53.8% of findings) was mostly limited to broken branches in canopy (D_{ave} = 12.0 cm), *Vuilleminia comedens* (Nees) Maire was particularly common at top of the branches of living trees (23.1%, D_{ave} = 2.0 cm). *Hypholoma fasciculare* (Huds.) P. Kumm. (on stem base), *Phlebia radiata* Fr. (on stem bark) and *Stereum hirsutum* (Willd.) Pers. (in the photosynthesising myco-horizon) were detected on a single deadwood piece. The analysis of vitality of *Carpinus betulus* L. revealed that a half of the observations of xylotrophic fungi (46.2%) was detected on trees in III Kraft development class (with 30.0% frequency at the plot). The analysis of the health conditions of *Carpinus betulus* L. and species composition of xylotrophic fungi showed that the greatest number of xylotrophs (41.7% of findings) occurred on the trees of III (24.0% frequency at the plot, I =2.79) and IV (12.0%, I = 3.77) state categories. This is understandable since these categories of trees have the highest probability to be damaged by plant pathogens and are least resistant to other negative factors. No wood-destroying fungi were detected on the healthy trees (20.0%).

The plantings of *Acer platanoides* L. and *Tilia cordata* Mill. were weakened (I = 1.57, I = 1.65), but the weighted average of Kraft classes was optimum (2.6; 2.4). There was no V state category of *Acer platanoides* L. at the experimental plot. No wood-destroying fungi were detected on *Acer platanoides* L. We recorded 2 findings of *Peniophora rufomarginata* (Pers.) Bourdot et Galzin at the ends of the branches of living trees of *Tilia cordata* Mill. (heavily weekend, III Kraft class, photosynthesising myco-horizon).

3.3.5 Solom'yanskyy Landscape Park

EP5 (0.5 ha) was located in the valley of the river Mokra of tract "Kuchmyn Yar". The stand consisted of two storeys. The first storey composed of *Quercus robur* L. (A = 40 – 60) and *Q. rubra* L. (A = 20 – 40). The second storey consisted of *Acer platanoides* L. and *Tilia cordata* Mill. The canopy cover was 0.4 – 0.5. *Quercus robur* L.: G_n = 104.8 m^2 ha^{-1}, N = 170 pcs. ha^{-1}, H_{ave} = 16.1 m, H_{min} = 14.3 m, H_{max} = 17.9 m, S.D. = 1.81 m; D_{ave} = 36.7 cm; D_{min} = 29.1 cm, D_{max} = 46.3 cm, S.D. = 8.62 cm. *Quercus rubra* L.: G_n = 80.1 m^2 ha^{-1}, N = 103 pcs. ha^{-1}, H_{ave} = 17.1 m, H_{min} = 14.9 m, H_{max} = 19.1 m, S.D. = 1.72 m; D_{ave} = 22.0 cm; D_{min} = 18.1 cm, D_{max} = 31.3 cm, S.D. = 4.93 cm. Mechanical damage was observed especially on *Quercus robur* L. (9.8%, average area of 187.7 cm^2). Stand parameters for *Tilia cordata* Mill. (A = 40 – 60) were as follows: G_n = 29.6 m^2 ha^{-1}, N = 86 pcs. ha^{-1}, H_{ave} = 14.0 m, H_{min} = 12.4 m, H_{max} = 16.1 m, S.D. = 1.43 m; D_{ave} = 22.1 cm, D_{min} = 18.1 cm, D_{max} = 29.3 cm, S.D. = 7.35 cm. *Acer platanoides* L. (I = 2.25) occurred in undergrowth.

The total projected cover of herbaceous storey was 55.5%. *Dactilis glomeráta* L., *Senecio vulgaris* L. *Phalacroloma annuum* L. and *Urtica dioica* L. dominated this storey. The leaf-litter has begun to deteriorate. The soil surface was in IV stage of degradation: damaged areas occupied 28.0% of the total area, out of which 25.5% were in 3rd, 4th, 5th and 6th categories of the soil surface state. The clogging of the soil's surface was less than 0.08%. The overall stage of recreational transformation was IV.

Xylotrophic fungi were presented by 6 species, 5 genera, 5 families, 4 orders. 69.2% of findings of xylotrophic fungi were eurytrophes of II rank on deciduous trees: *Peniophora quercina* (Pers.) Cooke, *Radulomyces molaris* (Chaillet ex Fr.) Christ., *Stereum hirsutum* (Willd.) Pers. and *Vuilleminia comedens* (Nees) Maire. Stenotrophes (19.3% of findings) were represented by only one species: *Peniophora rufomarginata* (Pers.) Bourdot et Galzin. Eurytrophes of I rank (11.5%, findings) were also represented by one species: Schizopora paradoxa (Schrad.) Donk (Appendix 1). The shares of wood-destroying fungi in different substrate categories showed that species and findings were confined to trees in I – IV state categories. The greatest number of the identified wood-destroying fungi (96.2% of findings) occurred in the photosynthesising myco-horizon and 3.8% in the stem base myco-horizon (Appendix 2).

On *Quercus* spp. we detected 5 species of xylotrophic fungi, namely *Peniophora quercina* (Pers.) Cooke, *Radulomyces molaris* (Chaillet ex Fr.) Christ., *Schizopora paradoxa* (Schrad.) Donk, *Stereum hirsutum* (Willd.) Pers., *Vuilleminia comedens* (Nees) Maire, on *Quercus robur* L., and one finding of *Vuilleminia comedens* (Nees) Maire was also recorded on *Quercus rubra* L. (I state category, I Kraft class). Trees of *Quercus robur* L. were heavily weakened (I = 2.75). The greatest number of findings of fungi (63.2%) was observed on *Quercus robur* L. trees of III state category. No wood-destroying fungi were detected on healthy trees and fresh deadwood. The analysis of the vitality of *Quercus robur* L. revealed that 52.6% of the findings of fungi were confined to the highest Kraft class, and the smallest number of findings to IV, V Kraft classes.

There were no healthy and weakened trees of *Tilia cordata* Mill. at EP5 (I = 3.75). We detected 5 findings of *Peniophora rufomarginata* (Pers.) Bourdot et Galzin on trees of III – IV Kraft classes and III – IV state category. No wood-destroying fungi were detected on *Acer platanoides* L., *Fraxinus excelsior* L. and *Popupus tremula* L. The analysis of myco-horizons showed that most findings of xylotrophs (96.2%) were confined to the photosyntesising myco-horizon, and one finding of *Stereum hirsutum* (Willd.) Pers. was detected on the stem base of *Quercus robur* L.

3.3.6 Forest Park "Urochyshche Sovky"

EP6 (0.6 ha) was located in the Forest Park "Urochyshche Sovky" on the right bank of the river Dnipro. The stand was two-storeyed, the canopy cover was 0.4 – 0.5. The first storey was composed of *Pinus sylvestris* L. (A = 40 – 60; G_n = 112.5 m^2 ha^{-1}, N = 220 pcs ha^{-1}; H_{ave} = 21.9 m, H_{min} = 18.1 m, H_{max} = 24.5 m, S.D. = 2.90 m; D_{ave} = 32.3 cm, D_{min} = 28.5 cm, D_{max} = 45.3 cm, S.D. = 5.91 cm.), and the second storey was composed of *Quercus robur* L. (A = 40 – 60; G_n = 64.1 m^{2}ha^{-1}, N=220 pcs.ha^{-1}; H_{ave}=18.9 m, H_{min}=15.1 m, H_{max}= 20.3 m, S.D. = 2.16 m; D_{ave} = 23.4 cm, D_{min} = 17.9 cm, D_{max}= 35.8 cm, S.D. = 7.02 cm). The average area of the mechanical damage of *Pinus sylvestris* L. trees exceeded 178 cm^2 (2.7% of trees), and of *Quercus robur* L. – 123 cm^2 (9.1% of trees). The undergrowth was formed by *Fraxinus excelsior* L. (I = 2.60) and *Quercus robur* L. (I = 2.45). The understorey was formed by *Frangula alnus* Mill. (findings of *Schizopora paradoxa* (Schrad.) Donk, *Chondrostereum purpureum* (Pers.) Pouzar) and *Sambucus nigra* L. (findings of *Hyphodontia sambuci* (Pers.) J. Erikss.).

The projected cover of the herbaceous storey was 50.5%, the clogging of the soil's surface was 0.15%. *Chelidonium majus* L., *Dactilis glomerata* L., *Impatiens parviflora* L., *Stenactis annua* L. dominated in the herbaceous storey. The soil surface was in V stage of degradation: damaged areas occupied 35.3% of the total area, out of which 3rd, 4th and 5th categories of the soil surface state constituted 26.1%. The overall stage of recreational transformation was IV.

We detected 8 species of wood-destroying fungi from 7 genera, 7 families and 5 orders. 73.3% of findings of xylotrophic fungi were eurytrophes of II rank on deciduous trees: *Chondrostereum purpureum* (Pers.) Pouzar*, Hymenochaete rubiginosa* (Dicks.) Lév., *Hyphodontia sambuci* (Pers.) J. Erikss. and *Vuilleminia comedens* (Nees) Maire. 20.0% of findings of xylotrophic fungi were eurytrophes of I rank: *Coniophora arida* (Fr.) P. Karst., *Schizopora flavipora* (Berk. et M. A. Curtis ex Cooke) Ryvarden and *Schizopora paradoxa* (Schrad.) Donk. Eurytrophes of II rank on coniferous trees (6.7%, findings) was represented by only one species: *Trichaptum hollii* (J.C. Schmidt) Kreisel (Appendix 1). 50.0% of findings of fungi at EP6 were confined to stem base myco-horizon, while in stem and photosintesising myco-horizons we detected the same number of wood-destroying fungi (20.0%) (Appendix 2). 3 species of wood-destroying fungi were recorded on *Quercus robur* L. – *Hymenochaete rubiginosa* (Dicks.) Lév., *Schizopora flavipora* (Berk. et M. A. Curtis ex Cooke) Ryvarden and *Vuilleminia comedens* (Nees) Maire. The greatestof number of the findings of fungi (57.1%) was recorded on trees of I state category (8.4% of total trees). The analysis of the vitality of *Quercus robur* L. showed that a half of the findings of fungi were recorded on trees of III Kraft class (42.9%). The investigated stands of *Quercus robur* L. were heavily weakened (I = 3.01) similarly as *Quercus robur* L. at EP5. The distribution of xylotrophs in the myco-horizons of *Quercus robur* L. was as follows: 85.7% of xylotrophic fungi were in the photosynthesising myco-horizon, 14.3% at the stem baseend.

The analysis of the health conditions of *Pinus sylvestris* L. revealed that the stands were weakened (I = 2.15). The proportion of healthy trees was below 2.0%, of weakened trees was 33.3%, heavily weakened – 36.5%. 79.3% of trees belonged to I Kraft class, and 15.9% trees to II Kraft class. Trees of IV and V Kraft classes were absent. At this EP we recorded*Coniophora arida* (Fr.) P. Karst. and *Trichaptum hollii* (J.C. Schmidt) Kreisel (recently dead of *Pinus sylvestris* L., II Kraft class).

3.3.7 Park-monument of landscape art "Nyvky"

The study of the artificial phytocoenoses at EP7 was conducted in the park-monument of the landscape art "Nyvky", which belongs to the nature reserve fund of Ukraine. This territory has the most signs of recreational transformation from the studied parks of Kiyv. The stand was two-storeyed, with the first storey composed of *Quercus robur* L., the second storey composed of *Acer platanoides* L., *Ulmus glabra* Huds. and *Aesculus hippocastanum* L. The canopy cover was 0.4 – 0.5. The stand parameters of *Quercus robur* L. were: A = 60 – 80; G_n = 128.7 m^2 ha^{-1}, N = 190 pcs. ha^{-1}; H_{ave} = 26.2 m, H_{min} = 19.5 m, H_{max} = 28.1 m, S.D. = 2.87 m; D_{ave} = 82.8 cm, D_{min} = 78.2 cm, D_{max} = 95.1 cm, S.D. = 10.20 cm. The stand parameters of *Acer platanoides* L. were: A = 40 – 60; G_n = 98.7 m^2 ha^{-1}; N = 178 psc. ha^{-1}; H_{ave} = 16.0 m, H_{min} = 12.4 m, H_{max} = 18.1 m, S.D. = 2.56 m; D_{ave} = 31.1 cm; D_{min} = 20.5 cm, D_{max} = 46.1 cm, S.D. = 9.22 cm. The proportion of all woody species with mechanical damages amounted 19.5% (355 cm^2). The understorey was absent. The leaf-litter is completely absent too.

The total projected cover of the herbaceous storey was 25.5%. The soil surface in V stage of digradation: damaged areas occupied 45.5% of the total area, out of which 37.1% were in 3rd, 4th, 5th and 6th categories of the soil surface state. The clogging of the soil´s surface was 0.20%. The plots was assigned the overall stage of recreational transformation of V.

In total, we detected 11 species of wood-destroying fungi from 10 genera, 8 families, and 4 orders. 74.1% of findings of xylotrophic fungi were eurytrophes of II rank on deciduous trees: *Dendrothele acerina* (Pers.) P.A. Lemke, *Peniophora quercina* (Pers.) Cooke, *Phellinus robustus* (P. Karst.) Bourdot et Galzin, *Radulomyces molaris* (Chaillet ex Fr.) Christ.*, Stereum hirsutum* (Willd.) Pers. and *Vuilleminia comedens* (Nees) Maire. 25.9% of findings of xylotrophic fungi were eurytrophes of I rank: *Agaricus squarrosus* Oeder, *Armillaria mellea* (Vahl) P. Kumm., *Corticium roseum* Pers., *Phellinus ferruginosus* (Schad.) Pat. and *Schizopora paradoxa* (Schrad.) Donk. The frequency of biotrophic species *Phellinus robustus* (P. Karst.) Bourdot et Galzin at EP7 was 0.7%. The greatest number of findings of fungi at EP7 (45.5%) occurred in the photosynthesising myco-horizon, while in the stem base and stem myco-horizons we detected the same number of wood-destroying fungi (18.2%). The minimum species (11.7%) and number of findings (3.9%) were detected in the stem base myco-horizon of *Aesculus hippocastanum* L. (Appendix 1, 2).

On *Quercus robur* L. we detected 8 species of xylotrophic fungi: *Agaricus squarrosus* Oeder, *Phellinus ferruginosus* (Schad.) Pat., *Peniophora quercina* (Pers.) Cooke, *Phellinus robustus* (P. Karst.) Bourdot et Galzin, *Radulomyces* *molaris* (Chaillet ex Fr.) Christ., *Stereum hirsutum* (Willd.) Pers., *Schizopora paradoxa* (Schrad.) Donk and *Vuilleminia comedens* (Nees) Maire. The analysis of vitality of *Quercus robur* L. revealed that all findings of fungi were recorded on trees belonging to I Kraft development class. The analysis of health conditions and species composition of wood-destroying fungi showed that the proportion of xylotrophic fungi was the same (33.3% of findings) in II (17.5%, trees) and III (32.5%, trees) state categories. There were no old dead stands of *Quercus robur* L. at EP7.

Only *Dendrothele acerina* (Pers.) P.A. Lemke and *Corticium roseum* Pers. developed on *Acer platanoides* L. 93.3% findings were detected in I state category (7.7%, I = 1.44) indicating that the development of the communities of *Acer platanoides* L. and wood-destroying fungi is not balanced. The analysis of the vitality of *Acer platanoides* L. showed that the proportion of xylotrophic fungi in I (31.0% of trees) and II (38.0% of trees) Kraft classes was the same (33.3% of findings). Only one species was detected on *Aesculus hippocastanum* L. (*Armallaria mellea* (Vahl) P. Kumm, wilting tree, I Kraft class, root myco-horizon). On *Ulmus glabra* Huds. (I = 2.75, I – II Kraft classes), wood-destroying fungi were absent.

3.4. Species richness of xylomycobiota

The analysis of species richness of wood-destroying fungi in the urban conditions of parks along the gradient of recreational transformation showed that the highest species richness was at EP4 and EP7 (the investigated stands were to 60 – 80% composed of *Quercus robur* L.). In general, species diversity of xylotrophic macromycetes at experimental plots caused by the occurrence of species that grow on different substrates: *Schizopora paradoxa* (Schrad.) Donk and *Stereum hirsutum* (Willd.) Pers. It is also associated with the development of stenotrophic fungi.

We take the xylomyco-complex of *Quercus robur* L. as an example, in which 110 mycological findingsoccurred, out of which 57.3% findings were stenotrophic fungi. These species developed only on *Quercus robur* L. trees. The value of Menhinik's Index is increases along the gradient of recreational transformation. No correlation was found between the level of recreational transformation and value of Shannon's Index. The assessment of the evenness of wood-destroying fungi showed that the value of Pielou's Index is increased along the gradient of recreational transformation (Fig. 3). The amalysis of the occurrrence of wood-destroying fungi on different substrates showed that 66.9% of the findings were recorded on living trees of *Quercus* spp. (I – IV categories of state), 31.12% – on minor and middle branches.

Most of the findings of wood-destroying fungi on *Acer platanoides* L. also occurredon living trees, but only on their undamaged parts. The findings of wood-destroying fungi on *Carpinus betulus* L. dominated on living trees (53.3%) and the findings on *Tilia cordata* Mill. occurred only on living trees (100%). Wood-destroying fungi on *Pinus sylvestris* L. were recorded only on old deadwood or debris. The distribution of wood-destroying fungi in the myco-horizons showed that the maximum number of findings was in the photosynthesising myco-horizon (90 findings), and the minimumin the ground myco-horizon (1 finding of *Armillaria mellea* (Vahl) P. Kumm. on *Aesculus hippocastanum* L.). The analysis of the trophic composition of wood-destroying fungi at all EPs showed that the greatest number of eurytrophes of II rank on deciduous species (100.0%) was detected at EP1; eurytrophes of I rank (48.0%) – at EP4; eurytrophes of II rank on coniferous species (6.5%) were found only at EP6. The highest share of stenotrophes (63.0% of findings) was detected at EP7.

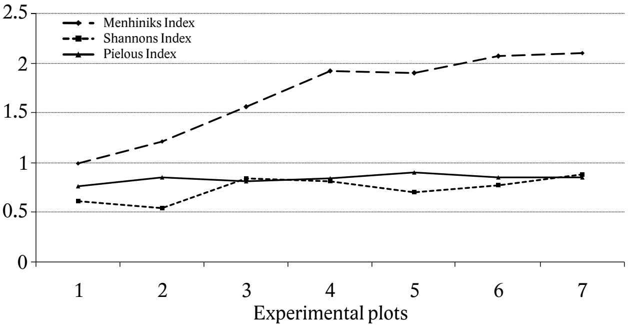

Fig. 3. Species richness of wood-destroying fungi in individual experimental plots.

3.5. Peculiarities of the studied communities

The analysis of the functioning and the development of communities between the established links in the studied parks. We constructed clusters on the base of the similarities between the individual data points using the Group Average clustering algorithm (Fig. 4). It is clear that the tree vegetation-fungi links of EP5, EP6 and EP7 are more similar one to another than to EP1-EP4. In addition, the tree vegetation-fungi links of EP1 and EP2 are more similar to each other. The obtained results need to be examined further to analyse the similarities of clusters, comparison of compositions of trees and fungi in the established communities in the parks in relation to the recreational transformation of environment in urban conditions.

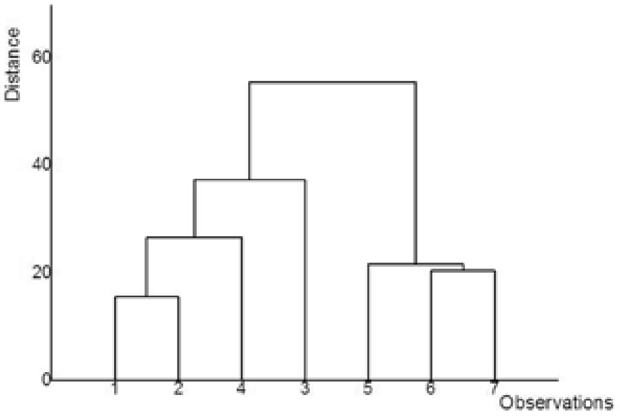

Fig. 4. Clustering Dendrogram of ecological links of parks (EP1–EP7).

PCA method was used to clarify the relationships between the compositions of trees and fungi. This method describes the variance in a dataset by linearly independent variables.

The direct dependence (in one quadrant) between the findings of xylotrophic fungi and the stand state index of woody plants was found, which is predictable for artificial phytocoenoses in urban conditions (Fig. 5). No direct dependence between the Kraft classes and the findings of xylotrophic fungi was revealed. The absence of such correlations can be explained by the differences in stand vitality betweeen parks. The inverse relationship between the age and the morphometric parameters of woody plants is explained by biological peculiarities of trees.

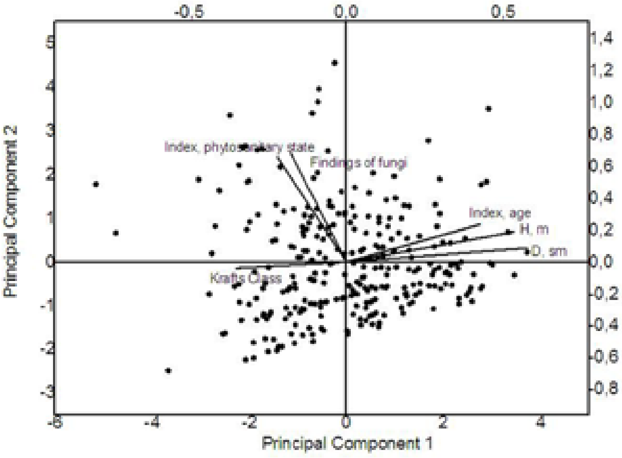

Fig. 5. Biplot of principal components by compositions of tree layer and findings of xylotrophic fungi.

4. Discussion

The relationship between the compositions of trees and fungi in urban conditions have long attracted the attention of scientists. The pioneering research by A. Shigo (1984) and his associates has produced a series of pictorial guidelines to improve the understanding of how trees respond to wounding and subsequent microbial infections that lead to wood decay.

The role of wood-destroying fungi as potential causes of stem breakage was shown on hazardous trees removed in the Megapolis (Helsinki City). The occurrence of the fungi was investigated in terms of frequency, visibility and as potential causes of stem breakage. Mechanical injuries, subsequent infections, and environmental changes are typical features of life for urban trees (Terho et al. 2007). Moreover, our results showed that the state of the communities between tree vegetation and xylotrophic fungi in urban conditions depends on the level of recreational transformation of the environment, particularly on the related changes in the structural and functional integrity of parks. The species richness of wood-destroying fungi in parks increases with the recreational transformation, which is evidenced by the values of Menhinik's Index and Pielou's Index.

The identification of common wood decay fungi associated with urban living trees is presented in the works of other authors (Dai et al. 2007). The connections between mechanical wood injuries, settlement of fungi and drying of trees; and the mechanisms of compartmentalisation are shown in these studies (Shigo 1984; Smith 2006; Shortle & Dudzik 2012). Our data on the changes in the conditions of woody plants due to transformation correspond with the results of other authors. The case study of the Kyiv City has shown that as the recreational transformation of parks increases, the interrelation of trophic, ecological and systematic compositions of xylotrophic fungi to vitality, age structure and health conditions of tree vegetation is lost.

The identification of the fungi responsible for the decay enhances both the prediction of the consequences of wood decay and the prescription of management options including tree pruning or removal. The Sudden Oak Death outbreak has drawn attention to hardwood tree species, particularly in urban forests (Glaeser & Smith 2010). Among broad-leaved tree vegetation the greatest number of findings of xylotrophs is detected on *Quercus* spp. Our results showed that health conditions of urban ecosystems with dominating woody species (*Quercus robur* L., *Q. rubra* L., *Carpinus betulus* L., *Pinus sylvestris* L., *Acer platanoides* L., *Aesculus hippocastanum* L., *Tilia cordata* Mill.) decrease from healthy to heavily weakened by level of recreational transformation of parks.

Woody species were categorised as resistant, moderately resistant, non-resistant and perishable for their non-resistance against wood-decaying fungi (Suprapti 2010). Our results showed that in the case of broad-leaved tree species, 60.1% of findings of wood-destroying fungi were detected on living trees of I – IV state categories. Xylotrophes on coniferous species were detected only on old deadwood.

Previous publications have shown the complexity of the interactions between trees, fungi and the environment from the macro to the micro level (Schwarze 2008). Our analysis of myco-horizons at macro level revealed that wood-destroying fungi develop more often in the photosynthesising myco-horizon, which is probably connected with the substantial transformation of other myco-horizons by recreants. The composition of xylotrophes changes also due to the species composition and the structure of the parks. It has been proved that the composition of xylotrophic fungi in broad-leaved and coniferous artificial phytocoenoses is not balanced, as the dispersal of xylotrophic fungi in them is limited by a lower quantity of available living and dead rooting substrate, by greater openness of stand canopy, by fewer protective properties of the herbaceous cover, and the degradation of the soil surface layer. This is in agreement with other studies, which presented the structures of pioneer fungi species in dead branches of various morphometric parameters (Rayner & Boddy 1987). The facultative species of xylotrophes with a high level of pathogenicity take an active part in the formation of the most durable forest ecosystems. The dispersal of xylotrophic fungi in such phytocoenoses is limited by the amount of the available substrate and by extremely high evaporation that depends on the canopy openness and slight development of projective cover of herbaceous storey (Zmitrovich 1997). The differences in Fungal Community Ecology resulting from the presence of different species, interactions between spatial and temporal locations within wood species, and microclimatic variation are presented too (Boddy 2001).

Hence, the inter-links between tree vegetation and xylotrophic fungi are significantly influenced by human activities.

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Appendix 1. Taxonomic and trophic compositions of xylotrophic fungi at all experimental plots.

Order	Family	Species	Trophic groups*
Corticiales	Corticiaceae	*Corticium roseum* Pers.	EI
		Dendrothele acerina (Pers.) P.A. Lemke	E2d
		Vuilleminia comedens (Nees) Maire	E2d
Hymenochaetales	Hymenochaetaceae	*Hymenochaete rubiginosa* (Dicks.) Lév.	E2d
		Phellinus ferruginosus (Schad.) Pat.	E1
		P. robustus (P. Karst.) Bourdot et Galzin	E2d
	Schizoporaceae	*Basidioradulum radula* (Fr.) Nobles	E2d
		*Schizopora flavipora (*Berk. et M.A. Curtis ex Cooke) Ryvarden	E1
		S. paradoxa (Schrad.) Donk	E1
	Tubulicrinaceae	*Hyphodontia sambuci* (Pers.) J. Erikss.	E2d
Polyporales	Ganodermataceae	*Ganoderma lucidum* (Curtis) P. Karst.	E1
	Meruliaceae	*Phlebia radiata* Fr.	E2d
	Polyporaceae	*Fomes fomentarius* (L.) Fr.	E2d
		Trichaptum biforme (Fr.) Ryvarden	E2d
		T. hollii (J.C. Schmidt) Kreisel	E2c
Russulales	Peniophoraceae	*Peniophora cinerea* (Pers.) Cooke	E2d
		P. quercina (Pers.) Cooke	E2d
		P. rufomarginata (Pers.) Bourdot et Galzin	S
	Stereaceae	*Stereum hirsutum* (Willd.) Pers.	E2d
Agaricales	Agaricaceae	*Agaricus squarrosus* Oeder	E1
	Cyphellaceae	*Chondrostereum purpureum* (Pers.) Pouzar	E2d
	Physalacriaceae	*Armillaria mellea* (Vahl) P. Kumm.	E1
		Cylindrobasidium evolvens (Fr.) Jülich	E2d
	Pterulaceae	*Radulomyces molaris* (Chaillet ex Fr.) Christ.	E2d
	Schizophyllaceae	*Schizophyllum commune* Fr.	E1
	Strophariaceae	*Hypholoma fasciculare* (Huds.) P. Kumm.	E1
Boletales	Coniophoraceae	*Coniophora arida* (Fr.) P. Karst.	E1

Note: *Eurytrophes of I rank (E1), eurytrophes of II rank on deciduous trees (E2d), eurytrophes of II rank on coniferous trees (E2c), stenotrophes (S).

Appendix 2. Distribution of xylotrophic fungi in myco-horizons at all experimental plots

No.	Fungi-consorts	Trees-edificators of consortium	Myco-horizons* 1	2	3	4	5
1	*Agaricus squarrosus* Oeder	*Quercus robur* (1)	—	—	1/5,6	—	—
2	*Armillaria mellea* (Vahl) P. Kumm.	*Aesculus hippocastanum* L. (1)	1/100,0	—	—	—	—
3	*Basidioradulum radula* (Fr.) Nobles	*Quercus robur* L. (2)	—	2/5,4	—	—	—
4	*Chondrostereum purpureum* (Pers.) Pouzar	*Frangula alnus* Mill. (1)	—	—	1/5,6	—	—
5	*Coniophora arida* (Fr.) P. Karst.	*Pinus sylvestris* L. (1)	—	—	1/5,6	—	—
6	*Corticium roseum* Pers.	*Acer platanoides* L. (2), *Quercus robur* L. (3)	—	3/8,1	—	—	2/2,2
7	*Cylindrobasidium evolvens* (Fr.) Jülich	*Quercus robur* L. (2)	—	—	—	—	2/2,2
8	*Dendrothele acerina* (Pers.) P.A. Lemke	*Acer platanoides* L. (14)	—	—	8/44,4	6/35,3	—
9	*Fomes fomentarius* (L.) Fr.	*Aesculus hippocastanum* L. (1)	—	—	1/5,6	—	—
10	*Ganoderma lucidum* (Curtis) P. Karst.	*Quercus robur* L. (1)	—	—	1/5,6	—	—
11	*Hyphodontia sambuci* (Pers.) J. Erikss.	*Sambucus nigra* L. (4)	—	—	2/11,1	2/11,8	—
12	*Hypholoma fasciculare* (Huds.) P. Kumm.	*Carpinus betulus* L. (1)	—	—	1/5,6	—	—
13	*Hymenochaete rubiginosa* (Dicks.) Lév.	*Quercus robur* L. (1)	—	—	1/5,6	—	—
14	*Peniophora cinerea* (Pers.) Cooke	*Aesculus hippocastanum* L. (1), *Quercus rubra* L. (1)	—	1/2,7	—	—	1/1,1
15	*P. quercina* (Pers.) Cooke	*Quercus robur* L. (13)	—	4/10,8	—	—	9/9,7
16	*P. rufomarginata* (Pers.) Bourdot et Galzin	*Tilia cordata* Mill. (11)	—	—	—	—	11/11,8
17	*Phellinus ferruginosus* (Schad.) Pat.	*Quercus robur* L. (9)	—	6/16,2	—	—	3/3,2
18	*P. robustus* (P. Karst.) Bourdot et Galzin	*Quercus robur* L. (6)	—	—	—	4/23,5	2/2,2
19	*Phlebia radiata* Fr.	*Carpinus betulus* L. (1)	—	—	—	1/5,9	—
20	*Radulomyces molaris* (Chaillet ex Fr.) Christ.	*Quercus robur* L. (14)	—	5/13,5	—	—	9/9,7
21	*Schizopora flavipora* (Berk. et M.A. Curtis ex Cooke) Ryvarden	*Quercus robur* L. (1)	—	—	—	—	1/1,1
22	*S. paradoxa* (Schrad.) Donk	*Carpinus betulus* L. (8), *Frangula alnus* Mill. (1), *Quercus robur* L. (5)	—	1/2,7	—	3/17,6	10/10,8
23	*Schizophyllum commune* Fr.	*Acer platanoides* L. (1), *Quercus robur* L. (1)	—	2/5,4	—	—	—
24	*Stereum hirsutum* (Willd.) Pers.	*Aesculus hippocastanum* L. (3), *Carpinus betulus* L. (1), *Quercus robur* L. (3)	—	1/2,7	1/5,6	1/5,9	4/4,3
25	*Trichaptum biforme* (Fr.) Ryvarden	*Quercus robur* L. (1)	—	1/2,7	—	—	—
26	*T. hollii* (J.C. Schmidt) Kreisel	*Pinus sylvestris* L. (1)	—	1/2,7	—	—	—
27	*Vuilleminia comedens* (Nees) Maire	*Carpinus betulus* L.(3), *Quercus robur* L. (46)	—	10/27,0	—	—	39/41,9
All together species /findings:		9/166	1/1	12/37	10/18	6/17	12/93
% of species / findings:			3,7/0,6	44,4/22,3	37,0/10,8	22,2/10,2	44,4/56,0

Note: * - pcs./%; 1 – root; 2 – ground; 3 – stem base; 4 – stem; 5 – photosynthesising myco-horizon; "—" – not detected.

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REVIEW PAPER

Wind – an important ecological factor and destructive agent in forests

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Abstract

Wind is both an ecological provider and disturbance facilitator influences trees and other organisms in forests. Impacts of wind on induvidual trees and forests mainly depend on the strength (or intensity) of the wind and the stability of the trees. Wind causes large-scale damage to forests and serious economical losses for the forestry sector within Europe. Therefore, knowledge of interactions between wind and trees and/or forests provides the baseline for developing adequate prevention or mitigation of the negative consequences associated with wind disturbances in forest ecosystems. Herein, we analyse the wind as an ecological and disturbance factor in forests in Europe, emphasising forests in Slovakia. Here, strong winds destroy mostly spruce dominated forests in the following regions; Orava, High and Low Tatra Mountains, Great Fatra Mountains, Pohronie, Poľana Mountains and Slovak Ore Mountains. Increasing volumes of timber damaged by windstorms have been documented since 1961, with the maximum damage recorded in 2004. Yearly volumes of damaged timber of approximately 2.5 mil. m^3 are predicted from 2016 to 2030. This highlights the data requirement regarding wind disturbances for integrated forest protection against dangerous winds and other disturbance agents in forest ecosystems in Slovakia and other European countries.

Key words: wind; forest damage; climate change; Slovakia; Europe

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1. Introduction

Wind is one of the most important disturbance dynamics and ecological factors in many types of ecosystems (Ennos 1997). In forest ecosystems, wind influences trees directly e.g. by damaging stems or uprooting, or indirectly e.g. through modifying temperature and soil moisture. Over time, the prevailing wind can shape the morphology of trees. A good example of this are dwarf-like tree forms, flag-like asymmetric tree crowns, converging stems, leaning stems (Fig. 1), asymmetric cross-sectional stem profiles, compressive and tensile wood (Zhu et al. 2004). Influence of wind on forest trees and stands depends on wind strength. Low intensity winds usually do minimal damage to forests, however, strong winds may cause serious damage. As strong winds are infrequent, they only damage forests occasionally. Strong winds destroy interim unstable trees (e.g. trees growing in soils excessively saturated with water) and their stands become unstable in the long-term due to inadequate forest management. Gardiner et al. (2016) classified the types of wind damage to forests from negligible to fatal. He recognized, for example, microscopic damage to foliage, partial or total defoliation, branch breakage, breakage or uprooting at the tree level, gap formation at the community level, and successional changes across space, at a regional level.

Wind influences physiological processes in trees and modifies mechanical and technical properties of wood (Peltola et al. 1999; Gardiner & Quine 2000; Konôpka B. 2000; Zhu et al. 2004). It promotes the dispersal of fungal spores, plant pollen and seeds, and regulates spatial distribution of forest flora and fauna (Grubb 1975; Kozlowski et al. 1991; Belanger & Arbas 1998; Wyatt 2003; Zhu et al. 2004).

Herein, we focus on wind as an important ecological factor and disturbance agent in forest ecosystems and present some of the negative consequences of wind disturbances in European forests, with emphasis on forests in Slovakia.

2. Wind as an ecological factor and disturbance agent

Wind is essential to deliever precipitation, crucial for all types of forest ecosystems (Coutts & Grace 1995). Wind affects evaporation, transpiration, spatial distribution of snow, and regulates temperature and moisture regime in forests (Zhu et al. 2004; Konôpka B. & Konôpka J. 2009). In arid regions with aeolian sand soils, wind causes intensive erosion (Coutts & Grace 1995; Zhu et al. 2004) and may substantially modify the relief (Krippel 1965). Wind contributes to the transportation of industrial pollutants, some of which can affect tree health (Jaffe et al. 1995; Vančura et al. 2000). Wind often transfers sharp particles of various origin and chemical composition. These may cause the abrasion of bark and damage foliage and reproductive organs (Zhu et al. 2002b). Wind also moves particles (e.g. crystals of salt from the sea) causing the intoxication of foliage (Fig. 2). Wind is

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Fig. 1. Leaning stems of Scots pine trees (*Pinus sylvestris*) in the alley shaped by the wind. Photo: B. Konôpka.

Fig. 2. Browning of pine needles due to intoxication with salt brought by the winds from the Mediterranean Sea. Intoxication decreases with the distance from the sea edge. Photo: B. Konôpka.

often in a synergistic relationship to other factors in forests. It promotes forest fires (Letelier et al. 1988) and creates favourable conditions for dissemination of pathogenic organisms, such as viruses, fungi, phytophagous insects etc. (Barnes et al. 1998).

While a breeze or low wind operate almost always in forests, strong winds are much less frequent, and cause disturbances varying in intensity. Disturbance is defined as an event which changes (impair) structure of populations, communities and ecosystems, influences resources and the availability of substrates for organisms, and modifies physical properties of the environment (White & Pickett 1985). Wind disturbances operate independently from or in combination with other disturbances (Letelier et al. 1988). Wind can temporally cause cascade disturbances (Dale et al. 2001). Temporal and spatial occurrence, frequency and intensity, as well as the extent of natural disturbance depends on local, regional and global processes, especially changes in the atmosphere and in particular, the temperature regimes and rainfall (Baker 1995). Models of global climate change suggest stimulative effects of inherent phenomena of changing climate on destructive processes in ecosystems (He et al. 1999). Various modelled future scenarios predict an increase in frequency and intensity of storms (Schönenberger 2002).

“Catastrophic winds” such as storms, hurricanes, tornadoes or typhoons influence forests all over the world (Zhu et al. 2004). Strong winds break branches, stems or uproot trees and result in lower densities of trees in forests due to increased tree mortality (Dale et al. 2001; Zhu 2004; Konôpka B. & Konôpka J. 2009). Knock out of trees by the wind is associated with structural changes in forest ecosystems (Odum 1983). More heterogeneous (structured) forests provide open patches (gaps) and an environment created to develope future generations of trees (Ennos 1997). Very strong winds are known to modify the structure of both pioneer and climax forests (Valinger et al. 1993; Gardiner 1995; Zhu et al. 2002a).

Changes in forest structure caused by wind can be classified as follows: (i) primary damage, occurring within a few hours or a couple of days after wind disturbance, is direct, people may be injured and properties and infrastructure may be destroyed; (ii) secondary damage, recorded over a couple of weeks, months or years after disturbance, is successive and caused by various harmful agents taking part in the process; (iii) tertiary damage, documented over many years or even decades after disturbance, is mainly seen in socio-economic relationships (e.g. forest utilization by man with regard to the availability of resources, esthetical values of forests, other ecosystem services, market and prices, employment possibilities etc). Changes in forest structure due to wind disturbances reflect varying interactions (often synergistic) between the wind velocity, duration of wind, local relief, site and stand characteristics such as water content in soil, tree species composition, tree height, tree density, tree health (Gardiner et al. 2016).

Probability that the trees and forest stands will be damaged by the wind is determined by three groups of factors: (i) weather conditions, (ii) site conditions, and (iii) properties of forest stands (Cremer et al. 1982; Schindler et al 2012). Influence of the wind on forests is geographically specific and the frequency of disturbance differs between regions (Quine 2003). Wind direction, frequency and intensity are influenced by relief (Hannah et al. 1995), and there are no management techniques to deal with this kind of factors (Matsuzaki 1994). Influence of windstorms on forests can be mitigated in part, e.g. by management practices in the type of silviculture and forest protection (Mitchell 2013; Konôpka B. & Konôpka J. 2009; Zhu et al. 2004).

Since wind disturbances are stochastic events, it is not possible to predict their exact occurrence in time and space (Schelhaas et al. 2003b). Temporal and spatial occurrence of winds and their influence on stability and sustainability of forest ecosystems are continuously detected and analysed by modern methods and data processing, e.g. using automatized field devices for continuous measurement, computer tools of GIS, approaches of mathematical modelling etc. (Schelhaas et al. 2002; Blennow & Sallnäs 2004; Zeng et al. 2010).

3. Wind disturbances in Europe

Wind is one of the most relevant natural disturbance factors in Europe. Between 1950 and 2000, wind contributed to 35% of the overall damage from natural disturbance in

European forests, this was followed by forest fires, snow, phytophagous insects and other factors (Schelhaas et al. 2003a). Negative impacts of disturbances on European forests have been increasing during the last 150 years (Gardiner et al. on: www.efi.int). The same is true for disturbances in spruce forests in the eastern Carpathians since 19th century (Svoboda et al. 2014). The gradually increasing damage to forests within Europe has evoked numerous discussions about the causes (Lässig & Schönenberger 2000). Some link this phenomenon to climate change and its inherent processes (Schönenberger 2002; Blennow & Olofsson 2008), while others carefully judge inaccurateness and incompleteness of records from the past (Gardiner et al. on: www.efi.int). Unsuitable forest management resulting in even-aged monocultures, especially those of Norway spruce (*Picea abies*), is also considered as an important source of damage to forests where stands with high stocking density are more prone to wind damage when reaching critical height (Schelhaas et al. 2003b; Mitchell 2013).

The influence of wind on forests varies in frequency and intensity acorrs Europe. The most destructive cases of forest damage are reported from the temperate and boreal zones, especially spruce dominated forests (Peltola et al. 2000; Schönenberger 2002; Skuhravý 2002). Large-scale wind disturbances seriously affect all of the components of forest ecosystems and often cause serious socio-economical impacts, especially in densely populated regions. Even low intensity wind disturbance can cause serious disturbance in urbanized areas through damage to infrastructure and/or alteration of quality of life. On the other hand, large-scale wind disturbances in remote, non-populated areas and regions, e.g. in Siberia, may not cause any serious problems and, often, they are not documented and may remain undetected (Skuhravý 2002).

Serious wind disturbances associated with bark beetle outbreaks within Europe were summarized by Skuhravý (2002). Over the period 1990 – 2010 European forests were hit by several intensive wind disturbances which markedly modified forests and landscapes and had a negative influenced on socio-economical functions. For example, large-scale wind disturbances in western and central Europe were caused by the orkan Viviene (Vivian) on 28 – 29 February 1990, and orkan Wiebke on 29 February – 1 March 1990 (Skuhravý 2002). At that time, as much as 72.5 million m^3 of timber was damaged in Germany (Schelhaas et al. 2003b). In December of the same year, the storms Lothar and Martin hit France, Switzerland and Germany (Skuhravý 2002), causing serious damage to forests. Extremely strong windstorm Erwing (Gudrun) hit mostly Northern Europe on 8 – 9 January 2005. In Sweden only, it damaged a total of 270 thousand hectares of forests (77.5 million m^3 of timber). In January 2009, the windstorm Kiryll swept over western and central Europe and also caused serious damage to forests in Germany, the Netherlands, France and Britain. An extremely strong windstorm Klaus hit on 24 January 2009, damaging approximately 684 thousand hectares of forest (e.g. 45 million m^3 of timber) (Gardiner et al. on: www.efi.int). The majority of excessive wind disturbances within Europe were recorded during the winter when large-scale disturbances are often accompanied or followed by numerous smaller ones.

Attempts to create a comprehensive data set about natural disturbances in forests in Europe were reflected in the activities of the European Forest Institute, with the aim to summarize abiotic, biotic and anthropogenic disturbances in specific countries in the Database of Forest Disturbances in Europe (Schelhaas et al. 2003b). This database contains, for example, information about damage to forests around Nürmberg, Germany, by non-specified leaf-eating caterpillars in 1449 and 1450. The first record of a windstorm included in this database is from Buisson de Bleu in Normandy, France, where a total of 66 thousand trees were damaged on 15 March 1519. Quantity and quality of historical records about natural disturbances in forests varies amongst countries and regions. For example, rich datasets about forest fires are available from Spain and numerous historically valuable datasets about forest disturbances are available in Germany. A list of the most severe wind disturbances during the last few centuries (up to 2015) is available from Wikipedia (link: en.wikipedia.org/wiki/List of European windstorms).

In Slovakia data on forest damage by regional and disturbance regime is regularly collected, processed and archived by the Forest Protection Service in Banská Štiavnica within the National Forest Centre, Forest Research Institute in Zvolen. Data exists since the end of World War II, more detailed information (broken by damage with regard to harmfull agents) is available for the last 55 years.

When observing forest ecosystems worldwide, damage caused by wind disturbance is not as significant as other disturbance mechanisms. For example, a severe decline in *Pinus contorta* has been monitored long-term in the forests of western Canada e.g. in the proviences of British Columbia and Alberta. The decline is mainly caused by synergistic effects of a large sacle outbreak in the bark beetle *Dendroctonus ponderosae* (Scolytinae), milder winters attributed to long-term changing climate and forestry practices such as the suppression of forest fires resulting in large areas of even-aged monocultures of pine. Between 1995 and 2008 severe and widespread damage to pine forests was documented over 14 million hectares (Westfall 2007; Raffa et al. 2008; Robertson et al. 2009; Kärvemo 2010). This area is approximately 7-times larger than the total forest area in Slovakia. Nevertheless, declining mature stands of *P. contorta* are being replaced by young forests composed of pioneer tree species, including pine (R. Alfaro, personal comm.). However, damage to forests cannot be judged by magnitude only. For small countries such as Slovakia, disturbances on a smaller scale may be crucial for the locals and the community.

4. Wind disturbances in Slovak forests

Wind is amongst the most important abiotic factors and harmful disturbance agents in forests in Slovakia (Konôpka J. et al. 2008). Over the last 55 years, there has been an increasing trend in damage caused by wind disturbance in Slovak forests. This is well documented in Konôpka B. & Konôpka J. (2009) where the mean annual volume of timber damaged by wind between 1999 and 2008 was 3.3-fold that of timber damage between 1969 and 1978. The volumes of fallen timber increased after a severe wind disturbance on

19 November 2004 (Kunca et al. 2015). This disturbance markedly modified forests, especially in the High Tatra and Low Tatra Mountains (Kunca & Zúbrik 2006), whereas the impact was less pronounced in nearby mountain regions. In the High Tatra Mountains, this unexpected storm damaged mostly spruce-dominated stands across approximately 12.5 thousand hectares. The estimated volume of damaged timber was as high as 2.5 million m^3 (Koreň 2005), nearly half of the 5.2 million m^3 total volume of damaged timber in Slovakia in 2005 (Konôpka B. & Konôpka J. 2009). Large spruce stands adjacent to the disturbed area were consequently destroyed by bark beetles, the most important of which was the Spruce bark beetle *(Ips typographus)* (Nikolov et al. 2010). The outbreak of *I. typographus* in the Tatra Mountains, persisted until the end of 2014, shifting in space and over time (Zach et al. 2015). After the wind disturbance in November 2004 the amounts of timber damaged by subsequent bark beetle disturbance exceeded the timber damaged by the initial windstorm (Konôpka et al. 2011). This occurred mainly in regions where timber remained unmanaged and unprocessed i.e. without salvage logging (Nikolov et al. 2014).

Damage by strong wind in Slovakia prevailingly occur in spruce dominated forests. For instance, between 1998 and 2007 as much as 2/3 of total damaged timber was damage to spruce trees (Konôpka B. & Konôpka J. 2009). Excessive damage to spruce stands relates to their unfavourable stability due to shallow roots and dense exposed crowns that intercept the wind (Stolina et al. 1985). However, the stability of spruce stands also changes with altitude. Spruce stands in Slovakia are relatively stabile in high altitudes, especially within the spruce vegetation tier above 1250 m a.s.l (Konôpka B. & Konôpka J. 2003). Generally, the number of trees per square unit decreases with altitude. Spruce trees in high altitudes are usually of uneven ages and heights, the canopy is more open, stems are more convergent, crowns are longer, buttresses and roots are larger and trees are well anchored in the soil (Konôpka J. 1977). This enhances the stability of spruce stands related to the performance of the wind (Stolina et al. 1985), even though the wind velocity increases with altitude (Coutts & Grace 1995).

The probability of wind damage in spruce forests, especially in even-aged stands, increases rapidly after a sudden decrease in tree density due to managed thinning or other events that cause selective tree mortality, or due to the creation of new forest edges. Even small alteration of structure (compactness) of a spruce stand may increase the risk of damage from the wind (Mitchell 2013; Zeng et al. 2010). Other factors influencing the stability of spruce stands include e.g. forest fragmentation which exposes individual trees to the wind and bark beetles (Wermelinger 2004; Zach et al. 2009, 2010, 2016) and increased mortality of trees in forests due to intensified disturbance from harmful agents (e.g. bark beetles) related to climate change (Konôpka B. 2007).

Considering the risk of forest destruction by wind in Slovakia, dangerous winds are those of the seventh degree (Stolina et al. 1985) or eighth degree (Konôpka B. & Konôpka J. 2009) of the Beaufort wind force scale. Specifically, the seventh degree represents “moderate gale” with wind speeds of 13.9 – 17.1 m s^{-1} (50 – 61 km h^{-1}) at which trees in a forest are intensively swaying and walking against the wind becomes difficult. The eight degree is a “gale” with wind speeds of 17.2 – 20.7 m s^{-1} (62 – 74 km h^{-1}) that usually breaks branches off trees and walking against the wind is nearly impossible. Based on the analyses of spatial occurrence of winds across Slovakia (Slovak Hydrometeorological Institute, 1971 – 2010) the frequency of dangerous winds is highest in the Low Tatra and the High Tatra Mountains. Both regions experience frequent windstorms but damage in forests here is usually scattered and occurs in relatively small patches (Konôpka B. & Konôpka J. 2009).

According to Koreň (2005) the windstorm that destroyed the spruce forests in the High Tatra Mountains on 19 November 2004 consisted of two main currents: (1) diffusive westerly wind and (2) northerly wind (bora) from over the mountain ridges to the valleys. Although the wind damaged forest stands in high altitudes, especially in valleys, most of the damage occurred in the foothills and in flat open areas of the Podtatranská kotlina Basin (Fig. 3). The highest numbers of damaged spruce trees (mostly uprooted) were recorded in the wetlands and, specifically, in the Kežmarské Žľaby area. The spruce trees that were damaged had weak root anchorage as their root systems were shallow and saturated with water reducing the cohesion between the roots and soil (Konôpka B. et al. 2010b). The wind disturbance in Novem-

Fig. 3. Large-scale wind disturbance in a mature Norway spruce stand (Podtatranská kotlina Basin, 19 November 2004). Photo B. Konôpka.

Fig. 4. Windstorm on 15 May 2014 damaged also man-made stands of Scots pine (*Pinus sylvestris*) and European larch (*Larix decidua*). Broken and uprooted 8 years old pine trees were documented near Nový Smokovec in the Tatra National Park. Photo: B. Konôpka.

ber 2004 occurred mainly at sites where similar events have been previously documented (Koreň 2005). It was connected with extremely strong wind, the velocity of which varied from 160 km h^{-1} in lower altitudes up to 200 km h^{-1} on mountain ridges (Kunca & Zúbrik 2006).

Another severe, large-scale wind disturbance in Slovakia was 15 May 2014. This partly overlapped in area with the November 2004 storm however, the affected area was smaller. In this particular case, the wind also damaged young pine and larch stands in planted forests (Fig. 4). Such damage can be explained by heavy rains which excessively saturated the soil, decreasing the stability of trees resulted in high numbers of locally uprooted or broken trees (Pajtík et al. 2015).

Direction, velocity and the effects of winds on forests in Slovakia can be related not only to synoptic-meteorological circumstances, but also the geography (diverse relief) of the western Carpathians (Konôpka J. et al. 2008). The relief determines varying exposition of forest stands to wind. The probability of wind damage to forest stands varies over the segmented relief. Generally, the more diverse the relief the more heterogeneous "behaviour" of the wind. In mountain areas, wind most frequently causes damage to forests in valleys, especially if the valleys follow the most dangerous wind direction and in places where the wind is funneled into a vally bend. Falling wind from mountain ridges accelerates fast (Stolina et al. 1985) and strong wind currents damage forests on the slopes and foothills.

In eastern Slovakia the prevailing direction of dangerous winds is from the north. In southwestern Slovakia, the most dangerous winds come from the northwest, followed by winds from the north and the west. In central Slovakia, heterogeneous relief means the direction of dangerous winds varies. However, considering Slovakia as a whole, southwesterly and northerly winds prevail (Konôpka J. et al. 2008).

In central Europe, the forests are exposed to dangerous winds, mainly in November, March and April (Stolina et al. 1985). Nearly half of the dangerous winds in Slovakia are recorded in winter (Konôpka B. & Konôpka J. 2009). Long-term analyses of meteorological records do not prove significant changes in frequency of dangerous winds compared to the past (Konôpka B. et al. 2010a). However, some modifications in seasonal distribution of dangerous winds exist (Fig. 5). Specifically, they include an increase in the number of dangerous windstorms in the spring and in contrast, a decrease in windstorms during the winter and summer. Further, changes in the direction of dangerous winds may be noticed, for example an increase in prevelance of the "traditional" nortwesterly winds (Table 1).

Table 1. Share of dangerous winds (velocity over 62 km h^{-1}) by direction (in percentages) over the period 1961–1990 and 1991–2010 in Slovakia (after B. Konôpka et al. 2010a, modified).

Period	N	NE	E	SE	S	SW	W	NW	Total
1961–1990	25	3	1	4	23	9	8	27	100
1991–2010	23	3	1	2	21	8	8	34	100

Explanations for main wind directions: N – north, NE – northeast, E – east, SE – southeast, S – south, SW – southwest, W – west, NW - northwest.

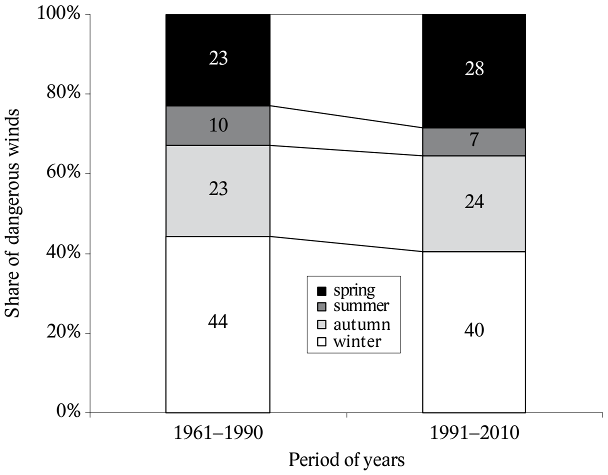

Fig. 5. Share of dangerous winds (velocity over 62 km h^{-1}) in Slovakia over the period 1961–1990 and 1991–2010 (after B. Konôpka et al. 2010a, modified).

Spruce stands in Slovakia are the most frequently damaged by wind in the northern and central regions (Konôpka B. & Konôpka J. 2009), namely in the regions of Orava, High Tatra and Low Tatra Mountains, Great Fatra Mountains, Pohronie, Poľana Mountains and Slovak Ore Mountains. Despite relatively good knowledge about spatial and temporal occurrence of dangerous winds, it is impossible to predict precisely the time, location and size of future wind disturbances in forests. Based on the extrapolation of the time series data on wind damage in the Slovak forests, it can be predicted that windstorms in this country will damage about 2.5 million m^3 of timber annually from 2016 to 2030 (Fig. 6). However, this is a rough estimate as damage to forests by wind will strongly depend on future weather which cannot be adequately predicted in the long-term.

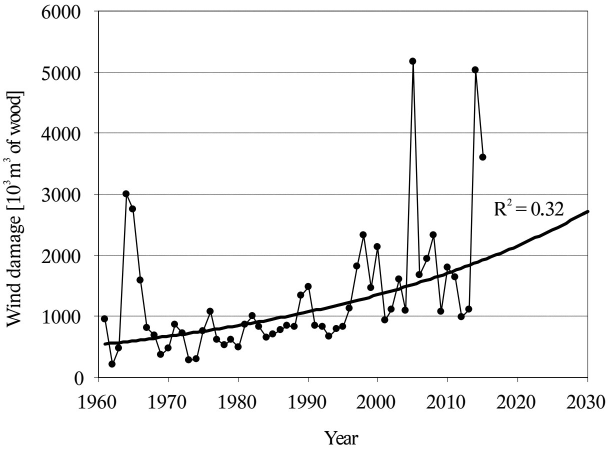

Fig. 6. Development of wind damage to forests in Slovakia between 1961 and 2015 in volumes of salvage felling (source: Forest Protection Service) and prediction up to 2030 as extrapolation by exponential function.

5. Conclusion

Wind is an important ecological factor affecting development, growth and reproduction of trees in forested ecosystems. Understanding interactions between wind and trees provides a baseline for prevention or mitigation of the negative impacts assocated with wind disturbances on forests worldwide. Forest destruction by wind and/or other harmful agents is a complex interaction, negatively influencing carbon reserves. The loss of carbon stored in tree biomass and forest soil is apparent in forests disturbed by wind. Forest recovery, to the former situation is long, usually taking several decades.

Since stimulating effects of inherent phenomena of climate change on frequency and intensity of destructive events in forests are associated with changes in carbon balance, the relationships (cycle) can be described as a positive feedback system as follows: climate change → induced disturbances to forest ecosystems → stimulated climate change. In the case of wind disturbances, there are no direct or immediate effective measures to eliminate the associated risks. However, conclusions can be made in the case of bark beetles, as early processing and removal of wind damaged and/or infested timber may mitigate or locally eliminate the outbreak. Thus, integrated forest protection becomes very important part of the forestry in the conditions of global change. It is also important in terms of stabilizing forest ecosystem services, especially with regard to carbon sequestration.

Knowledge on wind disturbances show that integrated forest protection against strong winds and other harmful agents in forest ecosystems in Slovakia and, highly likely, in other countries within Europe, will become important in the near future in the light of predicted global change.

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Aktuálne problémy v ochrane lesa 2016 – 25. ročník medzinárodnej konferencie

Medzinárodná konferencia „Aktuálne problémy v ochrane lesa 2016“ sa konala v dňoch 21. – 22. 1. 2016 v priestoroch Kongresového centra Kúpeľov Nový Smokovec, a. s. Organizačným garantom bola Lesnícka ochranárska služba Banská Štiavnica. Hlavnou témou už 25. ročníka bol zdravotný stav lesov po vetrovej kalamite Žofia z 15. 5. 2014, hynutie smrečín, kalamitné premnoženie podkôrneho hmyzu, premnoženie listožravého hmyzu, poškodzovanie sadeníc smreka tvrdoňom smrekovým *Hylobius abietis,* ohrozenie lesov Slovenska inváznymi organizmami a škody zverou a na zveri. Tieto témy odzneli počas 2 dní v 28 prezentáciách. Konferencie sa zúčastnilo 152 platiacich účastníkov, ktorým bol pri registrácii k dispozícii zborník referátov z konferencie s 30 článkami: Kunca, A. (ed.), 2016: Aktuálne problémy v ochrane lesa 2016. Zborník referátov z medzinárodnej konferencie konanej 21. – 22. 1. 2016 v Kongresovom centre Kúpeľov Nový Smokovec, a. s., Národné lesnícke centrum, Zvolen, 170 p. ISBN 978-80-8093-214-5.

Konferenciu otvoril generálny riaditeľ Národného lesníckeho centra Ing. Ľuboš Németh. V príhovore pripomenul základné problémy ochrany lesa, ktoré sa objavili po vetrovej kalamite Žofia z 15. 5. 2014. Pripomenul význam Lesníckej ochranárskej služby, ktorú zabezpečujú výskumní pracovníci Lesníckeho výskumného ústavu Zvolen a vďaka svojej odbornosti a skúsenostiam významne prispievajú k riešeniu praktických problémov ochrany lesa na Slovensku. Za Ministerstvo pôdohospodárstva a rozvoja vidieka SR za prihovoril účastníkom Ing. Jozef Spevár, štátny tajomník Ministerstva pôdohospodárstva a rozvoja vidieka. Za sekciu lesného hospodárstva a spracovania dreva vystúpil s prezentáciou jej generálny riaditeľ, Ing. Ctibor Határ. Zo zahraničných hostí vystúpil Ing. Miloš Knížek, PhD. z Výzkumního ústavu lesního hospodářství a myslivosti Praha a Dr. hab. Wojciech Grodzki, prof. IBL z Lesníckeho výskumného ústavu v Krakowe v Poľsku.

Druhý blok prezentácií bol venovaný dopadom vetrovej kalamity Žofia z 15. 5. 2014 na zdravotný stav lesov. S prezentáciami vystúpili za lesnícku prevádzku Ing. Peter Líška, riaditeľ ŠL TANAP-u a Ing. Jozef Bystriansky, výrobno-technický riaditeľ Lesy SR, š. p., za Lesnícku ochranársku službu Ing. Jozef Vakula, PhD. a Ing. Juraj Galko, PhD. Kým zástupcovia lesníckej prevádzky informovali o škodách na porastoch a prognóze vývoja, zástupcovia LOS upozorňovali na vplyv extrémov počasia na vývoj sekundárnych škodcov a ich hostiteľov v okolí kalamitných plôch. Taktiež bol dôraz kladený na drevokazných škodcov, ktorí môžu poškodzovať drevo na odvozných miestach alebo výrezy na skladoch dreva.

Tretí blok prezentácii bol zameraný na prezentáciu škôd spôsobovaných zverou a na zveri. Vystúpili pracovníci Lesníckej ochranárskej služby so štatistikou škôd na lesoch (Ing. Peter Kaštier, PhD.), za lesnícku prevádzku Ing. Jozef Staško (OZ Sobrance) poukázal na nárast škôd v oblasti Slánskych a Zemplínskych vrchov. Možnostiam zladenia chovu raticovej zveri a pestovania lesa sa venoval doc. Ing. Jozef Konôpka, CSc., príklad právneho vzťahu praktickej ochrany lesa oplôtkami prezentovala Mgr. Katarína Sujová, PhD. Problematika škôd zverou rezonovala v spoločnosti už niekoľko mesiacov. Výsledkom rokovaní zástupcov Slovenskej lesníckej komory, Slovenskej poľovníckej komory a Slovenskej poľnohospodárskej a potravinárskej komory bolo ich spoločné memorandum, ktorého aktuálne znenie predstavil predseda Slovenskej lesníckej komory Ing. Jaroslav Šulek.

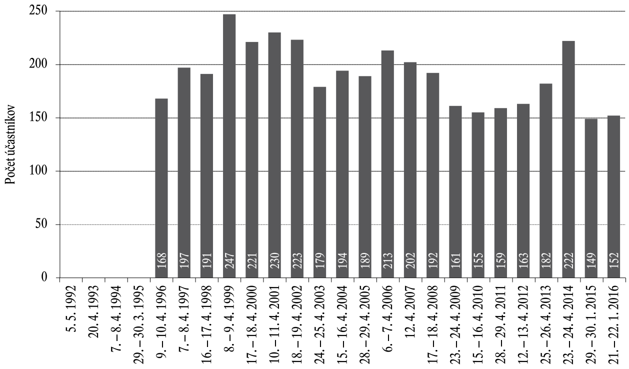
Štvrtý blok bol zameraný na lesnú hospodársku evidenciu z oblasti ochrany lesa. Na niektoré logické chyby vo výkazoch upozornil Ing. Andrej Kunca, PhD., ďalší zástupca LOS Banská Štiavnica Ing. Christo Nikolov, PhD. informoval o internetovom nástroji určenom na mapovanie výskytu škodlivých činiteľov v lesoch Slovenska a Ing. Milan Zúbrik, PhD. predstavil internetový atlas škodlivých činiteľov lesov strednej Európy.

V druhý deň rokovania pokračovali prezentácie o poznatkoch výskumu získaných v Lesníckom výskumnom ústave Zvolen, ale aj na SAV - Ústav ekológie lesa, Pobočka biológie drevín Nitra, na Výskumnej stanici ŠL TANAP-u a v České zemědělskej univerzite Praha. Odzneli príspevky o prebiehajúcom európskom monitoringu inváznych druhov hmyzu a húb, o ojedinelom výskyte podkôrneho hmyzu *Dendroctonus micans* na smreku východnom a pichľavom na Slovensku a v Čechách, o karanténnej hube *Gibberella circinata*, o potenciálnych problémoch so zdravotným stavom nepôvodnej rýchlorastúcej drevine Paulownia, a o metodike hodnotenia požiarov na Slovensku. V poslednom bloku pokračovali témy lesníckeho výskumu, napr. výskum biologických metód ochrany sadeníc pred tvrdoňom smrekovým, voltinizmus (počet generácií za rok) lykožrúta smrekového v Tatrách, mechanická stabilita stromov pred nárazmi vetra, analýza štruktúry dendromasy smrekového lesa poškodeného lykožrútom smrekovým a bez poškodenia a sekvestrácia uhlíka v biomase mladých lesných porastoch po vetrovej kalamite Alžbeta.

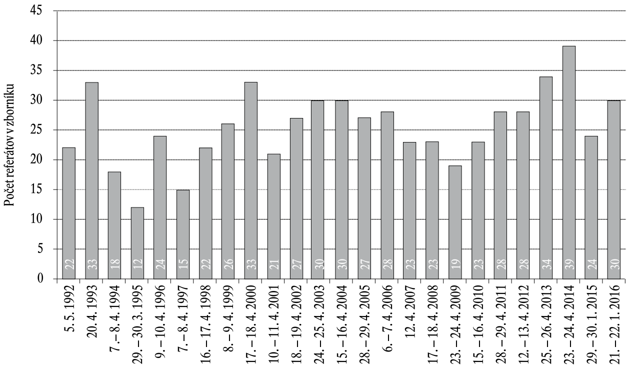
V roku 2016 išlo už o 25. ročník medzinárodnej konferencie o ochrane lesov, ktorú pripravujú pracovníci NLC-LVÚ Zvolen, Lesníckej ochranárskej služby pre lesnícku prevádzku. Hlavným problémom ochrany lesa v roku 2015 bol vietor, lykožrút smrekový a nárast škôd lesnou zverou. V roku 2016 sa očakáva nárast škôd spôsobených lykožrútom smrekovým. Tento rast škôd môže trvať až do roku 2020. Iba včasnými a dôsledne vykonanými opatreniami integrovanej ochrany lesa je možné znížiť škody vzniknuté lykožrútom smrekovým, ale aj inými biotickými škodlivými činiteľmi.

Poďakovanie

Tento článok ako aj 25. ročník medzinárodnej konferencie Aktuálne problémy v ochrane lesa 2016 vznikli vďaka finančnej podpore v rámci operačného programu Výskum a vývoj financovaného z Európskeho fondu regionálneho rozvoja pre projekty: Progresívne technológie ochrany lesných drevín juvenilných rastových štádií (ITMS 26220220120), ďalej Centrum excelentnosti biologických metód ochrany lesa – CEBIMOL (ITMS 26220120008), APVV-0707-12 a APVV-14-0567.



Obr. 1. Vývoj počtu účastníkov medzinárodnej konferencie Aktuálne problémy v ochrane lesa



Obr. 2. Vývoj počtu referátov v zborníku z medzinárodnej konferencie Aktuálne problémy v ochrane lesa

Andrej Kunca
Národné lesnícke centrum – Lesnícky výskumný ústav Zvolen, Stredisko lesníckej ochranárskej služby,
Lesnícka 11, SK – 969 01 Banská Štiavnica, Slovenská republika, e-mail: kunca@nlcsk.org; http://www.los.sk

Vedecké podujatia venované dopadom klimatickej zmeny a znečistenia ovzdušia na lesné ekosystémy v rokoch 2015 – 2016

Jednoznačné symptómy akútneho imisného poškodenia lesov, ktoré vrcholilo približne v osemdesiatych rokoch minulého storočia, dnes už nepozorujeme, no negatívne dôsledky procesov acidifikácie, eutrofizácie, fytotoxických účinkov prízemného ozónu, záťaže ťažkými kovmi a iných antropogénnych faktorov dodnes latentne pretrvávajú spolu s následným oslabením lesnej vegetácie. Chronické poškodenie lesov vplyvom imisného stresu je výsledkom synergického pôsobenia a interakcií množstva faktorov v lesnom ekosystéme. Uvedené vplyvy sú umocňované sprievodnými prejavmi recentných zmien klímy, ktorých sme svedkami v ostatných desaťročiach (bezprecedentný nárast teplôt vzduchu, výskyt frekventovanejších a dlhšie trvajúcich epizód sucha, zmeny v priestorovej a časovej distribúcii zrážok atď.). Problematika ozónového a iného abiotického poškodenia lesných porastov je stále vysoko aktuálna aj s ohľadom na narastajúcu frekvenciu výskytu extrémnych meteorologických udalostí v dôsledku prebiehajúcich klimatických zmien.

V oblasti výskumu dopadov klimatickej zmeny a znečistenia ovzdušia na lesné ekosystémy sa v rokoch 2015 a 2016 uskutočnili viaceré zaujímavé odborné podujatia, ktorých sa zúčastnili aj vedeckí pracovníci NLC-LVÚ Zvolen, a na ktoré by sme chceli prostredníctvom tejto správy poukázať.

1) V dňoch 1. až 6. júna 2015 sa v prímorskom meste Nice vo Francúzsku uskutočnil 27. ročník bienálnej vedeckej konferencie s názvom “*Global Challenges of Air Pollution and Climate Change to Forests*”. Medzinárodná konferencia bola organizovaná v rámci výskumnej divízie IUFRO “Impacts of Air Pollution and Climate Change on Forest Ecosystems (Research Group 7.01)” a jej program bol rozdelený do 6 sekcií: 1. Životné prostredie a zdravotný stav lesných ekosystémov v stredomorských oblastiach; 2. Dopady znečistenia ovzdušia a zmeny klímy na lesy na rozhraní urbanizovanej a neurbanizovanej krajiny; 3. Fyziologické a genetické mechanizmy podporujúce stresové reakcie lesných drevín a ekosystémov; 4. Zdravotný stav a rast lesov: prepojenie monitoringu a modelovania; 5. Biogeochemické procesy a viacnásobné stresory; 6. Lesné ekosystémy, atmosférická depozícia a kolobeh vody.

Na uvedenom medzinárodnom podujatí, ktorého sa zúčastnilo takmer 150 účastníkov z mnohých významných európskych aj mimoeurópskych krajín boli za NLC formou posterov prezentované nasledovné výstupy výskumných aktivít: “*Exceedance of critical levels of ozone along vertical profile in High Tatra Mts. / Prekračovanie kritických úrovní ozónu na výškovom tranzekte vo Vysokých Tatrách*” (Pavlendová et al. v sekcii 2) a príspevok “*Drought-related physiology and growth of mature European beech: linking measurements and model / Fyziologické procesy a rast dospelých bukov v podmienkach sucha: prepojenie meraní a modelu*” (Sitková et al. v sekcii 3).

Ďalšia významný ročník IUFRO kongresu, prestížneho medzinárodného podujatia v oblasti interdisciplinárneho spájania lesníckeho výskumu, sa uskutoční v dňoch 19. – 22. septembra 2017 v nemeckom Freiburgu, pri slávnostnej príležitosti už 125.výročia. Hlavným krédom a stratégiou výročného lesníckeho kongresu IUFRO je vzájomné prepojenie zložiek “Lesy – veda – ľudia” a je tematicky otvorený pre všetkých 9 vedeckých divízií, takmer 50 výskumných skupín a viac ako 180 pracovných zoskupení. Okrem účastníkov z vedeckej a akademickej obce majú byť na medzinárodnom mítingu prítomné aj ďalšie významné zainteresované strany z politickej, riadiacej a rozhodovacej sféry. Detaily sú uvedené na stránke podujatia http://iufro2017.com.

Obr. 1. Prezentácia výsledkov výskumu prebiehajúceho na NLC-LVÚ Zvolen v rámci 27. ročníka konferencie IUFRO 7.01 v Nice (1. – 6. jún 2015) a odborná exkurzia účastníkov do národného parku na ostrove Sainte-Marguerite (Îles de Lérins) v okolí Cannes na francúzskej riviére

2) V dňoch **7. – 9. októbra 2015** sa v Kongresovom centre SAV Academia v Starej Lesnej vo Vysokých Tatrách uskutočnil odborný seminár s názvom *„Monitoring a modelovanie prízemného ozónu, výskum interakcií v lesných ekosystémoch"*, ktorého hlavným organizátorom bolo NLC v partnerskej spolupráci s Ústavom vied o Zemi SAV. Seminár prebiehal na domácej pôde, v komornej atmosfére užšieho kruhu odborníkov a bol realizovaný v rámci riešenia projektu *Mapovanie fytotoxických ozónových dávok v lesnom prostredí Vysokých Tatier* (APVV-0429-12). Prítomných bolo 25 účastníkov z rôznych vedeckých a akademických inštitúcií ako aj pracovníkov lesníckej prevádzky, štátnej správy a iných dotknutých organizícií (ŠL TANAP-u, SIŽP, SHMÚ).

Cieľom seminára s medzinárodnou, česko-slovenskou účasťou, bola výmena vedeckých poznatkov a praktických skúseností v komunite vedeckých pracovníkov zaoberajúcich sa výskumom znečistenia ovzdušia a ich dopadov na lesné ekosystémy v podmienkach prebiehajúcich environmentálnych zmien. Zámerom podujatia bolo prezentovať aktuálne výsledky v oblasti mapovania a modelovania koncentrácií prízemného ozónu, diskutovať o metódach monitoringu a zdieľať najzaujímavejšie poznatky z výskumu ozónových interakcií v systéme ovzdušie – les – pôda. Významným poslaním seminára bolo predstaviť zainteresovaným zodpovedným organizáciám (Štátna správa, Štátna ochrana prírody, orgány samosprávy) návrh nového systému hodnotenia vplyvu ozónu na lesné porasty a prezentovať dosiahnuté výsledky projektu.

Súčasťou seminára boli 2 odborné exkurzie na výskumné lokality Stará Lesná – Štart – Skalnaté Pleso – Lomnický štít a druhá do oblasti Tatranská Javorina – Podmuráň – Kolové pleso so zámerom oboznámiť účastníkov s výskumom na experimentálnych plochách, konkrétne s terénnymi meraniami ozónových koncentrácií, meteorologických a fyziologických parametrov. So skúsenosťami a vlastnými poznatkami z oblasti praktického lesníckeho manažmentu v chránenom území postihnutom vetrovou a lykožrútovou kalamitou, ako aj ukážkami iných negatívnych dôsledkov prebiehajúcich environmentálnych zmien na severnej strane Tatier (masívne zosuvy pôd, škody po prívalových dažďoch a pod.) oboznámil účastníkov vedúci ochranného obvodu Tatranská Javorina Ing. Ján Slivinský (ŠL TANAP-u).

Z podujatia bol vydaný zborník príspevkov a rozšírených abstraktov na CD: Sitková, Z., Bičárová, S., Pavlendová, H. (eds.): *Monitoring a modelovanie prízemného ozónu, výskum interakcií v lesných ekosystémoch*, ktorý je spolu s prezentáciami jednotlivých účastníkov publikovaný na stránke www.nlcsk.org/mapfod.

3) Ďalším významným a tématicky relevantným vedeckým podujatím, ktoré sa uskutočnilo v dňoch **10. – 12. mája 2016** v Luxemburgu (Luxembursko), bol 5. ročník medzinárodnej konferencie v rámci programu ICP Forests s názvom *"Tracing air pollution and climate change effects on forest ecosystems: trend and risk assessments / Monitoring prejavov znečistenia ovzdušia a zmeny klímy na lesných ekosystémoch: trendy a hodnotenie rizík",*

Obr. 2. V rámci odborného seminára *„Monitoring a modelovanie prízemného ozónu, výskum interakcií v lesných ekosystémoch"* sa v dňoch 8. a 9. októbra 2015 vo Vysokých Tatrách uskutočnila exkurzia na meteorologický stacionár a EMEP stanicu v Starej Lesnej, kde SHMÚ dlhodobo monitoruje znečistenie ovzdušia a meterologické prvky, ďalej exkurzia účastníkov na Lomnický štít a návšteva výskumnej lokality Kolové pleso spojená s odborným výkladom Ing. Slivinského o praktických problémoch lesníckej praxe v ochrannom obvode Tatranská Javorina

Medzinárodný kooperatívny program pre posudzovanie a monitorovanie účinkov znečisťovania ovzdušia na lesy (ICP Forests) pôsobí už od roku 1985 a v rámci neho sa nepretržite monitoruje stav lesov a environmentálnych faktorov v celej Európe. Získané údaje z meraní a pozorovaní využíva stále viac vedcov hľadajúcich odpovede na zložité výskumné otázky, ktoré sú relevantné aj z politického hľadiska. Piaty ročník vedeckej konferencie ICP Forests bol zameraný na vyzdvihnutie hodnoty a významu dlhodobých údajov o lesných ekosystémoch v lesníckom výskume. V zmysle záverov podujatia bol potvrdená skutočnosť, že vplyv znečisťujúcich látok v ovzduší na lesné ekosystémy a ich interakcie so zmenami klímy, gradáciami škodcov a inými patogénnymi vplyvmi na lesy môžu byť doložené len na báze dlhodobých údajov, ktoré umožňujú nielen odhadnúť priestorové a časové trendy vývoja, ale aj analýzu rizík v budúcnosti.

Konferencia bola tematicky zameraná na aktuálne a stále problematické oblasti životného prostredia (depozície dusíka, prízemný ozón, zmeny klímy) a odozvy lesných porastov na ne (zdravotný stav a rast drevín, obsah živín, mykoríza a aspekty biodiverzity). V rámci rokovania boli diskutované otázky udržateľnosti ekosystémových služieb a možností obhospodarovania lesov, ktoré sú úzko spojené s reakciami lesných ekosystémov na dopady globálnych a regionálnych environmentálnych zmien.

Na podujatí boli za NLC-LVÚ Zvolen formou ústnej prednášky (kolektív Bičárová S., Pavlendová H., Sitková Z., Pavlenda P.) prezentované výsledky výskumu na tému "*Model estimation of POD$_1$ and growing season length / Modelovanie fytotoxických ozónových dávok vo vzťahu k dĺžke vegetačného obdobia*". Zoznam príspevkov a zborník abstraktov z podujatia (Seidling W., Ferretti M. eds.) sú publikované na http://icp-forests.net/events/5th-icp-forests-scientific-conference-tracing-air-pollution-and-c

4) V dňoch **18. – 20. 5. 2016** sa v Krkonošiach, Pec pod Sněžkou (Česká republika) uskutočnil bilaterálny odborný seminár s názvom *„Zdravotní stav a produkce lesa v dynamice změn antropogenních a přírodních podmínek – výsledky monitoringu a aplikovaného výzkumu*", ktorý organizačne zastrešoval Výzkumný ústav lesního hospodářství a myslivosti (VÚLHM, Jíloviště-Strnady). Zámerom 9. ročníka odborného česko-slovenského podujatia, ktoré sa koná každé dva roky, bolo zdieľanie a prezentácia výsledkov z oblasti dlhodobého lesníckeho výskumu, monitoringu stavu lesov a zložiek životného prostredia za posledných päť rokov, vyhodnotenie doterajších skúseností, získaných poznatkov, identifikácie rizík a diskusia o vhodných stratégiách výskumných a monitorovacích aktivít do budúcnosti. Dôležitou súčasťou seminára bola výmena skúseností s využitím postupov monitoringu lesov v aplikovanom ekologickom výskume a v manažmente lesov chránených území. Cenným prínosom bola najmä skutočnosť, že účastníci sa navzájom informovali o najnovších výskumných aktivitách a domácich či medzinárodných projektoch, ktoré sú na oboch stranách v súčasnosti implementované.

Vedeckí pracovníci NLC-LVÚ Zvolen prezentovali výsledky výskumu zamerané na nasledovný okruh tém: hodnotenie vývoja defoliácie a prírastku lesných drevín na plochách I. úrovne monitoringu vo vzťahu k výskytu škodlivých činiteľov a vývoju klímy (Ing. Jozef Pajtík); výskum vplyvu zimnej údržby ciest na lesy v chránených územiach (RNDr. Slávka Tóthová); výskum prvkov vodnej bilancie, výsledky ekofyziologického experimentu vplyvu sucha na buk a vplyv extrémneho v roku 2015 na prírastok (Ing. Zuzana Sitková); výsledky dlhodobých chemických analýz a vplyv depozičných vstupov látok na lesnú vegetáciu a pôdne prostredie (Ing. Danica Krúpová); výskum fytotoxických účinkov ozónu na lesné porasty horských oblastí (Ing. Zuzana Sitková) a dlhodobý monitoring stavu lesných pôd a úroveň výživy drevín z hľadiska produkčného potenciálu lesov (Ing. Pavel Pavlenda). Záverečná diskusia k jednotlivým tematickým blokom bola zameraná na porovnanie a praktickú konfrontáciu výsledkov v oboch krajinách, ale aj na otázky prepojenia tematicky príbuzných projektov pre integrované hodnotenia, na zabezpečenie zdrojov pre realizáciu monitoringu lesov a možnosti využitia výstupov v aplikovanom výskume.

Súčasťou podujatia bola terénna exkurzia, pod odborným vedením pracovníkov Správy Krkonošského národného parku (KRNAP), ktorí účastníkov oboznámili so špecifikami prírodných hodnôt tohto územia, informovali o úlohách Správy KRNAPu, základných princípoch obhospodarovania a ochrany lesných porastov v chránenom území. Exkurzia bola zameraná na praktické ukážky a otázky manažmentu lesov v podmienkach národného parku (zonácia územia, obnova lesa, ochrana lesa - najmä z hľadiska prevencie a boja proti podkôrnemu hmyzu, poľovníctvo a prezimovacia obora pre zver, opatrenia v podmienkach imisnej záťaže, náhradné dreviny a pod.). Súčasťou výkladu bolo porovnanie prístupu na českej (KRNAP) a poľskej strane (Karkonoski Park Narodowy), ako aj porovnania manažmentu v podmienkach užívania lesov štátnych a neštátnych subjektov.

Obr. 3. Kalamitné plochy pod vrcholom Sněžky (1 603 m n. m.) v oblasti Krkonošského národného parku a účastníci seminára z NLC-LVÚ Zvolen a VÚLHM Jíloviště-Strnady na odbornej exkurzii s pracovníkmi Správy KRNAP-u v rámci bilaterálneho seminára ČESLO 2016 (18. – 20. 5. 2016)

Poďakovanie

Referát vznikol vďaka podpore Agentúry na podporu výskumu a vývoja v rámci projektu APVV-0429-12 "Mapovanie fytotoxických ozónových dávok v lesnom prostredí Vysokých Tatier"; APVV-0111-10 „Ekofyziologické a priestorové aspekty vplyvu sucha na lesné porasty v podmienkach zmeny klímy" a z prostriedkov ČMS Lesy v rámci kontraktu medzi MPRV SR a NLC (č. 533/2015-710/MPRV SR).

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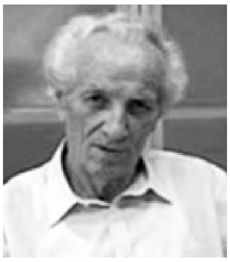
K nedožitým deväťdesiatinám prof. Ing. Dušana Zachara, DrSc.



Sú ľudia, ktorých život, činy a diela je potrebné občas pripomínať aj širšej verejnosti, a to aj vtedy, keď už nie sú medzi nami. A k takým určite patrí aj profesor Zachar, dlhoročný riaditeľ bývalého Výskumného ústavu lesného hospodárstva (VÚLH) vo Zvolene, ktorý by sa bol 6. mája 2016 dožil deväťdesiatich rokov († 2014). Z jeho života uvádzame aspoň niekoľko míľnikov. Narodil sa v Brezne, v rodine horára, 6. 5. 1926. Po absolvovaní Vyššej strednej lesníckej školy v Banskej Štiavnici (1946) pokračoval v štúdiách na Lesníckej fakulte Českého vysokého učení technického v Prahe (1950), kde absolvoval aj vedeckú ašpirantúru (1954) v melioračnom zameraní na využitie krycích kultúr pri zalesňovaní. Tam prednášal do roku 1955 predmet Meliorácie.

Na profesora Zachara si treba spomínať rovnako ako na významného vedca a vysokoškolského učiteľa, tak aj na známeho organizátora a skvelého manažéra lesníckej vedy a výskumu. V roku 1955 ho poverila Slovenská akadémia vied v rámci svojho Lesníckeho laboratória zriadiť a viesť odbor meliorácií a ekológie, ako súčasť neskoršieho lesníckeho centra vo Zvolene a „predchodcu“ lesníckeho výskumného ústavu v tomto meste. Na tomto pracovisku traja pracovníci skúmali eróziu pôdy, brehové porasty, lavínové územia a lesnícku bioklimatológiu. D. Zachar tu vypracoval viacero prác o erózii pôdy a jej vplyve na vznik spustnutých pôd a redigoval niekoľko zborníkov o erózii na Slovensku. Monografiou *Erózia pôdy (1960 a 1970)* položil vedecké základy erodológii vo vtedajšom Československu. Ňou sa v roku 1960 aj habilitoval za docenta meliorácií na Lesníckej fakulte Vysokej školy lesníckej a drevárskej vo Zvolene, kde externe prednášal Lesnícke meliorácie do polovice 70. rokov 20. st. Tu publikoval s autorským kolektívom z českých a slovenských vysokých škôl aj celoštátne učebnice *Lesnícke meliorácie (*vydavateľstvo Príroda, 1984) a *Forest amelioration* (Elsevier Oxford, 1986). V roku 1969 získal najvyššiu vedeckú hodnosť doktora vied (VŠZ Brno) a v roku 1974 bol menovaný za riadneho vysokoškolského profesora (VŠLD Zvolen).

Od roku 1960, ako došlo k zlúčeniu lesníckych výskumných organizácií na Slovensku do jedného ústavu - VÚLH v Banskej Štiavnici (neskôr so sídlom vo Zvolene) - stal sa doc. Ing. Dušan Zachar, CSc. riaditeľom tohto ústavu, ktorý úspešne viedol vyše 17 rokov! Pod jeho vedením pri vytrvalej práci vyrástol ústav na modernú vedeckú lesnícku inštitúciu s mnohými odbornými útvarmi, veľkým množstvom vedeckých pracovníkov (celkový počet pracovníkov bol až 294), pričom prikladal veľkú váhu aj vedeckej výchove a zvyšovaniu vedeckej kvalifikácie (počet vedeckých ašpirantov ústavu presahoval aj číslo 50).

Svojou cieľavedomosťou a húževnatosťou sa zaslúžil nevídanou mierou (a to aj napriek mnohým prekážkam, neprajným a odstredivým tendenciám) o postavenie centrálnej budovy VÚLH vo Zvolene ako aj niekoľkých výskumných staníc (VS) tohto ústavu – v Gabčíkove (zameraná na rýchlorastúce dreviny), v Bratislave (na lesnícku ekonomiku), v Košiciach (regionálny výskum na východnom Slovensku), Liptovskom Hrádku (lesnícka genetika, semenárstvo) – popri jestvujúcich VS v Banskej Štiavnici a Oravskom Podzámku. To všetko viedlo k skoncentrovaniu silného potenciálu vedeckovýskumných pracovníkov (vrátane zabezpečenia bytov pre zamestnancov), ale významným počinom jeho riaditeľovania bolo aj založenie série trvalých výskumných plôch (najmä na zalesňovanie spustnutých a nelesných pôd), ďalej všestranné rozvinutie metód lesníckeho výskumu na Slovensku i rozsiahlej medzinárodnej spolupráce ústavu (ústav spolupracoval až so 125 inštitúciami a jednotlivcami vo svete). Jeho negatívny politický postoj voči vstupu vojsk okupačných armád na územie Československa v roku 1968 znamenal pre neho ukončenie funkcie riaditeľa VÚLH.

Po vedeckovýskumnej stránke sa venoval problémom životného prostredia, najmä lesníckym melioráciám zo širšieho hľadiska – v užšom zameraní výskumu erózie pôdy (svoju najvýznamnejšiu vedeckú monografiu *Soil erosion* publikoval vo vydavateľstve Elsevier, 1982), príčinám degradácie a devastácie pôdy a krajiny, spevňovaniu pôdy a najmä zalesňovaniu spustnutých a nelesných pôd ako aj iných extrémnych stanovíšť. Dosiahol viaceré úspechy v tvorbe a inovácii metód zalesňovania, aj v samom zalesňovaní predovšetkým na karbonátových podložiach Slovenska. Výsledky publikoval vo viacerých knižných publikáciách (napr. *Zalesňovanie nelesných pôd, 1965; Výskum spustnutých pôd Perísk a ich zalesňovanie, 1969; Výskum zalesňovania spustnutých pôd v Slovenskom krase, 1973 a i.)* a v desiatkach príspevkov doma i v zahraničí, resp. ich rozpracoval a skonkretizoval v niekoľkých praktických projektoch.

Na výskum týchto problémov nadviazal prof. Zachar široko koncipovaným riešením krajinno-ekologických a lesnícko-ekologických problémov poľnohospodárstva a lesného hospodárstva.

Vypracoval metódu hodnotenia potenciálu krajiny a funkcií vegetácie, najmä lesa v nej. Postaral sa aj o položenie základov ďalším vývojovým prúdom, spočívajúcim v ekologickej optimalizácii usporiadania a využívania krajiny. Získané poznatky zhrnul v mnohých zborníkových prácach, v knihe *Les v krajine (1982,* v ruštine 1985), predovšetkým však v štyroch rozsiahlych kompendiách ČSAV a SAV (*Pôdny fond ČSSR, 1975; Ochrana krajiny ČSSR, 1981; Tvorba krajiny ČSSR, 1981; Využitie a ochrana vôd ČSSR, 1987).* Na základe 15-ročných výskumov funkcií lesa v krajine vypracoval prof. Zachar v posledných rokoch svojho pôsobenia na VÚLH vo Zvolene (do roku 1991) veľmi rozsiahlu monografiu *Forest and the Ecosphere*, v ktorej syntetizoval všetky svoje a celosvetovo známe poznatky o vzťahoch lesa a jednotlivých zložiek ekosféry. Išlo o vedecky a spoločensky veľmi záslužnú prácu.

Prof. Dušan Zachar vytvoril v priereze vyššie spomínaných vedeckých disciplín bezkonkurenčne bohatú vedeckú školu. Vychoval až 57 vedeckých ašpirantov (!), viacerí jeho žiaci pokračovali v rozsiahlom diele, ktoré začal.

Napísal vyše 800 vedeckých a odborných prác, ktoré vyšli v 13 jazykoch, medzi nimi viac ako 30 vedeckých knižných monografií a publikácií, editoval okolo 50 zborníkov z vedeckých a odborných podujatí, ktoré zväčša aj zorganizoval. Dlhodobo pracoval aj na publikácii *Encyklopédia Slovenska. Osobitne treba oceniť to, že* založil vydávanie viacerých vedeckých a odborných knižných edícií i časopisov - V*edecké práce Výskumného ústavu lesného hospodárstva vo Zvolene, Lesnícke štúdie, Acta Instituti Forestalis Zvolensis, Lesnícky časopis, Folia venatoria, Poľovnícke štúdie a i., kde sa doteraz odpublikovali stovky monografií, pôvodných vedeckých prác a koncepčných štúdií prevažne pracovníkmi ústavu.*

Okrem spomenutých okruhov venoval sa prof. Zachar mnohým činnostiam z oblasti vedecko-organizačnej práce aj mimo VÚLH. V roku 1974 bol zvolený za člena korešpondenta SAV aj ČSAV. V obidvoch Akadémiách bol členom vedeckých kolégií, predsedom odborov životného prostredia, lesného hospodárstva aj poľovníctva, v SAV koordinátorom publikačnej činnosti. Bol taktiež dlhoročným predsedom Slovenskej bioklimatologickej spoločnosti pri SAV.

Za viaceré vedecké i organizačné aktivity obdržal mnohé vyznamenania a ocenenia – napr. cena ČVUT (1955), cena SAV (1958), Zlatá medaila Medzinárodného zväzu lesníckych výskumných organizácií – IUFRO (1971), Zlatá medaila Ústredného výskumného ústavu lesníckeho v Budapešti (1973), Štátna cena Klementa Gottwalda (1975), Národná cena (1984), Pfeilova cena (1986), Medaila J. D. Matejovie, Medaila SAPV, Medaila SAV a iné.

Po takej pestrej činnosti s bohatou úrodou by bola väčšina ľudí pri odchode do dôchodku pravdepodobne odišla na zaslúžený odpočinok. Prof. Dušan Zachar sa však v súlade so svojou stratégiou života a vnútorným presvedčením po odchode z VÚLH ako 65-ročný zameral intenzívne na výskum *životného prostredia z najširšieho hľadiska* a od roku 1996 na problematiku *výživy človeka*. Tým naplnil posledný vytýčený míľnik svojej životnej *stratégie*. Pustil sa do všestranného štúdia výživy človeka a jej súvislostí, predovšetkým s cieľom odhaliť podstatu príčin rozličných degeneratívnych javov ľudskej populácie. Zistil, že zdravotný stav, vitalita, výkonnosť a vek človeka je závislý predovšetkým od uspokojovania jeho požiadaviek na živiny a možnosti ich využitia, čo možno dosiahnuť len plnohodnotnou stravou, ktorá je pre každého človeka v každom období jeho života a v každom type krajiny odlišná. Výživu človeka chápal ako podstatnú súčasť náuky o človeku a aj v tejto oblasti publikoval na pôde Academia vitae vo Zvolene niekoľko knižných monografií takmer do svojho skonu.

Prof. Dušan Zachar teda vždy vstupoval do riešenia nových, často neznámych, v každom prípade veľmi náročných problémov, ktorých vyriešenie prinieslo nielen osobné uspokojenie jemu, ale aj úžitok celej spoločnosti. Do tohto riešenia vkladal množstvo elánu, energie, úsilia a tvorivého ducha.

A na to všetko aj teraz s veľkou vďakou a úctou spomíname.

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Doc. Ing . Ferdinand Tokár, DrSc., 75-ročný

Narodil sa 30. 5. 1941 vo Veľkých Chrášťanoch, okr. Zlaté Moravce. Gymnázium v Zlatých Moravciach ukončil v roku 1958, Lesnícku fakultu VŠLD vo Zvolene v roku 1963. V rokoch 1963–1964 pracoval v Lesnom závode Partizánske, v rokoch 1965–1993 v ,,Arboréte Mlyňany“ - Ústave dendrobiológie SAV, v rokoch 1994–2007 v Ústave ekológie lesa SAV Zvolen, Pobočka biológie drevín Nitra.

Z odborného hľadiska sa orientoval sa ekologicko-produkčné otázky cudzokrajných drevín. Z tejto problematiky vypracoval a obhájil KDP (1974 LF VŠLD), DDP (1992 LF VŠLD), ako aj habilitačnú prácu (1998 LF TU ZVOLEN). Ako modelové dreviny spracovával gaštan jedlý (*Castanea sativa* Mill.), dub červený *(Quercus rubra* L.), orech čierny (*Jugland nigra* L.) a borovicu čiernu (*Pinus nigra* Arnold). Cenné vedecké poznatky získal z oblasti zhodnocovania štruktúry, produkcie, výchovy (fytotechniky) porastov a výskumu biomasy vybraných cudzokrajných drevín pestovaných v rôznych porastových typoch (nezmiešané a zmiešané porasty s rôznym zastúpením drevín). Založil v lesných porastoch juhozápadného Slovenska 27 trvalých výskumných plôch, ktoré systematicky zhodnocoval. Jeho súborné práce prinášajú nové vedecké poznatky z ekologicko-produkčného výskumu cudzokrajných drevín na Slovensku, ktoré nachádzajú dobré využitie v praxi lesného hospodárstva (spolupráca s lesnými závodmi Topoľčianky, Levice, Partizánske, Palárikovo, Sobrance), ovocinárstva (založenie 103 ha ovocných sadov gaštana jedlého v oblasti Modrého Kameňa), v expertíznej činnosti (vybrané rezortné inštitúcie). Dosiahnuté výsledky sú cenným prínosom pre oblasť produkčnej ekológie a pestovanie lesov týchto hospodársky významných cudzokrajných drevín na Slovensku.

Z ekologicko-produkčnej analýzy porastov borovice čiernej (*Pinus nigra* Arnold) v oblasti Malých Karpát vyplynuli tieto poznatky: borovica čierna sa v oblasti Malých Karpát pestuje na 2 212 ha skutočnej lesnej plochy a 1 537 ha redukovanej lesnej plochy. Najvyšší výskyt má v skupine lesných typov Querceto-Fagetum, Fageto-Quercetum a Fageto pauper. Najproduktívnejšie sú zmiešané porasty s borovicou čiernou s jej zastúpením do 30 %. Pre dosiahnutie vysokej kvality kmeňa sa odporúča pestovať borovicu čiernu vo dvoj a viac vrstvových porastoch, kde hornú vrstvu tvorí borovica čierna, a druhú prípadne ďalšie vrstvy, vytvárajú listnaté dreviny (buk, dub, hrab, prípadne kroviny, drieň, lieska, vtáčí zob, a pod.).

Výsledky o priemernej zásobe objemu zmiešaných a nezmiešaných porastov borovice čiernej podľa skupín lesných typov, prepočítané na plné zakmenenie, ukázali, že zmiešané porasty dosahujú vyššiu objemovú zásobu ako porasty nezmiešané o 10 až 64 %.

Z hľadiska výchovy nezmiešaných porastov gaštana jedlého sa odporúča uplatňovať silnú úrovňovú prebierku s pozitívnym výberom a intervalom opakovania 10 rokov. Vzmiešaných porastov gaštana jedlého sa odporúča mierna úrovňová prebierka s intervalom opakovania 5 rokov.

Aj pri výchove nezmiešaných a zmiešaných porastov duba červeného a orecha čierneho sa odporúča uplatňovať zo začiatku miernu úrovňovú prebierku s intervalom opakovania 5 rokov. Od tretieho zásahu sa odporúča silná úrovňová prebierka s pozitívnym výberom a intervalom opakovania 10 rokov. Pri prebierkach nezmiešaných a zmiešaných porastov gaštana jedlého, duba červeného a orecha čierneho sa uplatňuje voľba a trvalé označenie nádejných stromov za ktoré volíme stromy s vyhovujúcimi kvantitatívnymi a kvalitatívnymi požiadavkami, na ktoré sa upriamuje aj pestovateľská starostlivosť pri prebierkach.

Vzhľadom na krátky čas riešenia fytotechniky (prebierok) porastov vybraných cudzokrajných drevín na Slovensku, nie je možné vysloviť konečné závery k otázke sily a intervalu prebierok a ich vplyvu na objemovú a hmotnostnú produkciu. Riešenie týchto pre lesnícku prax významných úloh na interdisciplinárnej úrovni má však prispieť k vytvoreniu porastových modelov v rôznej rastovej fáze v záujme dosiahnutia optimálnej štruktúry, kvantitatívnej a kvalitatívnej produkcie pri zachovaní ich ekologickej stability a ďalšej produkčnej spôsobilosti.

Výsledky zo štruktúry, produkcie (objem, nadzemná biomasa) kvality a výchovy porastov gaštana jedlého, duba červeného a orecha čierneho poukazujú na opodstatnenosť ich introdukcie do lesných porastov na Slovensku a oprávnenosť ich pestovania, a to ako vo forme nezmiešaných, tak aj zmiešaných porastov.

Výsledky vedeckej práce publikoval ako monografie (4), ako pôvodné vedecké práce (132), ako odborno-popularizačné práce (59) a ako referáty v zborníkoch sympózií a konferencii (86), záverečné správy (14), projekty VEGA (6). Ohlasy na vedecké práce boli v 479 prípadoch.

Počas vedeckovýskumnej práce v SAV pracoval v zodpovedných riadiacich funkciách, a to v „Arboréte Mlyňany“ - Ústave dendrobiológie SAV vo funkcii vedúceho oddelenia systematiky a ekológie drevín, predsedu vedeckej rady tohto pracoviska, člen Rady vedcov SAV v r. 1990–1993. Po delimitácií Ústavu dendrobiológie SAV od 1. 1. 1994 bol námestníkom riaditeľa Ústavu ekológie lesa SAV (ÚEL SAV), vedúcim Pobočky biológie drevín v Nitre.

V r. 1994 – 2004 bol členom Vedeckej rady ÚEL SAV, člen Atestačnej komisie ÚEL SAV, člen komisie VEGA MŠ SR a SAV pre poľnohospodárske, lesnícke a veterinárne vedy, člen Komisií pre obhajoby doktorandských dizertačných prác v odbore 15-23-9 Ekológia lesa, 41-07-9 Pestovanie lesa a doktorských dizertačných prác v odbore 41-07-9 Pestovanie lesa. Bol predsedom redakčných rád pre časopis Folia oecologica a Acta dendrobiologica. V rokoch 1995–1998 bol členom Komisie P SAV pre propagáciu a tlač a v rokoch 1996–2000 člen Vedeckého kolégia pre poľnohospodárske, lesnícke a veterinárne vedy SAV.

Za dosiahnuté pracovné výsledky od P SAV získal v rokoch 1996 a 2009 „Čestnú striebornú plaketu SAV za zásluhy v biologických vedách“. Je nositeľom Fándlyho medaily a viacerých vyznamenaní od Lesníckeho výskumného ústavu Zvolen.

Pri príležitosti životného jubilea – 75 rokov prajeme doc. Ing. Ferdinandovi Tokárovi, DrSc. najmä dobré zdravie a pohodu v rodinnom kruhu.

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