Soil microbial community responses to windthrow disturbance in Tatra National Park (Slovakia) during the period 2006 – 2013

Erika Gömöryová1*, Peter Fleischer2, Dušan Gömöry1

1Technical University in Zvolen, Faculty of Forestry, T. G. Masaryka 24, SK – 960 53 Zvolen, Slovakia
2Research Station and Museum of the Tatra National Park, SK – 059 60 Tatranská Lomnica, Slovakia

Abstract
Soil microbial communities were studied in the Tatra National Park, which was affected by a windthrow in 2004 and by fire in 2005. The objective of the study was to compare the response of soil microorganisms to different management regimes on disturbed areas and to evaluate the microbial community changes during the period 2006 – 2013. Soil samples were taken from the A–horizon along 90 m transects on 4 plots (reference intact plot, plot with extracted wood, burnt plot, plot with fallen trees left in situ). Basal and substrate-induced respiration, microbial biomass carbon (C), nitrogen (N) mineralisation, catalase activity, and richness and diversity of microbial functional groups were determined in soil samples using the BIOLOG EcoPlates. Generally, the highest microbial activity and biomass C were revealed at the reference and fire plots. No distinct differences in microbial attributes were found between the extracted and non-extracted plots. At all windthrow plots, substrate-induced respiration, microbial biomass C and N–mineralisation showed a significant increasing linear trend with time what indicates a gradual recovery of microbial community at plots after windthrow.

Keywords: forest soil; microbial biomass; microbial activity; windthrow

1. Introduction
During the last decade, changes in climate have had impacts on natural and human systems across all continents and oceans (ICPP 2013). Climate changes are usually associated with increasing concentration of greenhouse gases which causes increase of air temperature and changes in precipitation; however, they can be accompanied also with other important changes, e.g occurrence of extreme weather events such long lasting droughts, flash floods, thunderstorms, wind storms, heat waves, but also in expansion of pests, weeds, pathogens, dangerous insects, etc. (Lindner et al. 2010; ICPP 2013). Windthrows belong to the most important natural disturbances in forest ecosystems of Europe, which can damage not only individual trees or groups of trees but also completely destroy forest stands on large areas. In November 2004, forest stands in the Tatra National Park (TANAP) in Slovakia (Central Europe) on an area of 12,000 ha were seriously damaged by northern winds with gusts over 200 km h−1 (Fleischer & Homolová 2011). Ten years later (in 2014), a windthrow again destroyed forest stands. Moreover, frequency and intensity of such disturbances is expected to increase, and temperate forests may experience growing damages in the future (Hlášny et al. 2014). Data from long-term monitoring plots can be very useful for answering the questions about the impacts of climate change on forest ecosystems and the feedbacks between forest ecosystems and climate (Clarke et al. 2011; Margesin et al. 2014).

Windthrow in the Tatra Mts. in 2004 offered an ideal opportunity to study and monitor changes in all landscape components, especially forest ecosystems on the affected area. Therefore, long-term research plots were established in 2005 to facilitate international and interdisciplinary comparative research and monitoring of abiotic and biotic components at plots (Fleischer & Homolová 2011). After
windthrow the missing crown canopy triggers changes in micro- or meso-climate due to a greater input of precipitation, solar radiation, heat input to the soil surface and a more intense air circulation, followed by changes in the herb layer cover and composition. Due to changed environmental conditions, changes in soil properties are also expected to occur, especially in surface organic layer and the topsoil. Consequently, abiotic forest disturbances influence habitat conditions for living soil organisms (Ulanova 2000; Certini 2005; Holden & Treseder 2013). The disturbance effect on soil microorganisms persists until aboveground vegetation re-grows and later succession of vegetation can reverse changes in soil properties (Holden & Treseder 2013). Long-term research plots at the windthrow-affected areas in TANAP have enabled monitoring not only of abiotic environments, but also vegetation, fauna and soil organisms. Among soil organisms the attention has been paid especially to soil nematodes, Collembola communities and soil microorganisms (Cerevková & Renčo 2009; Gömöryová et al. 2011; Čuchta et al. 2012; Čerevková et al. 2013; Čuchta et al. 2013; Urbanovičová et al. 2014).

Significant changes in the first months and years after the event are expected mainly for soil properties exhibiting a high temporal variability, such as soil moisture and temperature, soluble nutrient contents, soil organism abundance and activity, etc. Therefore, we hypothesize that windthrow plots and intact forest differ in microbial activity because of different microclimate and organic matter input. The same applies to plots differing in the management regime (plot with extracted fallen trees, plot after fire and plot with fallen trees left in situ), consequently having different microclimate and vegetation species composition. Objectives of this study are: (1) comparing the responses of soil microorganisms to different management regimes on disturbed areas, and (2) evaluating the trends in microbial community size and activity changes during the period 2006 – 2013. Such research is expected to improve our understanding of microbial processes recovery after windthrow.

2. Material and methods

2.1. Site description

The study was performed at four research plots established on windstorm-affected slopes by the Research Station of the TANAP immediately after windthrow and/or fire: a/ REF – reference plot, where spruce stand was not affected by windthrow; b/ EXT – windthrow plot with extracted fallen trees; c/ FIR – windthrow plot with extracted fallen trees, damaged by surface wildfire 6 months after the windstorm; d/ NEX – windthrow plot, where fallen trees were not extracted and the plot was left to undergo the spontaneous succession.

All plots are situated on south- to south-eastern slopes at the elevation of 1,000–1,250 m a.s.l. with slope of 5–10%. The predominant soil type is Dystric Cambisol formed from glacial moraine deposits with up to 10 cm thick surface organic layer. At the FIR, forest floor was completely burned in 2005, but the mineral soil was not affected by fire.

The intact Norway spruce (Picea abies Karst.) stand with an admixture of larch (Larix decidua Mill.) at the REF plot is >120 year old. In the ground-layer vegetation, mosses, Vaccinium myrtillus and Avenella flexuosa are the most abundant species. The vegetation composition did not change significantly during the observation period. At the EXT plot Calamagrostis villosa, C. arundinacea and Chamaenerion angustifolium are the dominant species and their abundance have not changed distinctly during observed period. Aboveground living and dead organic matter was completely burnt down at the FIR plot. During the following years, C. villosa, C. arundinacea and C. angustifolium spread rapidly and covered a major part of the FIR plot. At the NEX plot, small changes have occurred in comparison to standing forest, later light-demanding herbs and grasses occurred in a mosaic pattern in gaps.

2.2. Soil sampling and sample preparation

Soil samples were collected at 10 m intervals along 90 m long transects located in the central part of study plots, from the mineral A horizon (depth 3 to 10 cm) 1 to 3 times during each vegetation period since 2006. Usually 10 samples were taken from each plot except the summer 2006, and autumn 2011 and 2012, when only 3 to 5 samples per plot were taken. After coarse material and plant roots were hand-removed, a part of the samples were stored in field-moist condition at 4°C prior to microbial analyses. The other part used for chemical analyses was air-dried.

2.3. Laboratory analyses

In air-dried soil samples, soil acidity, organic C and total N were determined. Soil acidity (pH/KCl) was measured potentiometrically in 1 M KCl suspension. VarioMacro CNS Analyser was used to determine soil organic C and total N content.

In fresh soil samples soil water content (SWC) was estimated gravimetrically by oven-drying soil at 105°C for 24 h. Basal soil respiration (BR) was measured by estimating the amount of CO₂ evolved during incubation of 50 g soil in a closed jar for 24 h (Alef 1991). CO₂ absorbed in a 0.05 M NaOH was determined by the titration with 0.05 M HCl using the phenolphthalein indicator. For the assessment of substrate-induced respiration (SIR), glucose was added to soil samples and CO₂ evolved was measured as described above after 4.5 h. Soil microbial biomass C (Cmic) was estimated using the microwave-irradiation procedure according to Islam & Weil (1998). C content in the extract was quantified by the oxidation with K₂Cr₂O₇/H₂SO₄ and titrimetrically by (NH₄)₂Fe(SO₄)₂. N–mineralisation (Nmin) was determined using the anaerobic incubation according to the procedure described by Kandeler (1993). Catalase activity (Acat) was measured 10 min after 3% H₂O₂ was added to soil sample. The measurement is based on the volume of discharged oxygen based on the method of Khaziev (1976). The community-level metabolic profiles of soil microbial community were estimated using BIOLOG EcoPlates (Insam 1997). Inocula were produced by resuspending fresh soil in 0.9% NaCl.
supernatant was diluted 1:10,000, and 150 ml of extract were incubated in microtitration plates at 37°C during 7 days. Absorbance at 590 nm was recorded using the Sunrise Microplate Reader (Tecan, Salzburg, Austria). Metabolic activity was calculated as the area below the time-absorbance curve, and was used as a measure of the abundance of the respective functional group.

2.4. Data analyses

All the results were expressed on the oven-dry basis. The richness of the soil microbial community was assessed as the number of substrates with absorbance exceeding 0.2. The functional diversity of the microbial community was assessed using Hill’s $N^*_2$ diversity indices (Hill 1973):

$$N^*_2 = 1/Ep^2_i$$

where $p_i$ is the frequency of the i-th functional group.

Microbial activity data were treated by the analysis of covariance with season and plot as fixed categorical factors, observation year as a fixed factor nested within season, and soil moisture as a continuous covariate. Pairwise contrasts were tested using Tukey-Kramer tests. To assess overall temporal trends, microbial characteristics were regressed against observation dates (expressed as the number of days after January 1, 2006 when soil sampling was done). All statistical analyses were performed using the GLM procedure of the statistical package SAS/STAT® (SAS 1988).

3. Results

3.1. Differences in microbial community between plots

Soil microbial characteristics varied significantly during observed period at study plots (Table 1). Generally, richness and diversity of functional groups exhibited the highest variability. Basal and potential respiration varied less than microbial biomass and especially N−mineralisation. While the differences in variability of N−mineralisation and catalase activity between plots are small, the variability of the other characteristics differed much more. Basal and potential respiration varied more in the forest stand (REF) than at the other plots the differences in variability were small. The differences in variability in richness and diversity was found at the FIR plot; variability in richness and diversity of functional groups exhibited the highest variability. Basal and potential respiration varied less than microbial biomass and especially N−mineralisation. While the differences in variability of the respective functional group.

Table 1. Coefficients of variation (%) of soil microbial attributes at the study plots.

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<th>REF</th>
<th>EXT</th>
<th>FIR</th>
<th>NEX</th>
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<tr>
<td>Basal respiration (BR)</td>
<td>63.85</td>
<td>56.70</td>
<td>51.01</td>
<td>60.19</td>
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<tr>
<td>Substrate-induced respiration (SIR)</td>
<td>65.99</td>
<td>56.99</td>
<td>51.31</td>
<td>50.84</td>
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<tr>
<td>Microbial biomass C (Cmic)</td>
<td>59.43</td>
<td>70.22</td>
<td>68.27</td>
<td>66.25</td>
</tr>
<tr>
<td>N−mineralisation (Nmin)</td>
<td>68.63</td>
<td>74.41</td>
<td>72.32</td>
<td>71.84</td>
</tr>
<tr>
<td>Catalase activity (Acat)</td>
<td>57.53</td>
<td>49.57</td>
<td>56.81</td>
<td>54.58</td>
</tr>
<tr>
<td>Richness</td>
<td>127.68</td>
<td>126.88</td>
<td>136.35</td>
<td>128.24</td>
</tr>
<tr>
<td>Diversity</td>
<td>128.38</td>
<td>125.51</td>
<td>136.46</td>
<td>129.83</td>
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</table>

The analysis of covariance of soil microbial characteristics based on a nine-year-long monitoring showed that there are significant differences in most of soil microbial characteristics between years, seasons and plots (Table 2). There are some exceptions – microbial biomass did not differ between seasons, and interestingly, no significant differences in richness and diversity between plots were detected.

Table 2. Analyses of covariance of microbial community attributes (significances of F-tests).

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<tr>
<th></th>
<th>BR</th>
<th>Acat</th>
<th>SIR</th>
<th>Cmic</th>
<th>Nmin</th>
<th>Richness</th>
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<tr>
<td>Season</td>
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<td>Plot</td>
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<td>Season × plot</td>
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<tr>
<td>Year(season)</td>
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<tr>
<td>SWC</td>
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<td>ns</td>
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<td>ns</td>
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Significance labels: *** P<0.001, ** P<0.01, * P<0.05, ns – non-significant.

Generally, microbial activity was higher at the reference and fire plots in comparison to the extracted and non-extracted plots (Figures 1a–e). Although we expected that different management regimes will be reflected in soil microbial characteristics, the results indicate that there are no significant differences between the extracted and non-extracted plots. On the other hand, this pattern is not uniform among years as indicated by significant season × plot interactions for most microbial characteristics, except of catalase activity.

3.2. Changes of microbial community characteristics during the years 2006 – 2013

To find out if there is any trend in the increase or decrease of microbial activity at study plots during observed period we tested the significance of the linear regression (trend) between microbial characteristic and years. Among microbial characteristics only potential respiration, microbial biomass C and N−mineralisation showed a significant linear trend (Table 3) with a slight increase observed at all windthrow-affected plots. On the other hand the changes in basal respiration, catalase activity and richness and diversity were more fluctuating and no distinct trend was observed.

Table 3. Significance of temporal trends of microbial community attributes (significances of F-tests) during the observation period.

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<th>BR</th>
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<td>EXT</td>
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Significance labels: *** P<0.001, ** P<0.01, * P<0.05, ns – non-significant.

4. Discussion

The responses of soil microorganisms to natural and anthropogenic pressures or stresses on soil ecosystem are very quick due to their high surface-to-volume ratio, causing that they are capable of a much more intense exchange of matter and energy with their environment (Nielsen & Winding 2002). Therefore we supposed that soil microbial community will differ between different plots as well as between the plot
carbon are often reduced because of losing above- and below-ground sources (needles, leaves, root exudates) what can be reflected by decreased microbial activity. The analysis of covariance showed a significant effect of soil water content on most microbial attributes. However, the results from an earlier study (Gömöryová et al. 2011) showed that the response of soil microbial attributes to C content were more distinct than those related to soil water content; in addition, a positive relationship was found between soil organic carbon content and microbial activity. Unexpectedly, there are no significant differences between the EXT and NEX plots in spite of the fact that they differ in the above-ground biomass and microclimate. We suppose that soil microbiota was stressed after opening of the canopy considerably in comparison to the reference plot. On the other hand, a thick surface organic layer at both NEX and EXT plot has isolating and buffering effect on mineral soil and consequently on soil microbial communities from the above-ground microclimate and herb layer changes at these plots. This may be the reason why no significant differences between the EXT and NEX plots have been identified yet. Most studies showed that soil microbial biomass after fire decreases as surface temperature can reach up 600°C during with standing trees and closed canopy and the plots without canopy; the latter also differ from each other distinctly (the plot with extracted trees, the burnt plot, the plot with fallen trees left in situ). However, our expectations were fulfilled only partially. The highest microbial activity and biomass were observed at the REF and FIR plots, which are very contrasting localities. In contrast, these indicators were lowest at the EXT and NEX plots. In the case of intact forest this can be explained by the fact that soil microorganisms were exposed to smaller environmental stress than the windthrow-affected ones (sudden canopy opening leads to bigger fluctuations of soil temperature, moisture, etc.). In the case of FIR, higher microbial activity may be related to nutrients released from the burnt organic material (Gömöryová et al. 2011). Similarly different responses of soil microorganisms to the opening of canopy due to windthrow or harvesting were observed by Holmes & Zak (1999), Barcenas-Moreno et al. (2009) or Holden & Treseder (2013). On one hand abiotic disturbance can initiate higher microbial activity due to increased solar radiation, heat input to soil surface and better air circulation. On the other hand, openings can be associated with higher soil moisture due to the absence of water losses through transpiration and interception. Moreover, sources of labile Fig. 1. Comparison of means of microbial community attributes between plots. Homogeneous groups resulting from Tukey-Kramer test are designated by same letters.
Fire can also remove large amounts of organic C, including labile components (Certini 2005; Holden & Treseder 2013). We suppose that the surprisingly high activity and biomass at the FIR plot could be explained by better living conditions for soil microorganisms. Fire damaged the surface organic layer but not the A-horizon. A thick humus layer was burnt and reduced, and the released mineral nutrients could have enriched the underlying A-horizon. A missing difference in abundance and diversity of microbial functional groups between plots, however, does not imply that there are no differences in microbial community composition. BIOLOG EcoPlates contain only 31 carbon substrates; they do not necessarily reflect the status of the whole microbial community. In most studies it was shown that harvesting and fire altered the composition of microbial communities and that microbial species are differently affected by disturbance (Certini 2005; Barcenas-Moreno et al. 2011). However, the functional consequences of microbial compositional changes require further testing.

The season × plot interaction was significant, which means that differences between plots are not consistent throughout the year. Moreover, there is a high within-plot spatial variability (49–136%) of microbial attributes, which complicates the comparison of data. We expected the highest variability at the REF and NEX plots as standing or fallen trees do not enable uniform distribution of precipitation or heat on the soil surface. However, this was true only partially for basal and potential respiration in the REF stand. The highest within-plot variability of microbial functional-group richness and diversity at the FIR plot could result from differences in burning intensity across the study plot.

Monitoring of soil properties, including microbial characteristics, has been going on for nine years after the windthrow in the Tatra Mts. This is quite a short time in view of forest longevity. However, mesoclimate has completely changed and also rapid changes in the vegetation due to succession have occurred. Therefore, we expected to observe smooth increasing or decreasing trends in microbial biomass, activity or composition of microbial community. The first years after the windthrow, the herb layers at the REF and NEX plots were very similar, later at the NEX plot Calamagrostis appeared in gaps. Immediately after the windthrow and fire, extracted plots differed in plant cover because at the FIR plot the herb layer was destroyed, but during the following vegetation seasons C. angustifolium and C. villosa covered a major part of the FIR plot, and plant communities on the FIR and EXT plot converged. The results showed that in contrast to the standing forest, signs of a temporal trend can be detected at the windthrow plots. A gradual recovery of microbial community can thus be expected. Significant changes with time were found for microbial biomass, SIR and N-mineralisation. This is consistent with the meta-analysis by Holden & Treseder (2013). They showed that a soil microbial biomass decline was observed following disturbances in many studies and a significant positive relationship exists between the time since disturbance (fire and harvesting) and the microbial biomass recovery. Their finding suggests that forest disturbance can have long-term consequences for belowground communities and the recovery needs at least 10–15 years following the disturbance. Inconsistency of temporal trends among microbial characteristics can be associated with the methodology, as they were generally not assessed in situ but under optimized laboratory conditions (Dilly et al. 2003; Margesin et al. 2014).

5. Conclusions

The presented study showed that differences occur in microbial activity and biomass at the disturbed plots in comparison to an intact forest. Generally, the highest microbial activity and biomass were observed at the REF and FIR plots. At the REF plot this is probably due to the fact that soil microorganisms were not exposed to stress. At the FIR plot it can be associated with the reduction of thick surface organic layer after burning and a following enrichment of the A-horizon by released nutrients. Surprisingly, no significant differences in microbial characteristics were found between as different plots as the extracted and non-extracted plot. The present results indicate that at higher altitudes, the effect of mesoclimatic conditions is more important than the differences in microclimate due to different management. However, we cannot exclude methodological limits, as the plots were established without replication. Our results also show slight recovery trend of microbial community at windthrow affected plots.

Acknowledgement

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ICPP, 2013: http://www.ipcc.ch/report/ar5/#,UvCyy02YZYg


Large larch bark beetle *Ips cembrae* (Coleoptera: Curculionidae, Scolytinae) in the Czech Republic: analysis of population development and catches in pheromone traps

Lýkožrout modřínový *Ips cembrae* (Coleoptera: Curculionidae, Scolytinae) v České republice: analýza vývoje populací a vzorků z feromonových lapačů

Šárka Grucmanová*, Jaroslav Holuša, Jiří Trombik, Karolina Lukášová

*Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 129, CZ – 165 21 Praha 6 - Suchdol, Czech Republic*

**Abstract**

The paper summarises available data on the occurrence of *Ips cembrae* in the Czech Republic and analyses the effect of temperature and precipitation on its population growth; compares numbers of beetles of overwintering and offspring generation, and compares the proportion of females and males caught in pheromone traps. The analysed data of the Forestry and Game Management Research Institute about the volume of harvested wood infested by *I. cembrae* from 1994 to 2013 varied between 150 and 1,415 m³. During the entire study period *I. cembrae* attacked more than 0.5 m³ per ha of larch forest stands in only four districts. Temperatures over the period from March to October, from April to June and annual average temperatures during the preceding and actual years, and the ratio of the annual rainfall to long-term rainfall average obtained from the Czech Hydrometeorological Institute had no significant effect on the population growth. Adults were also caught with pheromone traps, in which two generations were documented. In 2013, the numbers of caught beetles of the offspring generation exceeded those of the overwintering generation. This was due to warm and dry weather and, probably also due to high reproductive success. Although more females were caught by pheromone trapping, numbers of males and females did not differ significantly. During the studied period several periods of local outbreak of *I. cembrae* occurred in the Czech Republic, but their causes remained unclear, although the increase of bark beetles populations is generally regarded as a result of hot and dry weather. Larch bark beetle represents only a marginal problem in the Czech Republic.

**Keywords:** *Ips cembrae*; population; outbreaks; Czech Republic

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1. Introduction

Larch bark beetle *Ips cembrae* (Heer, 1836) is a Euro-Siberian species, which practically occurs across the whole Europe (Austria, Croatia, the Czech Republic, Denmark, Finland, Sweden, France, Germany, Hungary, Great Britain, Italy, England, Wales, Scotland, the Netherlands, Poland, Romania, Serbia and Montenegro, Slovenia, Slovakia, Switzerland and Ukraine) and in central Russia (OEPP/EPPO 2005).

Its occurrence was erroneously reported also from East Asia (Postner 1974). After a review, the record was corrected to a closely related species of *Ips subelongatus* Motschulsky, 1860 (Stauffer et al. 2001; Zhang et al. 2007), whose occurrence in this area was confirmed by many other authors (e.g. Terasaki et al. 1987; Yamaguchi et al. 1989; Suzuki & Imada 1993; Westhuizen et al. 1995; Yamaoka et al. 1998; Zhang et al. 1992; 2000).
European larch (Larix decidua Mill.) is the main host plant of the larch bark beetle in its whole distribution range from the lowest elevations up to the subalpine zone (Postner 1974; Pfeffer & Knížek 1996; Grodzki 2008). Although larch bark beetle is occasionally able to attack Norway spruce (Picea abies [L.] Karsten (Pfeffer 1989)), especially during dry seasons, this happens only rarely (Holuša observ). In the past, its occurrence was also recorded on Swiss stone pine (Pinus cembra L.), but this record was reviewed and its accuracy could not be confirmed. It was confused with small spruce bark beetle (Ips amitinus (Eichhoff, 1871)) (Pfeffer 1995).

Larch bark beetle (I. cembrae) is considered a secondary pest of larch stands (Grégoire & Evans 2004). It reproduces on felled wood (Elsner 1997), in wind throws (Krehan & Steyer 2005), wind breaks (Luitjes 1974) or dying trees (Grodzki 2008). At naturally drier areas, periods with below-average rainfall may promote its attack of green vital trees (Bevan 1987; Knížek 2006; Grodzki 2008). In such cases, larch bark beetle reproduces and subsequently becomes a primary pest of healthy trees. Especially vulnerable to such conditions are young, but also older stands from lower and middle elevations (Grodzki & Kosibowicz 2009). With the growing population during the outbreak, larch bark beetle may act as a physiological pest of visually healthy standing trees in larch forests that succumbed to its massive raid. It can also act as a defoliator during mature feeding of young beetles in the crown twigs of healthy trees or during the regeneration feeding of older beetles in thin stems or thicker branches (Postner 1974; Krehan & Cech 2004). I. cembrae is considered a serious pest in several countries of Europe (Grégoire & Evans 2004). As in the case of other bark beetles of Ips genus, it is monitored using pheromone traps or logs and visually by searching for infested trees. The following measure then includes sanitation and the use of traps, logs, or baits in the form of slash or logging residues. Felled trees are also treated with insecticides (Grégoire & Evans 2004).

In Europe, four types of pheromone evaporators are currently in use: Cembräwit®, Cemprax (Shell Agrar Ltd.) (www.witasek.com), Cemsan (www.fluegel-gmbh.de), and Cembrodor (Glowacki 2008). In the Czech Republic, the experience with trapping I. cembrae is limited (Holuša et al. 2014), and the sex ratio in pheromone traps is not known yet. The ratios for I. typographus and I. duplicatus are known, females dominate in traps (Lubojacký & Holuša 2011; 2013). In comparison with other European representatives of Ips genus, protection against I. cembrae is problematic due to several reasons: (i) they develop also in branches; (ii) a substantial portion of population may overwinter in litter (as well as other species of Ips genus), and (iii) trees processed with harvesters are not protected from attack (Holuša et al. 2014).

Due to the fact that in the last years an outbreak of this species occurred at many places in the Czech Republic, and its importance is growing in several regions, the goal of this work was to (i) summarise available data on the occurrence; (ii) analyse the effect of temperature and precipitation on population growth; (iii) compare numbers of beetles of overwintering and offspring generations, and (iv) compare the proportion of females and males caught in pheromone traps.

2. Material and Methods

We summarised the volume of harvested wood in the Czech Republic that was infested by I. cembrae from 1994 to 2013 (Fig. 1 and 2), which is annually documented at a district level on the base of forest owners reports on forest disturbance factors and their predicted impact in the following year and published by the Forestry and Game Management Research Institute (Knížek 2001; 2002; 2003; 2005; 2008; 2009; 2010a; 2010b; Zahradník et al. 1996; 1997; Zahradník & Knížek 1998; 1999; 2000; Knížek & Zahradník 1996; 2004; Knížek & Holuša 2006; 2007; Lubojacký & Knížek 2013; Knížek & Lubojacký 2011; 2012; www.vulhm.cz). The volume of infested wood is not high due to the small portion of larch in tree species composition of the Czech Republic. Larch (Larix sp.) covers 115,159 ha or 4.2% of the total forest area of the Czech Republic (CR), which is 2,712,080 ha.

At elevations below 400 m a.s.l., larch covers 4.4% (27,600 ha), between 401 and 700 m a.s.l. it is 5.2% (84,400 ha), and above 700 m a.s.l. it is 0.7% (3,200 ha) of the forest area. The total number of larch trees in the Czech Republic was 192.1 million of trees (http://www.czechterra.cz/vystup.php?firstpage=26&lastpage=31). This explains the unbalanced amount of infested wood (Fig. 2), which depends on the area of larch stands in districts.

Air temperature is a key factor affecting the development of Ips typographus (Baier et al. 2007). Higher temperatures

Fig. 1. The volume of harvested wood infested by Ips cembrae in the Czech Republic from 1994 to 2013.
in spring and summer may have a positive impact on the population growth of bark beetles (Berryman 1989). Increasing temperatures during spring and summer resulting from global warming are considered to be the factors that increase the probability of insect outbreak in semiarid and temperate regions (Dobbertin et al. 2007). Rising temperature coupled with constant precipitation may increase water stress of trees (Rebetz & Dobbertin 2004), which is also one of the aspects that increase stand susceptibility to bark beetle attack.

Thus, using simple regressions we examined relationships between the population growth and mean temperatures over certain periods (from April to June, from March to October, whole year), annual precipitation total, ratio of annual precipitation total to long-term mean (annual precipitation sum as a percentage of long-term mean in the annual precipitation total), and Ellenberg climatic quotient. Ellenberg climatic quotient is calculated as $EQ = \frac{MTWM}{AP} \times 1000$, and defined as a ratio of mean air temperature of the warmest month from the long-term perspective (MTWM) and the annual precipitation total (AP). Ellenberg (1988) climatic quotient is a simple index evaluating landscape aridity. We used climatic series from the Czech Hydrometeorologic Institute available at www.chmi.cz, and represented by mean values for the whole regions (for the areas of regions see Fig. 2). Population growth was related to all factors in the same year and the two preceding years $n$ and $n-2$ (Table 2) using multiple regressions. Population growth ($-\log n/n-1$) was calculated as a ratio between the proportion of harvested wood infested with *Ips cembrae* in year $n$ and in year $n-1$ in individual regions (Jarošík 2005). Population growth was calculated only when the records of the harvests in the two subsequent years included bark beetle infested wood. Climatic factors, that are known from literature to have a most likely effect on the bark beetle population growth (see above), entered the multiple regression together with the volume of wood infested by bark beetle in year $n-1$ (Table 3).

Data normality was not ensured, hence, Spearman correlation coefficient was used. In the year 2013, larch bark beetles were being caught using flat pheromone traps (Theysohn®) with pheromone evaporators (Cembräwit®: Wittasek PflanzenSchutz GmbH, Austria) at three locations (Table 1). At each location, five traps were mounted at a distance of 10–15 m from the forest edge. Pheromone evaporators were activated at the end of April and replaced after eight weeks. They were emptied every 1 to 2 weeks until September. Trapped beetles were counted, and from each trap and each collection sample sexes of max. 100 individuals were determined on the basis of dissection and reproductive organs to estimate the ratio between females and males. Caught beetles were divided to overwintering and offspring generations according to a significant decrease in flight activity and the occurrence of callow beetles at the end of June. Regression analyses and comparisons of the frequency between overwintering and offspring generations, and between females and males in the samples from pheromone traps were performed with Mann Whitney U-test in Statistica 12.0 (StatSoft 2007). All hypotheses were examined at a 0.05 significance level.

### Table 1. Studied locations with pheromone traps set for *Ips cembrae*.

<table>
<thead>
<tr>
<th>Location</th>
<th>Altitude [m a.s.l.]</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Havířov</td>
<td>80</td>
<td>49°59'1.902&quot;N, 14°48'29.537'E</td>
</tr>
<tr>
<td>Hradec nad Moravici</td>
<td>300</td>
<td>49°51'26.520&quot;N, 17°53'6.559'E</td>
</tr>
<tr>
<td>Kostelec nad Černými lesy</td>
<td>400</td>
<td>49°59'1.902&quot;N, 14°48'29.537'E</td>
</tr>
</tbody>
</table>

GPS – geographical coordinates for given locations.

### 3. Results

#### 3.1. Volume of wood infested by bark beetle

In the Czech Republic, the total volume of harvested wood infested by *Ips cembrae* varied between 150 and 1,415 m³ in the years from 1994 to 2013. The largest volume was recorded in 2006 (Fig. 1). None of the analysed climatic factors alone had a significant impact on the population growth (Table 2). Multiple regression analysis revealed one positive significant relationship of the population growth to the harvest volumes of bark beetle infested wood in the preceding year (Table 3).

### Table 2. Results of the regression analysis of the influence of climatic factors on population growth, for all regions together.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Year</th>
<th>$r$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperatures from April to June of the actual year ($n$)</td>
<td>$-0.20$</td>
<td>0.852</td>
<td></td>
</tr>
<tr>
<td>Temperatures from April to June of the preceding year ($n-1$)</td>
<td>$-0.01$</td>
<td>0.990</td>
<td></td>
</tr>
<tr>
<td>Temperatures from June of the year before last ($n-2$)</td>
<td>$0.170$</td>
<td>0.149</td>
<td></td>
</tr>
<tr>
<td>Temperatures from March to October of the actual year ($n$)</td>
<td>$0.016$</td>
<td>0.877</td>
<td></td>
</tr>
<tr>
<td>Temperatures from March to October of the preceding year ($n-1$)</td>
<td>$0.005$</td>
<td>0.958</td>
<td></td>
</tr>
<tr>
<td>Temperatures from March to October of the year before last ($n-2$)</td>
<td>$0.111$</td>
<td>0.349</td>
<td></td>
</tr>
<tr>
<td>Average annual temperature of the same year ($n$)</td>
<td>$-0.069$</td>
<td>0.514</td>
<td></td>
</tr>
<tr>
<td>Average annual temperature of the preceding year ($n-1$)</td>
<td>$0.052$</td>
<td>0.622</td>
<td></td>
</tr>
<tr>
<td>Average annual temperature of the year before last ($n-2$)</td>
<td>$0.172$</td>
<td>0.146</td>
<td></td>
</tr>
<tr>
<td>Annual rainfall precipitation of the actual year ($n$)</td>
<td>$0.059$</td>
<td>0.574</td>
<td></td>
</tr>
<tr>
<td>Annual rainfall precipitation of the preceding year ($n-1$)</td>
<td>$-0.047$</td>
<td>0.652</td>
<td></td>
</tr>
<tr>
<td>Annual rainfall precipitation of the year before last ($n-2$)</td>
<td>$-0.197$</td>
<td>0.095</td>
<td></td>
</tr>
<tr>
<td>Percentage of annual rainfall precipitation vs long term average of the actual year ($n$)</td>
<td>$0.128$</td>
<td>0.221</td>
<td></td>
</tr>
<tr>
<td>Percentage of annual rainfall precipitation vs long term average of the preceding year ($n-1$)</td>
<td>$-0.079$</td>
<td>0.449</td>
<td></td>
</tr>
<tr>
<td>Percentage of annual rainfall precipitation vs long term average of the year before last ($n-2$)</td>
<td>$-0.155$</td>
<td>0.189</td>
<td></td>
</tr>
<tr>
<td>Ellenberg quotient in the actual year ($n$)</td>
<td>$-0.118$</td>
<td>0.262</td>
<td></td>
</tr>
<tr>
<td>Ellenberg quotient in the preceding year ($n-1$)</td>
<td>$0.050$</td>
<td>0.634</td>
<td></td>
</tr>
<tr>
<td>Ellenberg quotient in the year before last ($n-2$)</td>
<td>$0.289$</td>
<td>0.013</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Results of the multiple regression analysis of the influence of climatic factors on population growth, all parameters represent the preceding year, for all regions together.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$r^2$</th>
<th>$p^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant term</td>
<td>0.193</td>
<td></td>
</tr>
<tr>
<td>Volume of harvested wood</td>
<td>0.348</td>
<td>0.003</td>
</tr>
<tr>
<td>Average temperature from April to June of the preceding year</td>
<td>0.196</td>
<td>0.230</td>
</tr>
<tr>
<td>Average temperatures from March to October of the preceding year</td>
<td>0.100</td>
<td>0.530</td>
</tr>
<tr>
<td>Percentage of annual rainfall precipitation vs long term average of the preceding year</td>
<td>0.038</td>
<td>0.760</td>
</tr>
<tr>
<td>Ellenberg quotient in the preceding year</td>
<td>0.225</td>
<td>0.093</td>
</tr>
</tbody>
</table>

Explanatory notes: $^1$ Correlation coefficient; $^2$ $p$-value 0.05.

3.2. Catches in pheromone traps

In the year 2013, we caught in total 15,766 individuals of larch bark beetle using pheromone traps (Havířov 13,852; Hradec nad Moravicí 291; Kostelec nad Černými lesy 1,623). In the samples from traps we also recorded 1% of other bark beetle species. At all locations, the numbers of caught beetles of the offspring generation was higher than the numbers of caught beetles of the overwintering generation, but the difference was significant at one location only (Fig. 3).

In all examined seasons, we observed a clear peak of flight activity in July, while in May the catches were very small. Flight activity started in the second half of April and lasted until the mid-September. The sex ratio fluctuated between 1.03 and 2.18 of female beetles per one male beetle, but the frequencies of female and male beetles in traps were not significantly different (Fig. 4).

During the whole analysed period, larch bark beetle attacked more than 0.5 m$^3$/ha of larch stands only in four districts (Fig. 2). In all cases, mature stands were attacked (on the base of the references given in methods).

4. Discussion

In the analysed time horizon (1994–2013) several periods of local outbreak occurred and lasted three years at maximum, during 2003–2005 and 2006–2008. Similarly, three one-year-long periods with greater harvests (1995, 1997, 2013) were recorded, although the year 2013 can be the beginning of a longer lasting outbreak. The causes of their occurrence are unclear, because we could not prove the impact of temperatures and precipitation on the population growth, although it is expected that on naturally drier sites periods with below-average precipitation totals may also promote the attacks of green vital trees (Bevan 1987; Knížek 2006; Grodzki 2008). The increase of infested wood in the year 2003 is generally considered to be the result of warm and dry weather in the Czech Republic (Knížek & Zahradník 2004) and in the neighbouring countries (Krehan & Cech 2004; Stratmann 2004), although we could not prove this relationship. However, we need to note that the processed data are rough, as they represent districts, but no information at a lower spatial level was available. In addition, we were not able to account for the intensity and the quality of processing trees infested by bark beetle. The increase in the harvest of infested wood in the year 2013 corresponds with the high number of trapped bark beetles of the offspring generation in pheromone traps. A surprisingly positive impact of bark beetle harvests on the population growth of this beetle indicates that the beginning of *I. cembrae* outbreak is not captured by forestry service, and the intensity of protection measures is low. Protection measures become more frequent (complemented with intense installing of traps) only during the outbreak.

While in the Czech Republic, outbreak peaked in the year 2006 and these local outbreak were attenuated by intense search for attacked trees in the year 2007 (Holuša et al. 2014), in the neighbouring Poland, the volume of harvested wood infested by the bark beetle increased six times more (Grodzki & Kosibowicz 2009). However, local long-term outbreak
in Poland have different reasons, namely unfinished cutting of larch trees during first clearings which resulted in a large amount of wood attractive for bark beetle occurring on the site for a long time (Hutka 2006). In the year 2013, two generations were detected, which corresponds to the climate of Central Europe (Schneider 1977). Two generations were recorded also in the years 2006 and 2007 (Holuša et al. 2014). Although females prevailed in the pheromone traps, the difference between sexes was not significant. Many studies showed significant differences between the sexes for Ips typographus and Ips duplicatus caught in pheromone traps with males being less abundant than females (Annila 1971; Zumr 1982; Lindelow & Weslien 1986; Schlyter et al. 1987; Weslien & Bylund 1988; Faccoli & Buffo 2004; Lubojacky & Holuša 2011; 2013). It is assumed that there are behavioural differences between males and females. For example, female beetles of Ips paraconfusus fly directly towards higher concentrations of pheromones of male beetles colonising attacked (felled) trees, while male beetles have a tendency to land on adjacent non-colonised spots (Byers 1983). Byers (1983) also recorded a higher number of male beetles of I. paraconfusus flying several metres from traps that never occurred in the traps containing a large number of caught female beetles. Flat traps do not have a shape similar to their host plants.

5. Conclusion

In the examined time horizon (1994–2013), several periods of local outbreak of I. cembrae occurred. However, during these outbreak only a limited number of larch trees was attacked because the proportion of larch in the Czech Republic is not high. The causes of these local outbreak remained unclear. Although the population growth of bark beetles is in general connected to warm and dry weather, we could not confirm the impact of temperatures and precipitation on the population growth of larch bark beetle. The climate impact on the population growth of I. cembrae was insignificant, which may however result from rough data of insufficiently detailed information. In the current period of droughts and unbalanced climate it is important to monitor the population of I. cembrae mainly in the areas with higher proportion of larch. In spite of that, total damage is low and I. cembrae does not represent an important pest in the Czech Republic. Nevertheless, we may assume that the reaction of I. cembrae to expected climate change will be similar to the one of I. typographus or I. duplicatus, which could cause a greater threat to larch forests. Thus, it would be suitable to have pheromone evaporators for monitoring, although so far registration of pheromone traps for larch bark beetle has not been needed due to the low amount of infested harvests.

Acknowledgements

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Functions for the aboveground woody biomass in Small-leaved lime (*Tilia cordata* Mill.)

Funkce pro hodnocení biomasy nadzemních částí lípy malolisté (*Tilia cordata* Mill.)

Tomáš Čihák1, 2 – Tomáš Hlásny3, 1* – Radka Stolariková1 – Monika Vejpustková2 – Róbert Marušák1

1 Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 129, CZ – 165 21 Praha 6 - Suchdol, Czech Republic  
2 Forestry and Game management Research Institute, Jíloviště - Strnády 136, CZ – 156 00 Prague 5 - Zbraslav, Czech Republic  
3 National Forest Centre - Forest Research Institute Zvolen, T. G. Masaryka 2175/22, SK – 960 92 Zvolen, Slovakia

### Abstract

The Small-leaved lime (*Tilia cordata* Mill.) is currently not commercially important species, therefore the knowledge of biomass partitioning in a tree is rather incomplete. Moreover, lime biomass is estimated mostly using biomass functions designed for other species, without the knowledge of limits of such a use. For these reasons, we developed functions for the estimation of lime biomass in the aboveground woody parts. The functions were parameterized using 81 tree samples collected in two plots in the Czech Republic. In addition, we compared the biomass estimates produced by our functions with estimates produced by a function for beech, which has been obviously used as a surrogate for missing lime models in the Czech Republic and Slovakia.

On average, 78% of lime aboveground biomass was found to account for tree stem, 20% for branches and 2% for stump. Average biomass density was 374 kg m$^{-3}$ and no significant differences between tree compartments were found. Accuracy of all models in terms of the Root Mean Square Error (RMSE) significantly differed between tree diameter classes; in case of total aboveground biomass, the RMSE was ca. 20% of the average biomass weight in a given class up to a diameter of 45 cm, and then it rose sharply. The RMSE was higher in case of compartments with variable dimensions, such as branches and stump. RMSE was slightly higher in case of estimates produced using a beech-specific function than using that developed in the current study (average RMSE 27.95 and 29.42%, respectively); at the same time, beech-specific function overestimated lime stem biomass by ca 12%. The almost equal RMSE implies the usability of both parameterisations for lime biomass estimation, though the correction of the mentioned overestimation should be applied.

### Key words:

biomass weight and volume; wood density; temperate forests; tree compartments

### Abstrakt

Lipa malolistá (*Tilia cordata* Mill.) v současnosti nepředstavuje hospodářsky významnou dřevinu, což je jeden z důvodů proč jsou poznatky o distribuci její biomasy v rámci stromu značně nekompletní. Kromě toho, biomassa lípy je většinou hodnocená pomocí rovnic navržených pro jiné dřeviny, přičemž možné nedostatky tohoto postupu jsou ve značné míře neznámé. Z těchto důvodů jsme na základě údajů získaných z 81 stromů na dvou plochách v České republice vytvořili parametrizace rovnic pro odhad dřevnatých částí nadzemní biomasy lípy. Následně jsme porovnali odhady objemu biomassy lípy získané pomocí rovnic navržených v rámci na podkladě získaného modelu parametrizovaného pro buk, který je v České republice a na Slovensku pro hodnocení biomasy lípy obvykle používaný.

V průměru připadalo 78% nadzemní biomasy na kmen stromu, 20% na korunu a 2% na pařez. Průměrná hustota biomassy činila 374 kg na m$^{-3}$ a nebyl zjištěn významný rozdíl mezi hustotou jednotlivých kompartmentů. Přesnost všech modelů v intencích procentuální RMSE (Root Mean Square Error) byla vyšší do tloušťkové třídy 45 cm, následně se zhoršila. V případě celkové nadzemní biomassy se pohybovala kolem 20% z průměrných hodnot dané třídy, vysokých hodnot dosahovala při stromových komponentech s variabilními dimenzemi jako koruna a pařez. Rozdíly v hodnotě RMSE při odhadu biomassy kmene lípy pak pomoci námí navržených funkcí a na základě funkce pro odhad biomassy buku byly minimální (průměrné hodnoty RMSE 27.95 a 29.42%). Biomasa vzorníků lípy určena pomocí rovnic parametrizovaných pro buk nadhodnotila biomassu o přibližně 12%. Z hodnot RMSE vyplývá vhodnost využití obou typů funkcí, avšak v uvedené systematické nadhodnocení by mělo být zohledněno.

### Klíčová slova:

objem a hmotnost biomasy; hustota dřeva; lesy mírného pásma; stromové komponenty

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1. Introduction

An assessment of amount of timber and woody biomass accumulated in forests has been of high importance in forestry community for a long time (e.g. Burger 1937; Vyskot 1976; Wirth et al. 2004; Wutzler et al. 2008; Dong et al. 2014). Recently, with a growing realization of forest importance in global carbon cycle (Nabuurs et al. 1997, 2013), also the evaluation of forest carbon stocks become an important part of forestry research (e.g. Eggers et al. 2008; Rötzler et al. 2009; Tatarinov & Cienciala 2009; Zierl & Bugmann 2007; Hlášny et al. 2011, 2014). In response to national commitments on carbon accounting and needs of the precise assessment of timber and biomass resources, numerous regional parameterizations of allometric functions (Zianis et al. 2005) and biomass expansion factors (Lehtonen et al. 2007) have been developed for most of Central European countries and tree species (Cienciala 2005, 2006, 2008; Seifert et al. 2006; Neuman & Jandl 2005; Hochbichler et al. 2006; Konôpka & Žilinec 1999). Tree biomass equations allow the calcula-
tion of tree biomass on the basis of straightly measurable tree dimensions, such as stem diameter, tree height, crown dimensions, etc. (Cienciala et al. 2008). Although biomass equations are mostly applied at tree scale, also methods addressing the aggregated stand level data have been developed (e.g. Lehtonen et al. 2007; Somogyi et al. 2007).

Despite the long-term research on biomass quantification, there are still unexplored areas, such as the biomass allocation in species with minor occurrence, commercially less important species or in early developmental stages (Pajtík et al. 2008; Pajtík et al. 2011; Vahedi et al. 2014; Uri et al. 2014). One of such species groups is Tilia, which is the genus comprising 40 species growing in the temperate forests of the northern hemisphere (Větvička 2000). Five species occur in the Czech Republic, two of them being considered as commercially important – Small-leaved Lime (Tilia cordata Mill.) and Large-leaved Lime (Tilia platyphyllos Scop.). Only the latter two species will be considered in this study, and, because of their ecological and morphological resemblance, they will not be differentiated further. A share of lime in the Central Europe varies among countries (e.g. 1.1% in the Czech Republic; 0.4% in Slovakia). Species share has substantially decreased during the recent decades in the Czech Republic, from 6.5% in 1970–1990 to the current share of ca. 1%, mainly as a consequence of low interest in the species in forestry practice in 80’s and 90’s. However, growing interest in forest non-productive functions, which lime is capable to provide (e.g. soil ammelioration, honey production, aesthetics, recreation etc.), promotion of the growing interest in forest non-productive functions, which lime is capable to provide (e.g. soil ammelioration, honey production, aesthetics, recreation etc.), promotion of the species in forestry practice in 80`s and 90`s. However, growing interest in forest non-productive functions, which lime is capable to provide (e.g. soil ammelioration, honey production, aesthetics, recreation etc.), promotion of the...
ume was calculated using the Eq. 4.

\[ V_{sw} = \frac{m_{sw} \times (100 - W_{sw})}{\rho \times 100} \]  

\[ V_{sw} \] is the volume of small branches with bark in m³; \( m_{sw} \) is weight of small branches in kg; \( W_{sw} \) is relative small branches moisture in %; \( \rho \) is wood density.

Dry mass weight of tree compartments, for which the volume data were available, was calculated using the Eq. 2.

In addition, volume and weight of stump was evaluated. The volume calculation was based on the basis of stump height and basal area calculated from \( d_0 \). As a result, a total aboveground biomass was determined for all sampled trees, consisting of stem, branch and stump biomass.

2.2. Statistical analyses

We used Eq. 5 for the approximation of the relationship between tree dimensions and tree biomass, which is the equation which has been repeatedly found suitable for tree biomass estimation (Cienciala et al. 2008; Hochbichler et al. 2006; Bollandás et al. 2009):

\[ \ln(Y) = a + b_1 \ln(X_1) + b_2 \ln(X_2) + \ldots + b_n \ln(X_n) + \varepsilon \]  

where \( Y \) is biomass of a tree compartment; \( a, b_1, \ldots, b_n \) are estimated parameters, \( X_1, \ldots, X_n \) are predictors (tree height and diameter in the current study), and \( \varepsilon \) is the error term.

Tree heights and diameters were used as biomass predictors; and predictive power of both diameter and the combination of height and diameter was tested. Models for biomass volume and dry mass of the total above-ground biomass, stem, branches and stump were parameterized; altogether, 16 models were developed and tested.

The following equations were used for the final biomass estimates:

\[ B = e^{b_0 + b_1 \ln d + b_2 \ln h} \lambda \]  

\[ B = e^{b_0 + b_1 \ln d + b_2 \ln h} \]  

where \( B \) is the biomass estimate, \( d \) is tree diameter, \( h \) is tree height, \( \lambda \) is a correction coefficient described below.

A correction factor \( \lambda \) was introduced into the equations above (Marklund 1987) as the back-transformation of the logarithmically transformed values causes a bias:

\[ \lambda = \frac{\sum Y}{\sum \hat{Y}} \]  

\[ \hat{Y} \] denotes empirical values, and \( \hat{Y} \) predicted values.

To perform a robust validation of the models, the set of 81 sampled trees was randomly split 20-times into parameterisation (n=61) and validation (n=20) sample. While the former dataset was used for the estimation of model parameters, the latter dataset was used for the calculation of the root mean square error (RMSE), which is an estimate of models accuracy. The RMSE represents the sample standard deviation of the differences between the predicted and observed values:

\[ \text{RMSE} = \sqrt{\frac{\sum (Y - \hat{Y})^2}{n}} \]  

where \( \hat{Y} \) is a vector of \( n \) predictions, \( Y \) is the vector of the true values, and \( n \) is the sample size.

In addition to the mean RMSE calculated using all samples, we also calculate the RMSE per diameter class, which can provide useful information supporting the use of the proposed parameterisations. Both RMSE in terms of original units (kg, m³) and in terms of per cent of the predicted values was calculated.

The final biomass models were parameterized using all 81 samples.

The analyses were conducted in Statistica v.12 (StatSoft 2013).

3. Results

3.1. Exploratory analysis of the empirical material

Diameters \( d_{1.3} \) of sampled trees ranged from 7.3 to 58.6 cm, with mean 22.2 cm. Tree heights ranged from 11.7 to 31.2 m, with mean 21.1 m (Table 1). Average biomass density (\( \rho \)) was 374 kg m⁻³, and relative biomass moisture (\( W_{rel} \)) was 54.1%. Biomass moisture and density were not found to differ significantly between the stem and branches, hence the mean values were used in all calculations.

On average, dry mass weight of the stem, branch and stump biomass accounted for 78, 20 and 2% of the total aboveground biomass, respectively. In terms of volume, these compartments accounted for 80, 18 and 2% of the total aboveground biomass.

An average branch to trunk (stem + stump) biomass weight ratio in sampled trees was 0.26, though this relationship changes along tree diameters (Fig. 1). While the ratio is highly variable in diameters up to 15 cm, for bigger diameters the ratio is stable at 0.23.

<table>
<thead>
<tr>
<th>Diameter (d_{1.3})</th>
<th>Height (m)</th>
<th>Stem</th>
<th>Branches</th>
<th>Stump</th>
<th>Above-ground</th>
<th>Stem</th>
<th>Branches</th>
<th>Stump</th>
<th>Above-ground</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>22.2</td>
<td>21.1</td>
<td>211.8</td>
<td>55.9</td>
<td>8.7</td>
<td>276.4</td>
<td>0.57</td>
<td>0.12</td>
<td>0.023</td>
<td>0.70</td>
</tr>
<tr>
<td>Median</td>
<td>17.0</td>
<td>20.4</td>
<td>81.4</td>
<td>14.9</td>
<td>1.4</td>
<td>97.1</td>
<td>0.22</td>
<td>0.04</td>
<td>0.004</td>
<td>0.26</td>
</tr>
<tr>
<td>Maximum</td>
<td>58.6</td>
<td>31.2</td>
<td>1060.1</td>
<td>541.6</td>
<td>67.0</td>
<td>1422.9</td>
<td>2.84</td>
<td>1.32</td>
<td>0.179</td>
<td>3.64</td>
</tr>
<tr>
<td>Minimum</td>
<td>7.3</td>
<td>11.7</td>
<td>9.6</td>
<td>6.1</td>
<td>0.1</td>
<td>17.5</td>
<td>0.03</td>
<td>0.02</td>
<td>0.000</td>
<td>0.05</td>
</tr>
<tr>
<td>St. deviation</td>
<td>12.3</td>
<td>5.0</td>
<td>286.1</td>
<td>98.2</td>
<td>15.4</td>
<td>387.7</td>
<td>0.77</td>
<td>0.21</td>
<td>0.041</td>
<td>0.98</td>
</tr>
</tbody>
</table>
3.2. Biomass functions

In biomass weight estimation, the RMSE produced on the basis of 20-randomly generated validation samples (n=20) reached 29 to 127% of the measured values (Table 2–3). The error was higher in case of compartments with variable dimensions such as stump and branches. An estimation based on biomass functions with two predictors (d, h) produced lower RMSE in all cases; the magnitude of such a difference however largely differed between the compartments and depending on whether the biomass volume or biomass weight was estimated.

An effect of tree height was higher in volume than in biomass weight estimates. In case of stem volume, the RMSE was 28.8 and 33.3% in case when d, h and d were used as predictors. In case of the total aboveground volume, the errors were 33.0 and 38.9% respectively. In case of biomass weight estimation, the improvement due to height inclusion was up to 2% in all compartments.

Accuracy of all models in terms of the RMSE significantly differed between diameter classes, therefore the informative value of the above described RMSE, which was calculated using all samples, is limited. We found out that in case of the total aboveground biomass weight and stem biomass weight, the RMSE reached 10–30% of the average biomass weight in a given class up to a diameter of 45 cm, and then it rose sharply (Fig. 2–3, Appendix A). The effect of diameter class on the RMSE was weaker in case of biomass volume estimates; in case of stem volume, the RMSE was stable in all classes, ranging between 12–29%. In case of the aboveground biomass volume, model which used only d as predictor was performing better and RMSE was stable in the range of 12–34%. Generally, errors associated to branch and stem biomass estimations were significantly higher in all diameter cases as compared with the above mentioned estimates. Differences in R–square were between functions with one (d) or two (d, h) predictors were negligible in most of cases.

Table 2. Parameters of functions for the estimation of lime biomass volume in main tree compartments as well as of the whole aboveground biomass.

<table>
<thead>
<tr>
<th>Tree compartment</th>
<th>b₀</th>
<th>b₁</th>
<th>b₂</th>
<th>R²</th>
<th>λ</th>
<th>RMSE</th>
<th>RMSE in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>aboveground</td>
<td>-8.926</td>
<td>2.071</td>
<td>0.562</td>
<td>0.970</td>
<td>1.019</td>
<td>0.28</td>
<td>33.04</td>
</tr>
<tr>
<td>branches</td>
<td>-8.414</td>
<td>1.968</td>
<td>-0.114</td>
<td>0.753</td>
<td>1.138</td>
<td>0.14</td>
<td>112.13</td>
</tr>
<tr>
<td>stem</td>
<td>0.834</td>
<td>0.218</td>
<td>0.423</td>
<td>0.974</td>
<td>1.019</td>
<td>0.18</td>
<td>28.76</td>
</tr>
<tr>
<td>stump</td>
<td>-15.157</td>
<td>2.966</td>
<td>0.410</td>
<td>0.936</td>
<td>1.08</td>
<td>0.02</td>
<td>-83.24</td>
</tr>
</tbody>
</table>

Abbreviations: b₀, b₁, b₂ – parameters, RMSE – Root Mean Square Error, λ – corrections factor (explanation is given in the text), *first number denotes the estimated coefficient, second number denotes coefficient’s standard error.
Table 3. Parameters of functions for the estimation of biomass weight in main tree compartments as well as of the whole aboveground biomass.

<table>
<thead>
<tr>
<th>Tree compartment</th>
<th>( b_0^* )</th>
<th>( b_1^* )</th>
<th>( b_2^* )</th>
<th>( R^2 )</th>
<th>( \lambda )</th>
<th>RMSE</th>
<th>RMSE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>aboveground</td>
<td>-3.032</td>
<td>2.115</td>
<td>0.538</td>
<td>0.969</td>
<td>1.020</td>
<td>100.74</td>
<td>35.32</td>
</tr>
<tr>
<td>branches</td>
<td>-2.936</td>
<td>2.228</td>
<td>-0.175</td>
<td>0.799</td>
<td>1.135</td>
<td>59.24</td>
<td>101.64</td>
</tr>
<tr>
<td>stem</td>
<td>-3.728</td>
<td>2.074</td>
<td>0.726</td>
<td>0.974</td>
<td>1.019</td>
<td>62.21</td>
<td>28.57</td>
</tr>
<tr>
<td>stump</td>
<td>-2.928</td>
<td>2.074</td>
<td>0.151</td>
<td>0.974</td>
<td>1.019</td>
<td>62.21</td>
<td>28.57</td>
</tr>
<tr>
<td>aboveground</td>
<td>-2.086</td>
<td>2.342</td>
<td>-</td>
<td>0.965</td>
<td>1.023</td>
<td>109.44</td>
<td>38.37</td>
</tr>
<tr>
<td>branches</td>
<td>-2.451</td>
<td>2.154</td>
<td>-</td>
<td>0.979</td>
<td>1.135</td>
<td>67.50</td>
<td>115.82</td>
</tr>
<tr>
<td>stem</td>
<td>-2.451</td>
<td>2.154</td>
<td>-</td>
<td>0.979</td>
<td>1.135</td>
<td>67.50</td>
<td>115.82</td>
</tr>
<tr>
<td>stump</td>
<td>-8.512</td>
<td>3.139</td>
<td>-</td>
<td>0.935</td>
<td>1.081</td>
<td>8.65</td>
<td>93.39</td>
</tr>
</tbody>
</table>

Abbreviations: \( b_0, b_1, b_2 \) – parameters, RMSE – Root Mean Square Error, \( \lambda \) – corrections factor (explanation is given in the text), \(^*\) first number denotes the estimated coefficient, second number denotes coefficient’s standard error.

3.4. Lime biomass estimation using a beech-specific function

We compared the lime biomass estimates produced using the equations parameterized in the current study with estimates produced using biomass functions for beech proposed by Petráš & Pajtík (1981) (PP); such equations have been obviously used for lime biomass estimation in the Czech Republic and Slovakia. However, as the definition of tree compartments used by the latter authors differed from that used in our study, we compared only the estimates of stem biomass weight.

Assuming that the estimates produced by the lime model are the reference, the PP model overestimated lime biomass weight by 12% (Fig. 4). We found no significant differences between the RMSEs produced using the PP model and lime-specific functions. While stem biomass weight estimated using the function with \( d \) as predictor was 0.17 (30.21%) and with \( d \) and \( h \) 0.16 (27.95%), the PP model \((d, h)\) produced RMSE 0.17 (29.42%). This finding implies that both parameterisations can be used for lime biomass estimation, though the earlier mentioned overestimation could be subjected to correction. R–square was almost identical in both models.
4. Discussion and conclusions

Biomass estimation of commercially less important species has been receiving only a marginal attention so far, however, the importance of carbon accumulation in and biomass production of these species can be expected to increase as a consequence of efforts to support the diversity of current forests. Lime biomass is obviously estimated using functions parameterized for other morphological similar tree (Czech-Terra 2014; Jenkins et al. 2003). Lime biomass estimates are rare in the Central Europe at all. An exception is, for example, the study by Vyskot (1976), who estimated the biomass of a floodplain forest, though using a very limited number of sampled trees; or the study by Tokár (1986), who analysed a biomass of mixed stand of black walnut and lime. A model of lime aboveground biomass was proposed by Bunce (1968), the author however used only 10 sample trees with diameter range from 3.2 to 15 cm. In general, low tree age and diameter is typical of most of available studies; hence the limited applicability of the designated functions. Another model was proposed by Lambert et al. (2005), who used 80 sample trees with mean diameter 26.5 cm. However, as the model was developed for the Tilia americana L. using samples collected...
in Ontario (USA), such model’s applicability is limited in the Central Europe.

Mean wood density of lime trees found in our study was 374 kg m$^{-3}$, which is the value in the range reported by other authors. For example, lime wood density by IPCC (2004) is 430 kg m$^{-3}$. Gschwantner & Schadauer (2006) suggested the value of 490 kg m$^{-3}$ for lime branch biomass, and mean wood density of 320 kg m$^{-3}$ was found for $T$. americana and $T$ lia heterophyla Vent., which occur in the North America. Such differences can be attributed to several factors, for example the inter-species and inter-compartment differences as well as the differences in measuring methods. For example, while we calculated wood and bark biomass together, Bunce (1968) evaluated wood without bark, and used trees of smaller dimension; hence the limited comparability with our study.

Lime biomass functions parameterized in the current study showed much lower accuracy of stump and branch biomass estimation as compared with stem; this is valid for both biomass weight and volume. Such uncertainties were propagated to the total biomass estimate, however, as the stump and branch biomass accounted for ca. 20% of the total biomass, this effect was not substantial. On the other hand, relatively low errors were associated with stem biomass estimation, especially in lower diameter classes, what implies the reliability of our functions for the assessment of lime timber weight and volume. Similarly to other studies, effect of the use of two predictors ($d$, $h$) did not induce any substantial improvement as compared with the use of $d$ only. Therefore, the effect of including tree height should be carefully considered as increased cost of data collection does not need to be compensated by an increased accuracy of estimation.

The comparison of biomass estimates based on lime-specific functions parameterized in our study with available function for beech showed quite good match between the two models in terms of RMSE, although only the stem estimates were compared. However, the 12% overestimation of lime stem biomass estimate produced using a beech specific function should be considered. Of course, relatively limited extent of empirical material used in this study could question the general applicability of such a finding.

Biomass partitioning in lime seems to be slightly different than that in beech, mainly in small diameters. While we found the mean crown to stem ratio 0.26, Cienciala et al. (2005) found such ratio to be 0.18 in beech (85% stem, 15% branches). The difference was however pronounced in small diameters only, in diameters above 20 cm both tree species showed similar values around 0.2. Such findings suggest differences in biomass allocation between lime and beech in small diameters, which is the fact supporting the use of functions developed in this study.

Acknowledgments

We acknowledge the projects of the Czech Ministry of Agriculture NAZV Q1120317 “Integrated assessment of the impact of insect pests and fungal diseases on spruce forests of the Czech Republic as starting point of their operative management”, and Internal Grant Agency of the Faculty of Forestry and Wood Sciences Czech University of Life Sciences in Prague No. B0114. Part of this study was conducted within the framework of projects supported by the Slovak Research and Development Agency under contracts APVV-0111-10 and APVV 0243-110.

References


Hochbichler, E., Bellos, P., Lick, E., 2006: Biomass functions for estimating needle and branch biomass of spruce ($Picea abies$) and Scots pine ($Pinus sylvestris$) and branch biomass of beech ($Fagus sylvatica$) and oak ($Quercus robur$ and $petraea$). Austrian Journal of Forest Science 123:35–46.


### Appendix A: Results of the validation of lime biomass functions.

<table>
<thead>
<tr>
<th>DBH class [cm]</th>
<th>RMSE</th>
<th>Stem Branches Stump ABG</th>
<th>Stem Branches Stump ABG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–15</td>
<td>%</td>
<td>17.8 46.9 125.4 16.8 16.4</td>
<td>47.7 35.6 15.7</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>6.1 5.3 0.8 7.7 5.6</td>
<td>5.4 0.2 7.2</td>
</tr>
<tr>
<td>0.15–20</td>
<td>%</td>
<td>17.3 36.4 80.5 11.9 13.8</td>
<td>36.7 30.9 10.1</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>14.1 5.9 1.2 11.8 11.3</td>
<td>5.9 0.5 10.0</td>
</tr>
<tr>
<td>20.1–25</td>
<td>%</td>
<td>27.1 88.3 70.6 34.6 23.0</td>
<td>92.5 36.7 30.9</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>31.9 18.8 1.9 49.0 27.1</td>
<td>19.7 1.0 43.8</td>
</tr>
<tr>
<td>25.1–30</td>
<td>%</td>
<td>27.1 82.0 28.6 18.8 18.1</td>
<td>82.6 50.2 14.5</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>51.4 32.2 2.6 54.1 43.5</td>
<td>32.5 4.6 41.7</td>
</tr>
<tr>
<td>30.1–35</td>
<td>%</td>
<td>29.8 82.0 28.6 18.8 25.7</td>
<td>56.1 78.5 29.8</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>122.5 32.2 2.6 54.1 106.6</td>
<td>64.9 8.5 161.1</td>
</tr>
<tr>
<td>35.1–40</td>
<td>%</td>
<td>17.1 72.7 10.4 12.2 17.9</td>
<td>72.9 73.0 14.9</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>77.7 55.9 4.0 69.2 81.1</td>
<td>56.1 28.1 84.9</td>
</tr>
<tr>
<td>40.1–45</td>
<td>%</td>
<td>25.0 62.5 14.8 27.9 23.9</td>
<td>63.4 41.6 28.2</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>146.8 80.3 5.1 209.4 140.2</td>
<td>81.3 14.3 211.5</td>
</tr>
<tr>
<td>45.1–50</td>
<td>%</td>
<td>8.9 63.9 15.6 20.2 13.8</td>
<td>63.2 43.4 22.6</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>79.7 226.9 6.2 261.8 123.8</td>
<td>224.4 17.3 292.4</td>
</tr>
<tr>
<td>50.1 &gt;</td>
<td>%</td>
<td>24.6 32.1 16.6 21.0 19.4</td>
<td>32.5 22.3 17.7</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>242.4 74.6 7.2 264.9 190.8</td>
<td>75.5 9.7 222.4</td>
</tr>
</tbody>
</table>

RMSE – Root Mean Square Error; d – diameter in breast height; h – tree height; ABG – aboveground biomass.

### Appendix B: Results of the validation of lime volume functions.

<table>
<thead>
<tr>
<th>DBH class [cm]</th>
<th>RMSE</th>
<th>Stem Branches Stump ABG</th>
<th>Stem Branches Stump ABG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–15</td>
<td>%</td>
<td>16.69 56.35 35.54 17.86 16.71</td>
<td>57.11 36.39 25.82</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.02 0.02 0.001 0.02 0.02</td>
<td>0.02 0.001 0.04</td>
</tr>
<tr>
<td>0.15–20</td>
<td>%</td>
<td>17.00 43.85 35.80 12.17 12.31</td>
<td>43.66 36.83 18.02</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.04 0.02 0.001 0.03 0.03</td>
<td>0.02 0.001 0.05</td>
</tr>
<tr>
<td>20.1–25</td>
<td>%</td>
<td>27.12 86.02 36.08 34.37 24.31</td>
<td>86.90 33.77 39.63</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.15 0.06 0.015 0.14 0.14</td>
<td>0.06 0.014 0.17</td>
</tr>
<tr>
<td>25.1–30</td>
<td>%</td>
<td>21.30 88.00 50.83 17.39 19.30</td>
<td>88.49 50.24 20.97</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.10 0.02 0.015 0.14 0.14</td>
<td>0.06 0.014 0.17</td>
</tr>
<tr>
<td>30.1–35</td>
<td>%</td>
<td>29.07 46.37 69.40 34.37 24.31</td>
<td>46.62 66.94 27.96</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.32 0.10 0.027 0.42 0.26</td>
<td>0.10 0.026 0.38</td>
</tr>
<tr>
<td>35.1–40</td>
<td>%</td>
<td>23.90 41.78 72.27 19.95 21.43</td>
<td>41.77 71.74 25.66</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.34 0.06 0.056 0.33 0.31</td>
<td>0.06 0.056 0.43</td>
</tr>
<tr>
<td>40.1–45</td>
<td>%</td>
<td>25.11 48.10 39.55 27.21 23.30</td>
<td>47.72 39.20 37.16</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.40 0.11 0.038 0.53 0.38</td>
<td>0.11 0.038 0.72</td>
</tr>
<tr>
<td>45.1–50</td>
<td>%</td>
<td>22.15 72.42 41.82 22.70 15.36</td>
<td>74.48 40.63 60.86</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.54 0.58 0.043 0.76 0.32</td>
<td>0.58 0.041 2.01</td>
</tr>
<tr>
<td>50.1 &gt;</td>
<td>%</td>
<td>23.26 45.02 25.16 22.59 19.92</td>
<td>45.06 23.63 69.99</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>0.63 0.23 0.031 0.75 0.54</td>
<td>0.23 0.029 2.33</td>
</tr>
</tbody>
</table>

RMSE – Root Mean Square Error; d – diameter in breast height; h – tree height; ABG – aboveground biomass.
Analysis of governance systems applied in multifunctional forest management in selected European mountain regions

Zuzana Sarvašová1* – Emil Cienciala2 – Jana Beranová2 – Michal Vančo3 – Andrej Ficko4 – Marta Pardos5

1National Forest Centre - Forest Research Institute Zvolen, T. G. Masaryka 2175/22, SK – 960 92 Zvolen, Slovakia
2IFER – Institute of Forest Ecosystem Research, Ltd., Areal 1. Jilovské, a. s., ČZ – 254 01 Jílové u Prahy, Czech Republic
3National Forest Centre - Institute for Forest Consulting and Education, Sokolská 2, SK – 960 52 Zvolen, Slovakia
4Biotechnical Faculty, University of Ljubljana, Vecna pot 83, 1000 Ljubljana, Slovenia
5National Institute for Agricultural and Food Research and Technology (INIA), Crta. de la Coruña, 28040 Madrid, Spain

Abstract

The objective of this study is to map and analyse governance systems relevant for the implementation of multifunctional mountain forest management in selected European countries. This paper is based on the FP7 research project Advanced multifunctional forest management in European mountain ranges (ARANGE). Current governance systems relevant for the implementation of multifunctional forest management are analysed in seven case study areas: the Iberian Mountains (Spain), Western Alps (France), Eastern Alps (Austria), Dinaric Mountains (Slovenia), Scandinavian Mountains (Sweden), Western Carpathians (Slovakia) and Western Rhodopes (Bulgaria). Qualitative social research methods were applied for data collection. Semi-structured questionnaire was focused on the following elements of governance: participation and stakeholders interactions and inter-sectorial coordination. The results indicate that forest managers share a general perception of multifunctional forest management being focused on preserving or strengthening several forest functions and services including timber production. They believe that current governance systems basically support multifunctional management of mountain forests. The participatory and inter-sectoral processes are playing an important role in multifunctional forest management in selected European mountain regions.

Keywords: ecosystem services; inter-sectoral cooperation; forest management planning; environmental policy

1. Introduction

Governance is a multi-faceted concept frequently used in high-level policy discourse (e.g. OECD, World Bank, UNFF, Agenda 21, FLEG), but this approach has been also used in different forest related topics e.g. policy formulation (Hogl et al. 2004; Krott 2008; Giessen & Bocher 2009; Secco et al. 2011), forest certification schemes (Overdevest & Rickenbach 2006; Marx & Cuypers 2010), regional social-ecological systems (Lebel et al. 2006), utilization of forest management rights (Ostrom 2005; Agrawal et al. 2008; Bouriaud et al. 2013) or marketing of forest products and services (Robertson, 2004; Mavsar et al. 2008; Ernstson et al. 2010).

More specifically, the concept of adaptive governance systems has been addressed and described in relation to
practicable multifunctional and sustainable forest management, (e.g. Schmithüsen 2000; Wolf et al. 2006; Cubbage et al. 2007; Mander et al. 2007; Carvalho-Ribeiro et al. 2010; Secco et al. 2013). Adaptive governance becomes specifically complex in mountain regions where beyond the typical long planning horizons and existing risks of natural hazards (avalanches, storms, insects) specific environmental (nature protection) and social characteristics of that area are to be taken into account (e.g. changes in the settlement structure and livelihood patterns, traditional customs in land use).

In this study the governance is understood as an effective way how the multifunctional mountain forest management in case study regions is implemented.

This study is a part of a FP7 research project “Advanced multifunctional forest management in European mountain ranges” (ARANGE, 2012). The ARANGE project builds on seven case study regions in major mountain ranges throughout Europe covering a wide range of forest types, socio-economic conditions and cultural contexts. It seeks to develop and evaluate strategies for their multifunctional management considering risks and uncertainty due to changing climatic and socio-economic conditions (ARANGE, 2012).

In the ARANGE project, the analysis of governance systems serves as a supporting task focusing on the implementation of multifunctional mountain forest management in Europe. Clearly, this paper cannot represent the whole complexity of forest governance. Nevertheless, it offers an insight on the governance approaches in European mountain forests based on the selected case study areas and it can deliver basic information on various elements of governance.

The research hypothesis of this paper is that sustainable multifunctional forest management in European mountain ranges is based on case specific governance systems. Our research is topically related to works addressing governance systems for sustaining the ecosystem services and multifunctional mountain forest management (Glück & Weber 1998; Buttoud et al. 1998, 2002; Glück 2000, 2002; Hogl et al. 2004, 2008) and governance assessment approaches proposed by UNDP (2006, 2009).

The aim of this paper is to present the key elements of current governance systems in selected European mountain ranges using seven case study areas defined in the ARANGE project. Applying a qualitative research approach, it specifically investigates the participation and stakeholder interactions, inter-sectorial coordination, multi-level coordination, decision structures and processes, responsibilities, and the use of expert knowledge.

Specific objectives of the paper are to:

- identify how the stakeholders understand multifunctional forest management;
- identify the importance of different ecosystem services;
- identify the most important sectors involved in governance of multifunctional forests management;
- identify governance instruments used/applied in case study areas;

The paper aim is to identify specific elements of multifunctional mountain forest governance in the selected case study areas.

### Table 1. Case study areas description (based on ARANGE 2012).

<table>
<thead>
<tr>
<th>Mountain range</th>
<th>Country</th>
<th>Case study name</th>
<th>Total Area [km²]</th>
<th>Forest area [%]</th>
<th>Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iberian mountains</td>
<td>Spain</td>
<td>Montes Valsain</td>
<td>100</td>
<td>90%</td>
<td>public</td>
</tr>
<tr>
<td>Western Alps</td>
<td>France</td>
<td>Vercors</td>
<td>500</td>
<td>55%</td>
<td>private</td>
</tr>
<tr>
<td>Eastern Alps</td>
<td>Austria</td>
<td>Montafon</td>
<td>75</td>
<td>90%</td>
<td>common, private</td>
</tr>
<tr>
<td>Scandinavian mountains</td>
<td>Sweden</td>
<td>Villachina</td>
<td>950</td>
<td>97%</td>
<td>state owned</td>
</tr>
<tr>
<td>Dinaric mountains</td>
<td>Slovenia</td>
<td>Kozice chřiby</td>
<td>122</td>
<td>99%</td>
<td>church</td>
</tr>
<tr>
<td>Western Carpathians</td>
<td>Bulgaria</td>
<td>Shiroka laka</td>
<td>97%</td>
<td>97%</td>
<td>public, non-industrial, private, cooperative</td>
</tr>
<tr>
<td>Western Rhodopps</td>
<td>Serbia</td>
<td></td>
<td>97%</td>
<td>97%</td>
<td>public, private, church, management, cooperative</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Altitudinal range [m]</th>
<th>Main tree species</th>
<th>Ecosystem Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200–1900</td>
<td>Pinus sylvestris, Quercus pyrenaica</td>
<td>TP, CS, NC, REC</td>
</tr>
<tr>
<td>590–2750</td>
<td>Pinus sylvestris, Abies alba, Fagus sylvatica</td>
<td>TP, BMfE, CS, NC, REC, PF</td>
</tr>
<tr>
<td>600–2000</td>
<td>Picea abies, Abies alba, Fagus sylvatica</td>
<td>TP, PF (erosion, water resources)</td>
</tr>
<tr>
<td>250–1700</td>
<td>Picea abies, Abies alba, Fagus sylvatica</td>
<td>TP, GM, CP (water management)</td>
</tr>
<tr>
<td>600–1800</td>
<td>Picea abies, Abies alba, Fagus sylvatica</td>
<td>TP, GM, CP (water management)</td>
</tr>
<tr>
<td>700–2000</td>
<td>Picea abies, Abies alba, Fagus sylvatica</td>
<td>TP, GM, CP (water management)</td>
</tr>
</tbody>
</table>
2. Material and Methods

The method applied in this study is a comparative analysis of case study areas (CSAs). The CSAs are representing the mountain ranges in seven European countries: the Iberian Mountains in Spain (Montes Valsain), Western Alps in France (Vercors), Eastern Alps in Austria (Montafon), Dinaric Mountains in Slovenia (Sneznik), Scandinavian Mountains in Sweden (Vilhelmina), Western Carpathians in Slovakia (Kozie chrbty) and Western Rhodopes in Bulgaria (Shiroka laka). The selection of CSAs was made so as to represent the most important types of mountain forest ecosystems and the diversity of the environmental management patterns and societal specifics within the EU, including forest ownership, rural development and people’s demands on forests. The CSAs are concisely described in this paper, focusing on the aspects relevant to the purposes of the paper, i.e. characteristics related to provisioning of ecosystem services and ownership structure (Table 1).

Methods applied for data collection in the task dealing with governance systems are questionnaires and/or interviews (methodology of qualitative social research). The standardized interview (fill in the online questionnaire) was aiming at describing the local situation and identifying the local specifics of forestry governance in the respective CSAs. The survey respondents (1–8 per CSA) were representatives of local actors including forest owners and/or managers and relevant local forestry administrations (Table 2). To ensure the appropriate formulation of questions and adequate explanation of technical terms, the first version was initially tested as an face to face interview in the Slovakian CSA – Western Carpathians case study (Kozie Chrbty) and then commented by the national experts in all CSAs. Most of the questions were close-ended. However, a minor part of the interview consisted of open-ended questions to permit respondents to express their views without constraining them to particular response dimensions. Some closed-ended questions contained additional clarifying sub-items and/or text boxes where complementary information could be provided. There was also the possibility to add any comment at the end of the questionnaire if needed.

Table 2. Number of respondents by category.

<table>
<thead>
<tr>
<th>CSA</th>
<th>Montes Valsain</th>
<th>Vercors</th>
<th>Montafon</th>
<th>Sneznik</th>
<th>Vilhelmina</th>
<th>Kozie chrbty</th>
<th>Shiroka laka</th>
<th>Totally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authority</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Manager</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Owner</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Other expert</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Totally</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td>27</td>
</tr>
</tbody>
</table>

This study does not have an ambition to deal with all different governance structures in different socio-cultural backgrounds that might enhance or restrict multifunctional forest management in mountain regions.

In total 21 questions were structured into three parts:

I. Introduction (specification of the mountain forest types in the focused area, perception or understanding of multi-purpose forest management, objectives, and forest goods, functions and services provided by the particular mountain forests).

II. Governance systems, in which the following elements of governance were targeted: responsibilities, intersectoral coordination, participation and stakeholders interactions.

III. Governance instruments – divided into management plans, subsidy mechanisms, tax benefits, penalties, methodological guidance, education and research.

Moreover, the introductory part of the questionnaire covered the fundamental identification items, including the attribution of the respondents to the CSA and identification of the stakeholder group, which they represent.

The empirical material was gathered during the spring 2013. The national experts were requested to ensure the responses from their CSA by communicating with local stakeholders using the ARANGE Stakeholder interaction platform, which is a panel of selected actors created in advance in each CSA (ARANGE 2013c). There was a single common version of the questions prepared for all CSAs (in English language), and afterwards it was translated to the native language of respective CSA if necessary.

The respondents had the opportunity to consult their views with other local actors. As a face-to-face interviews with some of the responding stakeholders were conducted in case when interpretation of some technical terms in the national context was needed or when formal and informal decision structures and processes specific to respective CSA needed to be exemplified. The semi-structured questionnaire was prepared and implemented with the help of the Adobe Forms Central application (Adobe Forms Central, 2013). To fill up the online questionnaire took about 20 to 30 minutes. The respondents were encouraged to consult the glossary of terms attached to the questionnaire prior to filling in the questionnaire. All definitions in the glossary originated from a literature review and were generally focused on a common understanding of terminology used in the questionnaire.

The number of acquired responses varied, depending on the local circumstances and ownership structure, ranging from eight replies to a single reply from the respective CSAs. Based on the interviews 27 filled questionnaires in total were gathered from all CSAs (Table 2). Most commonly, the respondents identified themselves as forest managers (50%), there was about 30% of land and/or forest owners, who were often involved in practicing forest management. About 20% of the respondents were representatives of forest authorities or other type of stakeholders.

Data collected in the course of this survey allow using qualitative methods (generalization, comparison and storytelling) for context analysis and interpretation. Comparative cross-tables and Adobe visualization tools to synthesize the research findings were used. Evaluation of the aggregated data enabled reporting and interpretation of the main findings across the CSAs and the main ecosystem services.
3. Results

3.1. Conceptualization of multifunctional forest management

A concise understanding of governance and multifunctional forest management in a CSA requires an adequate comprehension of the key terms associated with multifunctional forest management. Multifunctional forest management as understood by the most questionnaire respondents is a management of forests focused on preserving or strengthening several forest functions and services. The respondents also understand that multifunctional forest management supports, besides timber production, also other specific forest functions. However, timber production should not be suppressed in favor of other forest functions, unless some forest functions are concurrent or not compatible with timber production (26 from 27 respondents). However, there were differences (among the CSAs as well as within them) in the understanding how multifunctional forest management is being implemented in practice distinguishing functional aggregation and segregation approaches.

In the aggregation approach (functionally integrated forest management), ecosystem services are considered as equal. This perception was accepted by less than a half of the respondents, while it was explicitly disapproved by one-third of the respondents. One supportive response from Montes Valsain stated: “The management of the forest tries to make compatible forest harvesting, cattle grazing with the proper practicing of traditional activities along with the preservation and improvement of the habitat of plants and animals, as well as the needs of the human population.” However, another respondent from the same region expressed a need to prioritize some ecosystem services, stating “...multifunctional forest management focuses on developing several forest functions and services, but with some functions or services being of more interest than others. A prioritization of functions is always needed, although difficult to establish at the different management levels”. However, a response from Vilhelmina illustrates the discrepancy between the theoretical concept of multifunctionality and the implementation: “Forest functions should perhaps be compatible and definition of functionally integrated forest management sounds fine but is far away from how forestry is working today due to the fact that timber production is very important as a main goal in forestry”. This last statement alters the understanding of multifunctional forest management towards the segregation approach. The segregation approach (functionally differentiated forest management), which matches the understanding of two-thirds of the respondents, results in a “multifunctional forest management that prioritizes a function, but maintains and strengthens all those functions that are compatible”.

Other respondents noted difficulties in adopting the definition of multifunctionality identically across different spatial units; evidently, spatial scale determines the applicable management decisions and strategy. This refers to Simoniec & Boncina (2013) who promote the concept of Priority areas to provide multiple forest ecosystem services that can help to differentiate priorities, objectives and measures within large forest areas. Also, there were notes of particular respondents about having inherently different priorities in multifunctional forest management. Moreover, a representative of forest authority from France noted a discrepancy between the formal support of multifunctionality and practical behavior: “As an owner the department is rather a protectionist, but as a subsidy manager, it is production-oriented”. However, despite some differences in the perception of multifunctionality within a CSA, the perceptions clearly differed among the CSAs than among the respondents from the same region when more than one answer where obtained. These results confirm that functionally differentiated forest management is applicable at a local level (forest management unit or smaller areas), while functional aggregation is the issue of forest management at a higher level (mountain range, forest land). This approach towards ecosystem services is also promoted in land-use planning and management (Fürst et al. 2013a, 2013b).

3.2. Practices of multifunctional forest management

All study regions recognized manifold goods and services being provided by forest ecosystems through active, targeted forest management. With the exception of one respondent from Montes Valsain, timber production was always reported as the main ecosystem service (Fig. 1 and Table 3). Soil/water protection and biodiversity protection were the two next most vital ecosystem services, perceived by the most of respondents across all CSAs. Hunting, recreation and firewood/biomass production were evaluated as secondary or main services in all CSAs. Production of other wood products and non-timber products were labeled mostly as ecosystem services of secondary importance (with the exception of two respondents from Shiroka Laka and one from Vilhelmina). Carbon sink was mostly considered to be of secondary importance and simultaneously as commented by a respondent from Vilhelmina, this service is provided “indirectly through tree production, but not actively considered”. Similarly, another respondent from Montes Valsain warned that “we could tell that we are managing for carbon sequestration but that’s not really true”. Other important ecosystem services in mountain areas include protection against gravitational and other natural hazards, fishing (angling), and grazing (cattle in Montes Valsain and reindeer husbandry in Vilhelmina).

Table 3. The importance of ecosystem services in the case study areas.

<table>
<thead>
<tr>
<th>Main ES</th>
<th>Main-secondary</th>
<th>Secondary</th>
<th>Case-Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber production</td>
<td>Hunting and fishing</td>
<td>Recreation services</td>
<td>Other wood products</td>
</tr>
<tr>
<td>Protection ES (soil and water protection, including protection against gravitational and other natural hazards)</td>
<td>Carbon sink</td>
<td>Firewood, chips and other energy biomass</td>
<td>Non-wood products</td>
</tr>
<tr>
<td>Protection of biodiversity</td>
<td>Other wood products</td>
<td>Animal grazing</td>
<td></td>
</tr>
</tbody>
</table>

The prioritized ecosystem services (Fig. 1, right) are dominantly, but not always actively supported by forest management. In almost all CSAs, the production of timber,
biodiversity protection, and the protection of soil and water resources were reported to be sustained through an active forest management (Fig. 1, left).

Hunting and recreation services are also actively supported in all CSAs; however, active measures concerning these services are being explicitly taken only in some CSAs. Moreover, the perception of active/passive measures differed among the respondents from Vilhelmina, Kozie Chrbty and Shiroka Laka. Similarly, active measures targeted at the production of other non-wood products range from no support in Montafon and Kozie Chrbty to explicit support in Montes Valsain and Sneznik. Active management supporting the animal grazing was reported for Montes Valsain and Vilhelmina.

3.3. Governance systems supporting multifunctional forest management

Taking into account the multifunctional value of forests and sustainable management in mountain ranges, we have focused on describing examples of governance systems in the CSAs. Similarly to Hogl et al. (2004), we have found that participatory and inter-sectoral processes are playing an important role in multifunctional forest management.

Generally, the most important sectors involved in governance of multifunctional forest management are forestry sector and nature protection – or similarly defined – environmental sector (Fig. 2). The sectors dealing with water management, regional development, recreation and tourism were reported as somewhat important. According to two thirds of the respondents, the intersectoral cooperation is more or less ensured, although the overlaps between sectors may occur sometimes. However, all respondents from Kozie Chrbty considered the intersectoral cooperation as minimal or not established at all. There is also a persisting presence of conflicting interests (environment vs. forestry, environment vs. agriculture, agriculture vs. forestry etc.) reported from CSAs. Overlaps or conflicts between forestry and nature protection have also been reported for Montes Valsain. Similarly, frequent overlaps between the sectors relevant to forest management were reported from Sweden.

The most important non-governmental organizations and associations contributing to forest governance in CSAs are the professional associations and, to less extent, also the interest associations (Fig. 3). Local action groups are important only in some case CSAs. Among the important

Fig. 1. The provisioning (left) and the perceived importance (right) of goods, functions and services in the case study areas.

Fig. 2. Sectors involved in forest governance in the case study areas.
non-governmental institutions, interest or professional associations, the following examples were provided by the respondents: district (Regional Park) forestry commission in Vercors, forestry chamber in Kozie Chrbty and reindeer husbandry districts and international research organizations in Vilhelmina.

Supervision of multifunctional forest management is ensured mainly by governmental but also by other (yet unspecified) regional, district or local organizations, and in some cases also by non-governmental organizations. Supervision that is relatively important is represented by certification bodies during their audits or inspections. Forest certification standards were agreed to support multifunctional forest management. Most of the forests within the CSAs are certified by either PEFC or FSC. Some non-certified forests within CSAs were reported from Shiroka Laka (90%), Montes Valsain (20%) and Vilhelmina (10%). There was not reported an absence of supervision in CSAs.

State supervision of forests is being undertaken mainly by governmental institutions from forestry sector or by the combination of agriculture and forestry sectors. Two respondents from Montes Valsain reported a governmental supervision by environmental sector.

Relevance of local public opinion for supervising forest management varies in CSAs. Almost two thirds of respondents considered public opinion as relevant: public opinion in Vercors lead to preference of selective cutting instead of clear-cutting, it increased the involvement of public in forest management planning in Montes Valsain and Sneznik and strengthened public interests in management of municipal forests in Montes Valsain. Public opinion is also influenced through the local associations and clubs, e.g. snowmobile clubs, hunters, anglers as well as through the comments of reindeer keepers and neighboring owners on harvesting plans in Vilhelmina.

Most of the reported indicators of multifunctional forestry that are controlled by the supervising bodies can be described as sustainable forest management indicators. They include planned harvest volume, state of endangered species, forest regeneration, water source quality, tree species composition, erosion, deadwood amount. Respondents also highlighted some national indicators such as the size of the clear-cuts, vehicle damage to soils, number of hunting permits and trophies, the extent of cattle grazing, the share of exotic tree species plantations, age of forest, and state of habitats.

Monitoring of social forest functions such as support for local inhabitants, environmental education, support of tourism, regional employment, health and safety etc. is less common and reported only for some of the CSAs. However, due to a high variability in the responses among CSAs as well as within them, the level of monitoring of social functions could not be evaluated accurately.

Forestry was generally considered as a sector strongly influenced by conventional practices and with relatively low implementation of innovations (Rametsteiner et al. 2005). The importance of collective decision-making processes in forestry is highlighted by Ramcilovic-Suominen and Epstein (2012), but they also stressed other factors like individual motivation, property regime, international market and forest culture that may affect decisions. Decision making in CSAs is mostly influenced by professional knowledge and experience (Fig. 4). Actual and expected financial profit as well as legal requirements, standards, and plans also have important influence on decision making. Transfer of knowledge among colleagues, traditional custom practice and current trends in forest management are less important; less than one third of the respondents considered these sources of knowledge as very important for decision making. A respondent from Slovenia drew attention to the unprivileged private actors in decision-making: “forest owners have only little influence on decisions about the system of multifunctional forest management. Every measure in the forest has to be allowed by public forest service”.

Fig. 3. The assessed contribution of NGOs and associations to governance of forest management in the case study areas.
Professional methodical guidance for multifunctional forest management is predominantly a responsibility of public and regional professional organizations (e.g. local and regional forest owners associations in Vilhelmina). Non-governmental organizations also participate in defining methodical guidance in some cases. Among other organizations, universities and certification bodies were most frequently mentioned. Our results confirmed that both above mentioned facts on forestry in mountain areas - conservative approaches (driven by law and professional standards) and individual motivations (knowledge and profit) are the key factors in the decision-making process.

3.4. Governance instruments
Governance in the CSAs is triggered and supported through various forestry-specific instruments. Forest management plans are the common tool for implementation of forestry related legislative and strategic documents at the operational level (i.e. forest stand level or forest management unit level). Their role in forest governance can nonetheless be different (ARANGE 2013b). Although the management planning is not obligatory in Austria, forest management plans are implemented in Montafon on a voluntary basis, which may partly be motivated by adopted certification scheme. A similar situation applies for Vilhelmina: forest management plans are not obligatory in Sweden, but required if the forest is to be certified. Even though forest management plans may be provided, they do not guarantee sustainability and multifunctionality of forest management in practice, since “the profitability of management is non-existing and public resources are diminishing due the economic crisis, what poses major threat to management” (forest authority, Montes Valsain).

Within most CSAs, forest management plans contain prescriptions directly related to the multifunctional forest management. The exception is Swedish Vilhelmina, where environmental values are considered as a rule without explicit declaration. Only for some stands of special nature values and other special circumstances (i.e. installations for reindeer herding, cultural heritage, special tourist facilities, etc.) there are comments and descriptions also in the forest management plan. To identify relevant economic instruments that are covered by legislative and policy documents in each CSA (ARANGE 2013b), the survey also included those economic instruments that could be relevant for assessing the performance of the local governance mechanisms.

Subsidies supporting multifunctional forest management have been applied in all CSA in the last 5 years. However, their sources (e.g. regional, national, EU) and the subject of support (e.g. forestry, nature and water protection, recreation) vary. Most frequently, an explicit support for forest management and nature protection is reported, with governmental support being slightly more frequent than the regional one or that of EU. Subsidies supporting recreation and water resource protection were reported by only three respondents. In addition to the four main ecosystem services, subsidies for employment in forestry, culture heritage preservation, bio energy, and forestry in a changed climate were reported from Vilhelmina.

Tax benefits for multifunctional forest management are usually not directly applied. However, various indirect support instruments can be applied on the national level. For instance, in Slovakia and Slovenia, property tax exemption is being applied on forest land where protection or other non-production ecosystem services are prioritized and forests are classified as “protection forests” or “special purpose forests”. Similarly, exclusion of taxes as a public economic instrument was also reported for Bulgaria. Tax exemption in forest reserves and NATURA 2000 sites is being applied in Vercors. Penalties for breaching multifunctional forest management are generally imposed implicitly - penalties are resulting from legislation. Their application and effectiveness varies among CSAs as different national laws are applied. Effective penalties were reported from Kozie Chrhby and Montes Valsain. Penalties in place but not fully adequate were reported from Montafon. Inadequate or ineffective penalties were reported by respondents from Shiroka Laka and Sneznik. Respondents from Vilhelmina did not share the same view of effectiveness of penalties.

The respondents also commented local threats to multifunctional forest governance, and proposed future tasks and implementation strategies, for example forest owner from Vilhelmina suggested “developing different strategies and strengthening the entrepreneurs who work with and from the forest”. Forest authority from the same site was convinced that “the keywords to reach multifunctional management are landscape perspective - partnership - sustainability”. However, as recognized by forest authority representative from Montes Valsain, the practical implementation of multifunctional governance is rather problematic and a long-term activity: “we are being able to maintain a rather positive and well supported multifunctional forest management in place, but (...) a serious problem is justify the disagreements, like with nature conservation organizations for land uses. (Forest management in the Guadarrama range)... is a clear success of a lot of people (provincial foresters, local majors, private forest owners, hunter, farmers, forest workers and others... under strong pressure of ecologists’ associations”.

4. Discussion
Mountain forests belong to the most preserved ecosystem in Europe, and as such they are subject of nature conservation in many cases. Mountain forests were preserved against deforestation for agricultural purposes, due to mostly slope terrain and/or climatic conditions. In order to understand multifunctionality of mountain forest ecosystems, it is necessary to explore which ecosystem services (MEA 2005) are affected by multifunctional forest management practices in the CSAs.

Results show that timber production and soil and biodiversity protection are considered equally important across the studied regions. This implies that timber production and protection (water, soil, biodiversity, etc.) should not need to be opposing or conflicting in practicing multifunctional forest management. Environmental monitoring is ensured within forest management in all CSAs preventing unbalanced use of ecosystem services.
Conflicts between nature conservation and other sectorial policies regarding management of mountain forests were reported from some regions, which indicate deficiencies in intersectoral cooperation and governance failure. One of the main problems in forest governance in European mountain ranges is also unbalanced involvement of regional structures in decision making (NGOs, interest associations, general public).

Sustainable multifunctional forest management refers to the necessity for new forms of governance (Rametsteiner 2009). There are described three main approaches for European forest governance (Pulzl et al. 2013). First one is legislative approach that follows traditional top-down models (Kokko et al. 2006). The second mixed approach based on cooperation and giving the priority to information sharing (Pulzl & Lazdinis, 2011). The third is based approach on so-called soft modes of governance that are neither top-down nor bottom-up (Kleinschmit 2012). All mentioned approaches are relevant for the CSAs. Besides the trend that mountain areas are more under the pressure of local and regional demands (water supply, protective functions, recreation), the support of multifunctional forest management is more national level of interest. There is a large number of governance instruments aimed at multifunctional forest management already exist at national level. The importance of economic instruments such as subsidies, taxes benefits or penalties was stressed due to increasing demands for ecosystem service payments. On the one hand the implementation of multifunctional forest management in mountain regions in the absence of financial support is disputable. On the other hand it would be difficult to expect that the subsidies or incentives solve the problem with multifunctional forest management. In this situation, the most important challenge is to involve the communities, governments, and public organizations at various levels in the decision process and secure the consistency in their objectives.

To consider biases that are typical for such one-time surveys, this analysis can be considered as a tentative qualitative assessment of governance in European mountain regions, while several aspects remain unclear such as evaluation of governance effectiveness and efficiency, aspects influencing participation, transparency, capacity. Such questions would require a more detailed analysis, which, however, was beyond the scope of this study.

5. Conclusion
Analysis of cases confirmed that sustainable multifunctional forest management in European mountain ranges is based on case specific governance systems. The governance of mountain forests differs from other forest areas because of their main role in protective functions, nature conservation and recreation. The main finding is that multifunctional mountain forest governance is case specific. Many different sectors and actors have an influence on governance in mountain regions and the coherence and consistence of management goals is not always secured. From the governance systems point of view multifunctional forest management applied in selected European mountain regions request high level of participation and coordination with different stakeholders beside forest sector.

Acknowledgment
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Co-adaptive system of tree vegetation and wood-destroying (xylotrophic) fungi in artificial phytocoenoses, Ukraine

Systém prispôsobenia sa stromovej vegetácie a drevokazných (xylotrofných) húb v antropogénnej fytoценóze, Ukrajina

Olena Blinkova, Oleksandra Ivanenko

Institute for Evolutionary Ecology NAS of Ukraine, 03143, Kiev, 37 Lebedeva str., Ukraine

Abstract
The co-adaptive system of tree vegetation and wood-destroying (xylotrophic) fungi in artificial phytocoenoses (in an old-aged, and middle-aged ash-hornbeam oakery and monocultures of Pinus L.) of Forest-Steppe zone of Ukraine was analysed from the point of selected forestry parameters. We investigated the vitality, age, phytosanitary structures of pure acerous (Pinus strobus L., P. sylvestris L.) and mixed broad-leaved stands (Carpinus betulus L., Fraxinus excelsior L., Quercus robur L., Tilia cordata Mill.) and species, systematic, trophic structures of xylotrophic fungi (39 species of macromycetes representing 32 genera, 22 families, 9 orders of 2 divisions: Ascomycota (classes Leotiomycetes and Sordariomycetes) and Basidiomycetes (class Agaricomycetes)). The results showed that the species composition and the structure (vitality, phytosanitary) of artificial phytocoenoses altered both the composition of xylotrophs and the levels of the damage of tree stands caused by them.

Keywords: consortial links; experimental plots; xylotrophic fungi; woody plants

1. Introduction
Nowadays a common knowledge is the scientific provision that when studying biota one should start from the concept of systematic biosphere organisation, since structural and functional unity of components, integrity of biotic and abiotic components are its characteristics. It is natural that each level of hierarchical organisation of biota has its own functional peculiarities, which are stipulated by its origin, structure, inter-relations with the environment and development. This complicates the process of educing the consequences of ecological factors' impacts upon ecosystems, in particular – the changes in their impact on structural and functional components of ecosystem (Arefyev 2010). Co-adaptive systems with their tight ecological links play a significant role in this issue. The study of such ecological objects is important for deeper noesis of not only their biological variety, but also of the issues of phylogeny, regularities of historical transformation of communities, the solving of which is in the initial stage.

In this context a co-adaptive system of tree vegetation and wood-destroying (xylotrophic) fungi is an essential element to study. The actuality of the ecological object is stipulated by the core role of forests in biosphere stability, preservation of landscape and especially biotic variety of land, including fungi, and its global influence upon the planet’s climate in accordance with the Rio Declaration on Environment and Development (1992). Taking into account the ecosystematic, and biospheric role of tree vegetation in cycling of substances, energy and information on the Earth, and its role as the environment for the existence of multiple living organisms' species, studying and preservation of forests remains one of the most significant aspects of natural management in the world. The experience in characterising hierarchic, species, geographic, trophic, informational, spatial structure of communities of xylotrophic fungi has been accumulated and the mechanisms of their substrate specialisation has been described in details (Stepanova & Mykhin 1979, Boddy & Rayner 1983, Schmidt 2006, Küffer et al. 2008). Numerous studies of the stated issues refer mostly to systematics and phytopathology of fungi. They differ mostly in the methodological approaches and the depth of studies of certain structural and functional components of forest ecosystems. This leads to
receiving incomplete information, especially under the terms of ecological objects being influenced by a complex of factors of different origin, intensity and unsafety.

The co-adaptive system of tree vegetation and xylotrophic fungi has not been sufficiently studied so far, although it is an important basis for correct indication and monitoring of the state of forest ecosystems. This concerns the necessity of a complex analysis of evolutionarily formed consortial links between tree vegetation and xylotrophic fungi. Following business practices in the countries where silviculture is intensive, in Ukraine major transformation of natural forests into cultivated forests (over 50 %) has taken place. Such a transformation of forest ecosystems caused deprivation of species composition and, accordingly, of structural and functional organisation, certain breach of the consortial links “tree – xylotrophs”. Due to this, the study of a co-adaptive system of these organisms in phytocoenoses of artificial origin is expedient.

The structure of xylotrophic fungi is a reflection of parameters of artificial phytocoenoses’ development and state, which evidences the unity of components at all hierarchic levels of their inter-links. In the phytocoenoses, which are not durable for anthropogenic or natural reasons, the resistance of biota species to negative influence is significantly diminished and in general, the attrition of the weakest plants and the reformation of species composition and ecosystem structures increases (Arefyev 2010). The facilitative species of xylotrophs which have a high degree of pathogenicity take an active part in the formation of the most durable forest ecosystems. The dispersal of xylotrophic fungi in such phytocoenoses is driven by the amount of available substrate and by crucially high evaporation that depends on the intensity of tree drying, canopy openness, stand closure, and protective cover of living on-surface cover (Zmitrovich & Vasilyev 2006, Safonov & Malenkova 2011).

Taking the above into account, the hypothesis of our study is that the species, trophic, systematic structure of xylotrophic fungi depicts the phytosanitary state, vitality and age structure of stands of artificial phytocoenoses.

2. Materials and methods

Study site. Artificial phytocoenoses were selected from the nature reserve fund of Ukraine since in these objects human intervention is minimised. Hence, inter-links between tree vegetation and xylotrophic fungi are not significantly influenced by human activities. That is why the study was conducted in the State Dendrological Park of Ukrainian National Academy of Science (NAS) “Oleksandriya” (dendropark), which is also a monument of garden art of nation-wide significance of nature reserve fund of Ukraine, and is one of the largest (49° 48′ 44″ N, 30° 04′ 02″ E, area 297 ha) and the most valuable dendrological parks in the territory of Ukraine (Klymenko & Mordatenko 2001). The dendropark is located North-East from the Right-bank of the Forest-Steppe zone, at the outskirts of Bila Tserkva town of Kyiv Region (elevation 80–106 m above the sea level). Architectural edifices and aged oak planted vegetation are extremely valuable landscape components in Ukrainian territory and worldwide. Probably the most valuable feature in Alexandria dendropark is the so called “old-aged oak-forest” with up to 2.100 trees of Quercus robur L. aged 220–250, and some even 400–600 years old, covering a total area of 44.6 ha. In literature these plantations are called “old-aged oak-forests” (Deriy 1958; Dragan 2010, 2012). However it is worth noting that according to forestry typological classification basics an “oak-forest” is a type of forests, an ecotope, which originates from natural regeneration of oak (Anuchin 1982). In turn a tree stand from oak planting is customarily called “oakery”. Ergo, this paper deals with an overmature oak stand – “old-aged oak-forest”.

Considering the data from inventory documents, forest management plans and the primary survey performed in September 2013 (17 – 24), we distinguished three types of artificial phytocoenoses, which grow on grey forest soils. To analyse vitality, phytosanitary conditions, age structure of stands and the species, systematic, trophic structure of xylomycoplex, three experimental plots (EP) in phytocoenoses, which differ in forestry characteristics – type (or species composition), age and phytosanitary state of stands were established as ecological profiles: 1) EP1 (0.5 ha) – in an overmature (old-aged) mixed oak stand (the “old-aged oak-forest” according to inventory documents) called “The Dancing Oaks” (the 12th sector of the park); 2) EP2 (1 ha) – in a middle-aged ash-hornbeam planting (Carpinus betulus L. and Fraxinus excelsior L.) called “The Hornbeam Building” (the 15th sector); 3) EP3 (0.5 ha) – in a monoculture of Pinus sylvestris L. and P. sylvestris L. called “At the Great Glade” (the 28th sector of the park) (Fig. 1).

Methods. In each experimental plot, ecological research was performed at different diagnostic levels of xylotrophic fungal infestation: organ, tree, population (species), bio-group (stratum) of phytocoenosis, phytocoenosis. The state of trees was evaluated according to common methods of forestry and landscape ecology (Vorobyov 1967, Anuchin 1982). The phytosanitary state of trees was appraised in accordance with the Sanitary Forest Regulation in 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 examined trees. Stands with the index value from the interval 1 – 1.5 are considered healthy (I), the weakened ones (II) – 1.51 – 2.50, heavily weakened (III) – 2.51 – 3.50, the wilting

![Fig. 1. State dendrological park of NAS of Ukraine “Alexandriia” and the position of the experimental plots.](image)
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, for each category of states the weighted average of Kraft classes (WAKC) was calculated as the sum of the number of trees in each Kraft class multiplied by stand state index (I–V), divided by the total number of trees in a certain category of state. For this purpose the trees in each category were divided into 5 groups according to Kraft classes. Classes Va and Vb were united into class V, since the trees of these categories were rarely found in the experimental plots. The WAKC depicts the localisation of the damage zone in the tree stratum: the closer the WAKC is to Kraft class I, the higher is the degree of damage. Hence, this evidences that the most persistent trees are influenced by negative ecological factors. For each stand, forest mensuration parameters were determined: age (A); weighted average diameter (D ave), height (H ave), fluctuations range (D min – D max; H min – H max) and standard deviation (S.D.), stand density (N), mean tree basal area (G), stand basal area as a sum of tree areas (Gn).

According to regular mycological methods (Arefyev 2010), the measuring unit is a host tree, on which carphophores of certain fungi species were detected. The collection of factual evidence was carried out during the period of visible growth and formation of carphophores of xylotrophic fungi in the vegetation period. Every detected species was photographed in vivo. The species that were easily identified “in oculo nudo” and did not require additional micro-morphological studies were not included in the exsiccates. If required, the colour, smell, and the structure of carphophores were noted including the reaction of carphophores to mechanical damage (change of colour, sap ooze) and the substrate. The determination of fungi species was effected by the methods of Ryvarden and Gilbertson (1993, 1994), Clémençon (2009), Bernicchia and Gorjón (2010). The dead substrate of the host tree of xylotrophic fungi was divided into two categories – fallen woody debris (branches and stems) and stump depending on the morpho-meteric parameters. Xylotrophic fungi species were identified on the base of macrosystem and phylogeny of higher fungi (Zmitrovich 2001, Zmitrovich & Wasser 2004, Hibeit et al. 2007) using the nomenclature base MycoBank (Robert et al. 2005). The names of fungi species are cited according to Kirk and Ansell (1992).

3. Results and discussion

Due to the construction of the park alleys, parkways, introduction of alien crops and creation of new landscape components during the past decades, the dendrological park has undergone an intensive anthropomorphic transformation, which is manifested in the breach of structural and functional integrity of phytocoenoses’ organisation. This in turn essentially affects the functioning of a co-adaptive system of C. betulus, F. excelsior, P. strobos, P. sylvestris, Q. robur, T. cordata and xylotrophic fungi. It is also notable that there is no data on mycobionta of tree vegetation from the territory of the dendrological park. Our mycological study detected altogether 39 species of macromycetes (30 species of xylotrophic fungi), 32 genera, 22 families, and 9 orders of 2 divisions: Ascomycota (classes Leotiomycetes and Sordariomycetes) and Basidiomycota (class Agaricomycetes) (Table 1) at all experimental plots of the dendropark’s ecoprofile.

At the first EP, the stand consisted of two storeys, the canopy cover was 0.5 – 0.6; mean tree basal area G of Q. robur (A = 220 – 250) (the first storey) varied between 0.1808 m²/ha and 0.6510 m²/ha, S.D. = 0.1263, stand basal area Gn at the ecoprofile was 140.4 m²/ha; N (stand density) = 401 pcs./ha; H ave = 29.5 m, H min = 21.5 m, H max = 34.7 m, S.D. = 3.62 m; D ave = 65.24 cm; D min = 44.5 cm, D max = 91.5 cm, S.D. = 12.16 cm.

The herbaceous storey is represented by oakery forbs only at plots with preserved forest structure (Veronica chamaedrys L., Pulmonaria obscura Dumort.). The dominating species at the EP were Dactylis glomerata L., Trisetum flavescens L., Asarum europaeum L., Urtica dioica L., etc. Altogether, 30 species of macromycetes were found at EP1, the fruiting of which occurs autumn. These fungi species represented 26 genera, 17 families, and 7 orders of 2 divisions: Ascomycota (class Leotiomycetes) and Basidiomycota (class Agaricomycetes). From the on-ground saprotrophs we detected Chlorophyllum rhacodes (Vittad.) Vellinga, Stropharia aeruginosa (Curtis) Quél., and dry carphophores of Calvatia utriformis (Bull.) Jaap, which grows mainly in July–August. From the fungi fruiting in spring and summer on small dry branches of T. cordata we found Polyporus alveolaris (DC.) Bondartsev et Singer, which is a xylotrophic fungus with broad substrate preference. On Q. robur 23 species of xylotrophic fungi were detected, while 3 were parasitic species, and their share in the artificial phytocoenosis comprised only 9%: Fistulina hepatica (Schaeff.) With., Inocutis dryophila (Berk.) Fiasson et Niemelä and Phellinus robustus (P. Karst.) Bourdot et Galzin. The latter 2 species were detected only on the trees of I–II phytosanitary stand categories. Their carphophores fruiting time coincides mainly with mechanically undamaged stem of Q. robur at a height of 4 – 10 m. On the contrary, Phellinus robustus preferred mechanical damages of stems (hollows, chaps, shear cuts of branches of the 1st and the 2nd order), which accelerate mechanical drain. Fruiting of Fistulina hepatica, on the contrary gravitate to dead substrata. The analysis of the vital structure of Q. robur plantings revealed that xylotrophic fungi were observed mainly on the trees in I Kraft class (45%), while their proportion on the trees of IV Kraft class was the lowest (7%) (Table 2).

Such a distribution of trees to individual Kraft classes is caused byover-maturity of Q. robur. Besides, the weighted average of Kraft classes (1.55) of healthy trees of Q. robur (1 phytosanitary stand category) indicates that the closer the trees are to forest roads and open landscape elements, the more increasing is the number of trees in Kraft classes II–III. The proportion of co-dominant trees among the weakened trees is growing with the increasing proximity of forest roads. Although the total proportion of very weakened trees is not high (15%), the number of trees in the weakened Kraft class III is increasing, which further increases the probability of the pathological process in the old-aged oakery. In general, 51% of Q. robur trees at the EP1 were healthy, the rest were weakened to different extent, including 3% of dying ones (Table 3). The phytopathological state of Q. robur trees at this plot...
### Table 1. Taxonomic structure of macrofungi at the experimental plots.

<table>
<thead>
<tr>
<th>Division</th>
<th>Subdivision</th>
<th>Class</th>
<th>Subclass</th>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCOMYCOTA</td>
<td>PEZIZOMYCOTINA</td>
<td>LEOTIOMYCETES</td>
<td>XYLARIOMYCETIDAE</td>
<td></td>
<td>Helotiales</td>
<td>Ascocoryne (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Helotiaceae</td>
<td>(1;1)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASIDIOMYCOTA</td>
<td>AGARICOMYCOTINA</td>
<td>AGARICOMYCETES</td>
<td>AGARICOMYCETIDAE</td>
<td></td>
<td>Corticiales</td>
<td>Vuilleminia (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Corticiaceae</td>
<td>(1;1)</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hymenochaetales</td>
<td>Schizophyllaceae</td>
<td></td>
<td>Hymenochaetales</td>
<td>Hymenochaete (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fistulinaceae</td>
<td>Fistulin (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inocybaceae</td>
<td>Crepidotus (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mycenaceae</td>
<td>Punctilus (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Petulaceae</td>
<td>Radulomyces (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Schizophyllaceae</td>
<td>Schizophyllum (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strophariae</td>
<td>Hypholoma (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stereaceae</td>
<td>Stropharia (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stereum (2)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Vitality structure of Quercus robur L. and specific structure of xylotrophic fungi at the first experimental plot.

<table>
<thead>
<tr>
<th>No.</th>
<th>Fungi-consorts</th>
<th>Kraft class (pcs./%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>1</td>
<td>Ascocoryne sarcoides (Jacq.) J.W. Groves et D.E. Wilson</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>Bjerkandera adusta (Willd.) P. Karst.</td>
<td>1/2,9</td>
</tr>
<tr>
<td>3</td>
<td>Crepidotus mollis (Schaeff.) Staude</td>
<td>1/2,9</td>
</tr>
<tr>
<td>4</td>
<td>Crucibulum crucibuliforme (Soop.) V.S. White</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>Cyathus striatus (Huds.) Willd.</td>
<td>3/8,8</td>
</tr>
<tr>
<td>6</td>
<td>Fistulinia hepatitis (Schaeff.) With.</td>
<td>1/2,9</td>
</tr>
<tr>
<td>7</td>
<td>Hypholoma fascicularis (Huds.) P. Kumm.</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>Inocutis dryophila (Berk.) Fissan et Niemelii</td>
<td>1/2,9</td>
</tr>
<tr>
<td>9</td>
<td>Peniophora quercina (Pers.) Cooke</td>
<td>1/2,9</td>
</tr>
<tr>
<td>10</td>
<td>Phellinus robustus (P. Karst.) Bourdot et Galzin</td>
<td>4/11,8</td>
</tr>
<tr>
<td>11</td>
<td>Radulomyces modaris (Chaillet ex Fr.) M.P. Christ.</td>
<td>3/8,8</td>
</tr>
<tr>
<td>12</td>
<td>Schizophyllum commune Fr.</td>
<td>1/2,9</td>
</tr>
<tr>
<td>13</td>
<td>Schizopora paradoxa (Schrad.) Donk</td>
<td>1/2,9</td>
</tr>
<tr>
<td>14</td>
<td>Stereum gausapatum (Fr.) Fr.</td>
<td>1/2,9</td>
</tr>
<tr>
<td>15</td>
<td>Trametes versicolor (L.) Lloyd</td>
<td>1/2,6</td>
</tr>
<tr>
<td>16</td>
<td>Vuilleminia comedens (Nees) Maire</td>
<td>2/5,9</td>
</tr>
</tbody>
</table>

*Note: * — % within the category of phytosanitary state.
indicates probable gradual decay of the growing forest in the absence of regular maintenance.

It is also clear that the composition and distribution of xylotrophic fungi is tightly connected not only with the vitality and phytosanitary structure of tree stands, but also with the type of substratum (Table 4). According to this, one half of the identified xylotrophic fungi (50%) occurred in the ground myco-horizon of Q. robur, and 37.5% – in the butt myco-horizon.

The frequency of xylotrophic fungi in stem and photosynthesising mycohorizons was equal – 8.3% at each horizon. Besides, the dead substrate of the two categories (woody debris and stumps of Q. robur) was also detected at the experimental plot (Fig. 2). It should be noted that the biggest number of species and findings of xylotrophic fungi on dead substrate coincides with the fine woody debris of Q. robur. We detected: Ascocoryne sarcoides (Jacq.), J.W. Groves et D.E. Wilson (1, finding), Bjerkandera adusta (Willd.) P. Karst. (1), Crepidotus mollis (Schaeff.) Staude (1), Crucibulum crucibuliforme (Scop.). V.S. White (1), Cyathus striatus (Huds.) Willd. (3), Peniophora quercina (Pers.) Cooke (1), Radulomyces molaris (Chaillet ex Fr.) M.P. Christ (2), Schizophyllum commune Fr. (2), Schizopora paradoxa (Schrad.) Donk (1), Stereum gausapatum (Fr.) Fr. (3), Trametes versicolor (L.) Lloyd (1), Vuilleminia comedens (Nees) Maire (6, findings). All together 13.3% stumps of Q. robur aged over 10 years occurred at EP1. The saprotrophs of Q. robur (D_min = 65.0 – 85.0 cm) were: Fistulina hepatica (4, findings), Hymenoconhae rubiginosa (Dicks.) Lév. (2), Hypholoma fasciculare (Huds.) P. Kumm. (3), Panellus stipticus (Bull.) P. Karst. (1, finding). On the stumps of Q. robur with average diameter of 45.0 – 65.0 cm we found: Ganoderma lipsiensis (Batsch) G.F. Atk. (1, finding), Hypholoma fasciculare (1), H. lateritium (Schaeff.) P. Kumm. (1), Stereum hirsutum (Willd.) Pers. (2), Trametes hirsuta (Wulfen) Lloyd (1, finding).

It was also detected that at the EP1 plantings of T. cordata (A = 100 – 120) located in the other storey, had the following inventory parameters of stand: G varied between 0.1205 m²/ha and to 0.2801 m²/ha, S.D. = 0.0840; Gª = 78.8 m²/ha, N = 151 pcs./ha, Hcw = 15.2 m, H = 10.0 m, H_min = 19.5 m, S.D. = 2.71 m; D_min = 29.7 cm, D_max = 16.5 cm, D = 37.5 cm, S.D. – 9.94 cm. Only heavily weakened trees of T. cordata of IV Kraft class (I = 2.2; 25% of the total amount of trees at the plot) were infested with xylotrophic fungi. The trees of II (41.7%) and III (8.3%) Kraft classes did not have a mycological component. In general, at the EP 58.3% (I = 1.21) of trees of T. cordata were healthy, 16.7% – weakened (I = 1.50) and 25% (I = 1.85) – heavily weakened. There were no fresh and old dead standing trees. Thus, the phytosanitary state of T. cordata was better compared to Q. robur. On T. cordata 3 fungi species were detected representing 3 genera, 3 families and 2 orders of Agaricomycetes class of Basidiomycota division. One of them is parasitic (there was dense fruiting of Crepidotus variabilis (Pers.) P. Kumm. on the intact stem bark), and two were saprotrophs on fine woody debris (Polyporus alveolaris, Schizothyllum commune). No stumps of T. cordata were found. 75% of observed fungi belonged to the ground myco-horizon and only 25% to the stem one (Table 4). The species, systematic and trophic structure of xylotrophs evidences that every fungi species of this group occupies its ecological niche depending on the conditions of the place in vegetation, its phytosanitary state, vital structure, morpho-metric parameters of Q. robur, T. cordata, and dead substrate.

An important component of the study of the co-adaptive system of tree vegetation and xylotrophic fungi in the dendrological park is the study of other soft-wooded broad-leaved tree species. At the second EP, the stand was two-storeyed, with the first storey composed of Q. robur, and the second storey composed of C. betulus (A = 120 – 140) and F. excelsior (A = 120 – 140); canopy cover 0.6 – 0.7. Stand parameters of C. betulus were: Gª = 95.5 m²/ha, N = 202 pcs./ha, Hcw = 22.5 m, H_min = 18.1 m, H_max = 27.2 m, S.D. – 3.21 m; D_min = 31.5 cm, D_max = 24.5 cm, D = 44.5 cm, S.D. – 7.11 cm. On C. betulus we detected 6 species of xylotrophic fungi, which

### Table 3. Phytosanitary structure of Quercus robur L. and specific structure of xylotrophic fungi at the first experimental plot.

<table>
<thead>
<tr>
<th>No.</th>
<th>Fungi-consorts</th>
<th>Category of phytosanitary structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>1</td>
<td>Ascocoryne sarcoides (Jacq.) J.W. Groves et D.E. Wilson</td>
<td>1/2,6</td>
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<td>3</td>
<td>Crepidotus mollis (Schaeff.) Staude</td>
<td>1/2,6</td>
</tr>
<tr>
<td>4</td>
<td>Crucibulum crucibuliforme (Scop.) V.S. White</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>Cyathus striatus (Huds.) Willd.</td>
<td>2/5,1</td>
</tr>
<tr>
<td>6</td>
<td>Fistulina hepatica (Schaeff.) With.</td>
<td>1/2,6</td>
</tr>
<tr>
<td>7</td>
<td>Hypholoma fasciculare (Huds.) P. Kumm.</td>
<td>1/2,6</td>
</tr>
<tr>
<td>8</td>
<td>Inocybe dryophila (Berk.) Fissou et Niemelia</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>Peniophora quercina (Pers.) Cooke</td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>Phellinus robustus (P. Karst.) Bourdot et Galzin</td>
<td>4/10,3</td>
</tr>
<tr>
<td>11</td>
<td>Radulomyces molaris (Chaillet ex Fr.) M.P. Christ.</td>
<td>2/5,1</td>
</tr>
<tr>
<td>12</td>
<td>Schizophyllum commune Fr.</td>
<td>1/2,6</td>
</tr>
<tr>
<td>13</td>
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<tr>
<td>15</td>
<td>Trametes versicolor (L.) Lloyd</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>Vuilleminia comedens (Nees) Maire</td>
<td>1/2,6</td>
</tr>
</tbody>
</table>

Sum of findings of xylotrophic fungi / number of trees in each category (pcs.)

| % findings of xylotrophic fungi / % of trees in each category / WAKC |
|-------------------------|-----------------|---------------|
| 63,6/51,0/1,55 | 18,2/31,0/2,31 | 9,0/15,0/3,42 | 9,0/3,0/3,55 |
Table 4. Distribution of macromycetes by macromycetes in myco-horizons at the experimental plots.

<table>
<thead>
<tr>
<th>№</th>
<th>Fungi-consorts</th>
<th>Trees-edificators of consortium</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ascocoryne sarcoides (Jacq.) J.W. Groves et D.E. Wilson</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>Auriscalpium vulgare Gray</td>
<td>P. strobus (2), P. sylvestris (3)</td>
<td>—</td>
<td>5/17,8</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>Boletus badius (Fr.) Fr.</td>
<td>P. strobus (2), P. sylvestris (1)</td>
<td>3/16,7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>Crepidotus mollis (Schaaff.) Staude</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>C. variabilis (Pers.) P. Kumm.</td>
<td>T. cordata (1)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1/11,1</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>Crucibulum crucibuliforme (Scop.) V.S. White</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>Cyathus striatus (Huds.) Willd.</td>
<td>Q. robur (3)</td>
<td>—</td>
<td>3/10,7</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>Fistulina hepatica (Schaeff.) With.</td>
<td>Q. robur (5)</td>
<td>—</td>
<td>—</td>
<td>5/18,5</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>Fomes fomentarius (L.) Fr.</td>
<td>C. betulus (1), F. excelsior (1)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2/22,2</td>
<td>—</td>
</tr>
<tr>
<td>11</td>
<td>Ganoderma lapaense (Batsch) G.E. Atk.</td>
<td>F. excelsior (1), Q. robur (1)</td>
<td>—</td>
<td>—</td>
<td>2/7,4</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>12</td>
<td>G. lucidum (Curtis) P. Kent.</td>
<td>C. betulus (2)</td>
<td>—</td>
<td>—</td>
<td>2/7,4</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>13</td>
<td>Hymenochaete rubiginosa (Dicks.) Lév.</td>
<td>Q. robur (2)</td>
<td>—</td>
<td>—</td>
<td>2/7,4</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>14</td>
<td>Hypholoma fasciculare (Huds.) P. Kumm.</td>
<td>Q. robur (5)</td>
<td>1/5,5</td>
<td>—</td>
<td>4/14,8</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>15</td>
<td>H. lateritium (Schaaff.) P. Kumm.</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>—</td>
<td>1/3,7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>Inocyntis dryophila (Berk.) Fiasson et Niemelä</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1/11,1</td>
<td>—</td>
</tr>
<tr>
<td>17</td>
<td>Laetiporus sulphureus (Bull.) Murrill</td>
<td>Juglans manchurica Max. (1)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1/11,1</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>Panellus stipitatus (Bull.) P. Karst.</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>19</td>
<td>Pentaphora quercina (Pers.) Cooke</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>20</td>
<td>Phellinus robustus (P. Karst.) Bourdot et Galzin</td>
<td>Q. robur (5)</td>
<td>—</td>
<td>—</td>
<td>3/33,3</td>
<td>2/20</td>
<td>—</td>
</tr>
<tr>
<td>21</td>
<td>Polyergus alveolaris (DC.) Bondartseteinger</td>
<td>T. cordata (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>22</td>
<td>Radulomyces molaris (Chaillet ex Fr.) M.P. Christ.</td>
<td>Q. robur (4)</td>
<td>—</td>
<td>2/7</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>23</td>
<td>Schizophyllum commune Fr.</td>
<td>Q. robur (2), Prunus avium L. (1), T. cordata (1)</td>
<td>—</td>
<td>4/14,3</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>24</td>
<td>Schizopora paradoxa (Schrad.) Donk</td>
<td>C. betulus (1), Q. robur (1)</td>
<td>—</td>
<td>1/3,7</td>
<td>—</td>
<td>1/10</td>
<td>—</td>
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<tr>
<td>25</td>
<td>Stereum gausapatum (Fr.) Fr.</td>
<td>Q. robur (3)</td>
<td>—</td>
<td>3/10,7</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>26</td>
<td>S. hirsuta (Wild.) Pers.</td>
<td>A. negundo (1), Q. robur (2), P. avium (1)</td>
<td>—</td>
<td>—</td>
<td>3/11,1</td>
<td>1/11,1</td>
<td>1/10</td>
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<tr>
<td>27</td>
<td>Suillus granulatus (L.) Roussel</td>
<td>P. sylvestris (2)</td>
<td>2/11,1</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>28</td>
<td>Thelephora terrestris Ehrh.</td>
<td>P. sylvestris (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>29</td>
<td>Trametes gibbosa (Pers.) Fr.</td>
<td>C. betulus (2), F. excelsior (1)</td>
<td>—</td>
<td>—</td>
<td>1/3,7</td>
<td>—</td>
<td>2/20</td>
</tr>
<tr>
<td>30</td>
<td>T. hirsuta (Wild) Lloyd</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,7</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>31</td>
<td>T. versicolor (L.) Lloyd</td>
<td>Q. robur (1)</td>
<td>—</td>
<td>1/3,6</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>32</td>
<td>Vuillemia comedens (Nees) Maire</td>
<td>Q. robur (3)</td>
<td>—</td>
<td>3/10,7</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>33</td>
<td>Xerocomellus chrysenteron (Bull.) Sutara</td>
<td>Q. robur (5)</td>
<td>5/27,8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>34</td>
<td>Xerocomus pruinatus (Fr. et Hök) Quél.</td>
<td>Q. robur (5)</td>
<td>5/27,8</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>35</td>
<td>X. rubellus (Krombh.) Quél.</td>
<td>Q. robur (2)</td>
<td>2/11,1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>36</td>
<td>Xylaria polymorpha (Pers.) Greve</td>
<td>C. betulus (2), F. excelsior (1)</td>
<td>—</td>
<td>—</td>
<td>3/11,1</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Sum of species /findings: 9/92 6/18 13/28 14/27 6/9 6/10

% of species /findings: 16,7/19,6 36,1/36,4 38,9/29,3 16,7/9,8 16,7/10,9

Note: * — pcs./ %; 1 – root; 2 – ground; 3 – butt; 4 – stem; 5 – photosynthesising mycohorizon; “–” – not detected.
Stand parameters for *F. excelsior* were as follows: $G_n = 88.5 \text{ m}^2/\text{ha}$, $N = 190 \text{ pcs./ha}$, $H_{ave} = 23.7 \text{ m}$, $H_{min} = 19.5 \text{ m}$, $H_{max} = 27.5 \text{ m}$, S.D. = 3.45 m; $D_{ave} = 54.5 \text{ cm}$, $D_{min} = 33.5 \text{ cm}$, $D_{max} = 69.7 \text{ cm}$, S.D. = 15.19 cm. The analysis of phytosanitary structure of *F. excelsior* showed that the trees of I state category (I = 1.25; 44.5%) were most frequent at this EP. The frequency of weakened and heavily weakened trees was 30.5% (I = 1.85) and 15.5% (I = 2.85), respectively. Only 9.5% trees (I = 3.55) were drying. No recent and old dead standing trees were found at the plot. We detected 4 fungi species representing 4 genera, 2 families, 2 orders, 2 classes of Asco- and Basidiomycota divisions (Table 1). One parasitic species was observed on an old drying tree of II Kraft class with a sawn off crown (*Fomes fomentarius*, normally a saprotroph), and 3 saprotrophs occupied neighbouring ecological niches on the same stump (*Ganoderma lipsiense, Trametes gibbosa, Xylaria polymorpha* – 75% of findings in the butt-end myco-horizon (Table 4)). A special note shall be taken to the findings of 3 saprotrophic species on the same stump of *F. excelsior*: the whole surface of the shear cut was covered with carpophores of *Trametes gibbosa*, the side of the surface was covered with *Ganoderma lipsiense*, and on and around the butt-end we found – *Xylaria polymorpha*. Two saprotrophic species were observed on the same stump of *Acer negundo L.*: *Stereum hirsutum* and *Bjerkandera adusta*. In general the vital and phytosanitary structure of the stands at EP2 (“The Hornbeam Building”) composed of *C. betulus* and *F. excelsior* together with the species, systematic, trophic structure of xylotrophic fungi depicts quantitative and qualitative parameters of the development and the state of the studied artificial phytocenosis in the park. The results of the study indicate the absence of significant pathologic processes in ash-hornbeam oakery.

The stands of *Pinus L.* (A = 180 – 200) were studied at EP3 (“At the Great Glade”) represented by small biogroups of *P. sylvestris* and *P. strobus* with 3 – 4 individuals in each group. The stand was single-storeyed, canopy cover was 0.1 – 0.2, $G_n = 22.6 \text{ m}^2/\text{ha}$, $N = 35 \text{ pcs./ha}$, $H_{ave} = 22.7 \text{ m}$, $H_{min} = 19.5 \text{ m}$, $H_{max} = 24.5 \text{ m}$, S.D. = 2.69 m; $D_{ave} = 82.5 \text{ cm}$, $D_{min} = 62.5 \text{ cm}$, $D_{max} = 95.8 \text{ cm}$, S.D. = 12.01 cm. Inside the biogroups grasses were significantly spread, from which graminoids prevailed. Therefore, the understorey of broadleaved species was absent. The intensity of the understorey rege-
eration of *P. sylvestris* and *P. strobus* was insufficient and irregular, and requires forest management measures. At the same time artificial plantings of *P. sylvestris* and *P. strobus*, regardless of stand age, continue saving viable stand state: 41.9% were healthy (I = 1.35), 34.9% were weakened trees (I = 2.25), and 20.9% were heavily weakened – (I = 2.80). No recent and old dead-wood was observed. According to the development of trees and their inhabitation with xylotrophs their distribution into individual categories was as follows: 32.6% of trees in I Kraft class (66.7% of fungi observations), 25.6% trees in II Kraft class (no fungi detected), 23.3% of trees in III Kraft class (16.7% of fungi observations), 16.3% in IV class (no fungi detected), 2.3% of trees in V Kraft class (16.7% of fungi observations). The study of *Pinus* L. plantings did not reveal any presence of pests and diseases.

It is known that in pine plantings moisture conditions for the development of xylotrophic fungi are subxeternal, and the spectrum of tree substrates is due to the regular maintenance insignificant (absence of stumps, shear cuts and fine branch-wood), which in turn leads to the development of the limited number of wood-destroying fungi and the improvement of stand phytopathological state (Safonov & Malenkova 2011). This was confirmed by our study in the dendropark. Only 4 species of marmycetes were detected. Three species (*Boletus badius* (Fr.) Fr., *Suillus granulatus* (L.) Roussel and *Thelephora terrestris* Ehrl.) were mycorhial fungi that develop in tight relationship with conifers. However, in our case the carpophores of *Thelephora terrestris* were not observed on roots, but in the butt-end mycorhizon of *P. sylvestris*, at the places mechanically damaged (ruptures and cracks of bark). On the cones of *P. strobus* (30%) and *P. sylvestris* (14%) we detected scanty frutitings of *Auriscalpium vulgar Gray*, which does not occur on other substrates. Single finding of carpophores of a saprotrophic fungus *Stropharia aeruginosa* on the ground was recorded. The data on the phytopathological state of old-aged plantings of *Q. robur* in the dendropark evidences the intensification of the pathological process due to the absence of regular maintenance, which is a natural phenomenon for oaks aged over 200 years. It was determined that from the artificial broad-leaved phytocoenoses where *P. sylvestris* was a co-edificator of tree stratum, *Boletus badius* dominated, whereas in the phytocoenoses where *Q. robur* was the co-edificator of the tree stratum, *Xerocomellus chrysenteron* (Bull.) Sutara was dominant.

### 4. Conclusions
The phytopathological state of old-aged plantings of *Q. robur* in the dendropark evidences the intensification of the pathological process due to the absence of regular maintenance, which is a natural phenomenon for oaks aged over 200 years. It was determined that from the artificial broad-leaved phytocoenoses the artificially created oak plantings were influenced to the most extent, especially their small isolated bio-groups aged 220 – 240 years, in which 23 species of xylotrophic fungi were detected. 9% of them were parasitic species: *Fistulina hepatica* (butt-end myco-horizon; I Kraft class), *Inocutis dryophila* (stem myco-horizon; I Kraft class) and *Phellinus robustus* (stem and photosynthesising myco-horizon; I and IV Kraft classes). The remaining xylotrophic fungi have a saprotrophic way of nutrition and are related to fine woody debris of *Q. robur* and stumps (with a proportion of 3:2). At

![Fig. 3. Relationship between the categories of phytosanitary state of *Carpinus betula* L. and the observations of xylotrophic fungi](image-url)
the same time, the age, vitality, and phytosanitary structure of stands of *C. betulus, F. excelsior* and the species, systematic and trophic structure of xylotrophic fungi evidence insignificant pathological processes in the ash–hornbeam oakery. At these tree species we detected a small number of xylotrophic species. For the artificial plantings of *P. sylvestris* grown in isolated biogroups at sodded open landscape elements, the lesser specific variety of xylotrophic fungi is characteristic. This is caused by biological peculiarities of *Pinus L.*, by a simplified structure of tree stands, absence of significant mechanical damage of stems and insignificant amount of dead substrate. Thus, the changes of species composition and structure (vitality, phytosanitary) of artificial phytocoenoses alter both the composition of xylotrophs and the levels of tree and stand damage caused by them. In contrast to natural forests, the structure of xylotrophic fungi in old-aged, and middle-aged ash–hornbeam oakery and monocultures of *Pinus L.* of the dendropark is not balanced, since the spread of xylotrophic fungi in them is limited due to a smaller quantity of available living and dead substrate, greater canopy openness, smaller protectiveness of herbaceous cover etc.

To conclude, we proved the study’s hypothesis that species, trophic, systematic structure of xylotrophic fungi depicts the phytosanitary state, vitality and age structure of stands. This confirms the unity and the inter-connection of these components at all hierarchical levels of forest ecosystem’s structural organisation.

**References**


Factors influencing forest owners and manager’s decision making about forestry services in logging-transport process

Faktory vplývajúce na rozhodnutia vlastníkov a obhospodarovateľov lesov o spôsobe zabezpečovania lesníckych služieb v ťažbovo-dopravnom výrobnom procese

Lucia Ambrušová1*, Rastislav Šulek2

1National Forest Centre - Forest Research Institute Zvolen, T. G. Masaryka 2175/22, SK – 960 92 Zvolen, Slovakia
2Technical University in Zvolen, Faculty of Forestry, T. G. Masaryka 24, SK – 960 53 Zvolen, Slovakia

Abstract
The aim of the paper is to present an overview of the forestry services market in Slovakia in terms of forestry services customers and to identify key factors determining existence and functioning of the market in the sphere of logging transport process. Methodically the paper is based on case studies elaborated on the basis of standardised interview carried out with selected forest owners and managers. As shown by the results, crucial factors influencing decision making about forestry services are machinery and technological equipment of forest enterprises, availability of financial resources, amount of performed work, production and transaction costs and legal constrains resulting from the Act on Public Procurement. The results of the questioning and case studies allowed defining basic economic assumptions of the forestry services market functioning under the current conditions in Slovak forestry.

Keywords: outsourcing; forestry services market; transaction cost; logging-transport process

Abstrakt
Cieľom predkladanej práce je poskytnúť prehľad o fungovaní trhu s lesníckymi službami na Slovensku z hľadiska objednávateľov služieb a identifikovať kľúčové faktory, ktoré determinantú existenciu a fungovanie trhu s lesníckymi službami v segmente ťažbovo-dopravného výrobného procesu. Metodicky je práca založená na metóde prípadových štúdií vypracovaných na základe dopytovania s vybranými objednávateľmi lesníckych služieb. Na základe dosiahnutých výsledkov možno za rozhodujúce faktory vplyvajúce na rozhodovanie o spôsobe zabezpečovania lesníckych služieb považovať disponibilitu kapitálu, objem vykonaných práct, výšku výrobných a transakčných nákladov a legislatívne obmedzenia vyplývajúce zo zákona o verejnom obstarávaní. Výsledky dopytovania a prípadových štúdií umožnili definovať základné ekonomické predpoklady fungovania trhu s lesníckymi službami v aktuálnych podmienkach lesného hospodárstva na Slovensku.

Kľúčové slová: outsourcing; trh s lesníckymi službami; transakčné náklady; ťažbovo-dopravný proces

1. Introduction
Requirements on effective performance of activities and their optimisation lead enterprises to strategic decisions, according to which they transfer performance of some corporate activities to external entities, which are able to carry them out in a higher quality and with lower costs. They use some form of outsourcing. Outsourcing refers to a process of functional and inter-organisational division of labour, by which enterprise functions previously performed in-house are transferred to legally independent i.e. external business entities. As a result of outsourcing these functions are wholly carried out by external contractors (Daňo et al. 2005).

Outsourcing principles in terms of long term contractual use of external services are known from economic theories of transaction costs. Breakthrough in the development of outsourcing from the perspective of economic theories can be ascribed to works of Coase (1937) and Williamson (1981). According to Coase (1937), achievement of efficient resources allocation in economy is possible, if property rights are well determined and then effectively enforceable, with very low bargaining costs. Generally, these costs have been named as transaction costs. Williamson (1981), who significantly followed up on Coase (1937), claims in his work, that managers, when deciding on projects, should consider the proportion of production and transaction cost of monitoring, control and transactions management.


In forest management, as in other sectors of economy, a business sphere providing forestry-related services to forest enterprises was also created. The change in ownership in Slovakia was the decisive factor during the process of economic transformation that had a strong impact on forestry services market formation and innovation development of enterprises providing forestry services.

The original owners, who got back their tenure and property rights to forest land, encountered problems in carrying out forestry operations themselves because they lacked...
even basic equipment. In the state forest sector, due to the optimisation of management structures and production processes, a significant decrease in the number of internal employees has been observed. These changes initiated the establishment of business entities that have begun to cooperate with forest owners and managers through outsourcing. The manner of carrying out forestry operations performed by internal employees and own capacities switched to contractual form provided by private forestry services contractors.

Recently, according to official data, more than 95% of felling and skidding operations and around 70% of activities performed in timber hauling is carried out externally, by independent business entities. In comparison with the year 2000, the volume of outsourced operations is more than double.

At present, especially in foreign countries, but also in Slovakia, the research has focused on outsourcing and business sector in forestry, as is proved by several publications: Rumukainen et al. (2006), Sarvašová & Svitok (2006), Paluš et al. (2010, 2011, 2012), Penttinen et al. (2010, 2011), Bouriaud et al. (2011), Kaputa et al. (2011), Ambrušová & Marttila (2012), Soirinsuo (2012), Ambrušová (2013) and others. However, it should be noted that previous studies focused primarily on forestry services contractors, while the issues of forest owners or managers in position of forestry services customers and their make or buy decisions have been solved so far very marginally.

The aim of the paper is to provide an overview of the functioning of the forestry services market in Slovakia from the perspective of service customers and to identify key factors determining the existence and functioning of the market in the sphere of logging-transport process.

2. Material and methods

Methodology for the investigation of factors influencing decision making about forestry services is derived from similar researches dealing with forestry services market survey in the area of silviculture and felling operations (Paluš et al. 2011) and survey of market conditions and innovation activities of enterprises providing services in forestry (Bouriaud et al. 2011, Kaputa et al. 2011).

The primary method for achieving the objectives of qualitative research was a case study method. The case study is a method that is able to fulfill the basic aims of qualitative research by examining a current phenomenon in depth within its real context, especially in cases when the boundaries between phenomenon and its context are not quite clear (Yin 2009). In particular, a method of multiple case studies was used, i.e. every owner or manager of forest land represented a separate case study.

Scientific methods of observation and questioning were applied as a basis for case studies elaboration. Relating to form of communication with respondents, questioning by interview was used. Depending on the chosen method of qualitative research, respondents were selected purposefully with respect to ownership type. Ownership is a significant economic category, which is the basis for social and economic relations. Each production method is characterised by certain peculiarities which result from the nature of ownership and their knowledge gives the opportunities to explain and understand real existing processes in economy and society (Demsetz 1967). Interview was realised with ten respondents, of which eight were representatives of non-state subjects and two representatives of state forest organisations. Within a non-state forest sector, a significant proportion of forest managers represent land associations which manage more than 0.5 million hectares of forests in Slovakia, therefore these entities form a substantial proportion of respondents. Basic characteristics of respondents are shown in Table 1.

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<thead>
<tr>
<th>Enterprise</th>
<th>Ownership</th>
<th>Legal form</th>
<th>Number of employees</th>
<th>Area of forest land [ha]</th>
<th>Volume of annual felling [m³]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3</td>
<td>223</td>
<td>1 000</td>
<td></td>
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<tr>
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<td>1</td>
<td>346</td>
<td>1 530</td>
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<tr>
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<td>5</td>
<td>446</td>
<td>630</td>
<td></td>
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<tr>
<td>4 Community land association</td>
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<td></td>
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<td>3</td>
<td>661</td>
<td>1 900</td>
<td></td>
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</tr>
<tr>
<td>6 Municipal Ltd.</td>
<td>8</td>
<td>1 560</td>
<td>6 000</td>
<td></td>
<td></td>
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<tr>
<td>7 Municipal Ltd.</td>
<td>12</td>
<td>1 850</td>
<td>17 000</td>
<td></td>
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<tr>
<td>8 Municipal Ltd.</td>
<td>31</td>
<td>7 520</td>
<td>31 600</td>
<td></td>
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<tr>
<td>9 State state enterprise</td>
<td>116</td>
<td>31 931</td>
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<tr>
<td>10 State state enterprise</td>
<td>103</td>
<td>34 810</td>
<td>148 000</td>
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</tr>
</tbody>
</table>

Interviews were carried out by standardised questionnaires with the exact order and number of questions. The questionnaire consisted of 25 questions, of which 22 were open and allowed to obtain comprehensive information and make a complete framework of the topic. The questions were divided into the following seven areas:

1. Characteristics of forestry services customers. Basic characteristics of forest owners or managers in terms of ownership type, legal form and human resources. It also includes a description of managed forest land, average annual volume of felling, structure and proportion of activities performed in logging-transport process by contractors.
2. Reasons for outsourcing. The aim of this part of the questionnaire was to find out the reasons why forest enterprises choose to outsource forestry operations in felling, skidding and timber hauling. If enterprises are unable to perform given operations in-house, we investigated the reasons that prevent them from doing so.
3. Transaction costs. This part of the questionnaire was focused on the identification of conditions under which it is convenient for enterprises to carry out forestry operations internally and when it is more advantageous to use contracting of forestry services. Theory of transaction costs in a new institutional economy says that transaction costs should also be considered when deciding on the mode of providing the service besides the traditional production costs. In some cases, transaction costs can go beyond the savings from production costs reached by contracting (Brown & Potoski 2005). Under transaction costs we understand all the costs associated with contracting besides production costs, i.e. cost of contractor selection; bargaining; preparation and conclusion an
agreement; monitoring compliance; and resolving disputes over non-compliance.

4. Social, environmental and legislative factors influencing decision making about forestry services. In addition to economic criteria, decisions between internalisations and externalisations of forestry services can be influenced also by other factors, e.g. social factors (un/employment of own staff), environmental requirements for forestry services contractors, legislative measures influencing forest owners or managers’ demand for forestry services and eventually other potential factors.

5. Problems of the forestry services market in Slovakia. In the last section of the questionnaire respondents had an opportunity to assess the forestry services market in Slovakia and to define the main problems of the market.

The achieved results allowed us to propose a model of the forestry services market which defines basic assumptions of the existence and functioning of the market in the actual conditions of Slovak forestry. Moreover, it was possible to answer the following scientific questions:

1. What reasons lead forest enterprises to outsource forest operations in logging-transport process?
2. What factors and how do they affect forest enterprises’ decision making about forestry services in logging-transport process?
3. How does ownership type affect enterprises’ decisions on forestry services?
4. What is the relationship between transaction costs associated with forestry services contracting and ownership type?
5. What are the basic assumptions of the functioning of the forestry services market in the actual conditions of Slovak forestry?

3. Results and discussion

3.1. Reasons for carrying out activities in logging-transport process by contractors

Nowadays, regardless of ownership type, almost all forest operations in timber harvesting (except timber hauling) are carried out by contractors. It should be emphasised that, according to outsourcing theory, complementary or supporting activities that are not related to the main purpose and the main activity of the enterprise - so called core business are usually bought as a service from external contractors. However, in the case of forestry, main production activities are outsourced, which is contrary to the declared mission and intended use of external services as it is stated in the literature, e.g.: Bacher (2000), Hodel et al. (2004), Rydvalová & Rydval (2007), Dvořáček & Tyl (2010). The following results based on the qualitative research explain why forest land owners or managers decide to have main forest activities performed by external service providers.

All interviewed entities, except for one enterprise, were not able to perform forestry operations in-house. The main obstacle which prevents them to do so is the lack of necessary equipment and technology or out-of-date mechanisms. A significant part of used machinery is physically and morally out-of-date and their further use in the production process results in the lower quality of performed work and increased costs of maintenance and repairs of machines which negatively affects profits of enterprises.

Nearly half of the respondents did not own any mechanisms. High acquisition costs needed to purchase new machinery are another significant limiting factor. The acquisition of new modern machines and technology is mostly a matter of financial resources that are often lacking in forestry enterprises. Forest owners or managers do not have enough internal financial resources. The bulk of their income is mainly from wood sales, the amount of which depends on price development in the timber market. Decline in timber prices due to the excess of wood supply over demand causes serious existential problems for forest enterprises. Moreover, it should be noted that the timber market in Slovakia is very specific because it is influenced by the dominant position of the state enterprise which basically sets price strategy what deforms the market in many cases.

Restricted access to bank loans is a hampering factor for investment and subsequent development of forest enterprises. Forest enterprises currently use external financial resources minimally. Interest rates for business sector are increasing due to no confidence and increasing risk charges, which causes problems for enterprises because of increasing financial costs. Other factors that restrict access to bank loans are associated with strict bank credit standards and high collateral required to secure loans. Furthermore, as results from the financial analysis carried out by Hajdúchová et al. (2013), enterprises in non-state forestry sector are usually undercapitalised. It means that the part of the fixed assets is financed by current assets, which causes the discordance between the stock turn rate of assets and term of liability payment. In case the enterprise will not be able to ensure the maturity of liabilities in required terms, the financial costs will increase rapidly which can lead to negative profit and threat to enterprise’s financial stability.

One of the main reasons of choosing contracted services in logging-transport process is reduction of production costs as well. Decreasing trend in forestry services price development allows enterprises to achieve lower costs of outsourced operation compared to the costs of performing activities in-house.

The reasons to outsource forestry activities to external service providers also include rationalisation measures related mainly to large enterprises. In relation to management structures optimisation and production processes in large businesses, the number of own employees in the category of forest workers has decreased. They have moved to external environment and begun to cooperate with enterprises through outsourcing. The transition to outsourcing results in simplified work organisation, which is another reason for contracting forestry services out to private entrepreneurs.
Small enterprises decide to outsource forest activities mainly because of the low volume of work associated with the inefficient use of own machines, as well as due to the lack of human resources because the low work volume does not allow permanent employment of their own staff.

According to the study of Palus et al. (2011), the seasonality of work performed, accidental felling, weather conditions, use of certain technologies, etc. have also significant impacts on contracting forestry activities out. The effectiveness of internalisation of intensive work on human resources, materials and technological equipment of forest enterprises is directly related to the possibilities of their use during the whole year.

The above-mentioned findings clarify why forest enterprises carry out main activities by external contractors. We can also take into account an assumption that forest owners or managers perceive the activities which produce revenues as the core business, therefore wood sale or manipulation are usually not outsourced.

3.2 Factors influencing decision making about forestry services

Impact of ownership type and legal form of entities

In the countries that have undergone the transition period of their economies, the most significant factors were those connected to the structure of property rights. These changes brought new decision on internalisation and externalisation of forestry operations (Kaputa et al. 2011).

Based on the result of the case studies, it can be stated that a degree of decentralisation of decision making processes is a very important factor in the case of state enterprises. Decisions at a lower level of management relating to contractual relationships with suppliers of forestry services are subordinated to decisions of top level management. In addition, it should be noted that there is a specificity of state enterprises regarding to the administration and management of non-state unclaimed forests in which timber harvesting and subsequent monetisation of produced wood cannot be fully realised due to the prohibition of reputed forest land owners.

In the case of land associations, there is a problem regarding to owners’ fragmentation and divergent or conflicting interests of members which often lead to inability to reach an agreement or uniform decisions in relation to contracting services. However, it is important to distinguish between land associations with and without the status of corporate entity. A land association with legal entity is a typical corporation with clearly defined competences of management bodies. On the contrary, a land association without legal entity is based on a free association of physical persons who are the owners of common property. Such an association is not a legal person therefore it cannot act on its own behalf. Decisions relating to contracting are realised directly through collective resolutions or indirectly through one authorised representative. According to the theory of property rights, ownership structures are effective if property rights are clearly defined and transferable (Demsetz 1967). Limited divisibility and transferability of property rights in case of land associations without legal entity lowers the effectiveness of such legal form of business.1

As regards to trading companies, decision making about contractual relationships with service suppliers can be significantly influenced by interests or priorities of owners which may differ in case of physical persons and legal persons or if it relates to municipalities (as in our case).

Transaction costs and ownership type

When deciding between internalisation and externalisation of forestry services it is necessary to deal with the issue of transaction costs, as it is referred by several authors, e.g. Williamson (1981), Brown & Potosky (2005), Meričková et al. (2010). The theory of transaction costs in a new institutional economy emphasises the need to consider not only production efficiency, but also the amount of transaction costs associated with the mode of service provision. In some cases, transaction costs can go beyond the savings of production costs reached by contracting. Although some alternatives of service externalisation seem to be convenient with regard to production efficiency, high transaction costs can change the final decision on service contracting.

As results from the case studies, when deciding whether to outsource forestry operations or not, forest owners or managers take transaction costs of contractor selection, bargaining, monitoring and controlling compliance into account. The respondents indicated the amount of transaction costs in the range of 7—30% of the total cost associated with the performance of forestry operations externally. The amount of transaction costs which is relevant in decision making about forestry services is influenced by several factors such as an ownership type or legal form of business.

In state enterprises, decisions of individual organisational units are subordinated to decisions of top level management. If decisions on contractual relations are carried out at several levels of management (as in the case of state enterprise), transaction costs increase. Moreover, under particular legislative provisions state enterprises have an obligation to manage forest land of unidentified owners. In case of not clearly defined ownership structure, transaction costs will increase.

In comparison with the state enterprise organised in a form of three-level management, the advantage of private ownership is a more flexible organisational structure that ensures a higher degree of flexibility in decision making processes leading to lower transaction costs.

As regards the non-state forest sector, it is necessary to draw attention to land associations without legal entity. Unclear relations in the functioning of these associations and

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1 By adopting the Act No. 97/2013 on Land Associations in May 2013, establishment of land association without legal entity is forbidden. Existing land associations without the status of corporate entity had to be transformed into associations with legal entity till the end of February 2014.
limited possibilities to enforce property rights lead to higher transaction costs.

When customers of forestry services conclude a contract with a new service provider, they frequently make decision on the bases of the references from other customers who have already cooperated with the contractor. This can lead to increased transaction costs of finding and gathering information on potential forestry services contractors. However, recently the forestry services market in Slovakia has been characterised by oversaturated supply which results in lower transaction costs of finding service suppliers. These costs are lower also in the case of concluding contracts with the same contractor. Based on the results of the case studies, it can be stated that the forestry services market in Slovakia is based on long-term relationships. When forest owners or managers make an agreement with the same, stable contractors, they try to conclude long-term contracts, which is typical for private ownership. Long-term partnership is the best solution in the environment of uncertainty. Nevertheless, the authors Bouriaud et al. (2011) and Penttinen et al. (2011) point out a trend aiming at replacing the long-term contracts, which is typical for private ownership. Long-term partnership is the best solution in the environment of uncertainty. Nevertheless, the authors Bouriaud et al. (2011) and Penttinen et al. (2011) point out a trend aiming at replacing the long-term relationships by tendered contracts for services, which fairly often do not respect or favour trustful past cooperation, but just the actual price offer. This is a huge threat for locally existing business networks.

Impact of legislative, social, ecological and environmental factors on decision making about forestry services

The state enterprise as well as trading companies managing forests of municipalities, when bidding for forestry services, are influenced by legislative factors or constrains which result from the Act on Public Procurement. When these enterprises award a contract for service provision, they have to call for tenders and proceed in accordance with relevant provision of this Act. Difficulty of the public procurement process and relating higher administrative burden of these enterprises can lead to higher transaction costs. In addition, the price is the main criterion for supplier selection and therefore enterprises have to accept the lowest price offer. It happens that the service supplier who obtains a contract has insufficient technology or human resources and has to perform contracted operations with subcontracting other subjects. Subcontractors are usually small family enterprises or sole traders and they often carry out forestry operations at unacceptable prices which have a negative impact on the quality of performed work and also on work safety. As results from the case studies, due to disproportionately low prices, forestry services contractors are not able to meet the agreed conditions and provide services in the required quality and within the deadline. Subsequently, enterprises have to cease cooperation with the supplier which results in incurred transaction costs of additional public procurement.

On the contrary, private enterprises do not have an obligation to choose a contractor with tendering system which results in lower transaction costs.

According to Paluš et al. (2011), significant legislative factors are also restrictions resulting from the two basic legal regulations – the Act on Forests and the Act on Nature and Landscape Protection that have a particular importance in cases when the subject of the contract are operations performed in territories under 4th and 5th degree of protection.

The demand for forestry services is influenced also by social factors and environmental requirements of customers.

The impact of social factors on decision making about forestry services is minimal in case of un/employment of own staff. However, many cases revealed that customers prefer local forestry services contractors to support employment in the given region.

Despite the fact that studies of Brogt et al. (2007) and Bouriaud et al. (2011) point out increasing requirements of customers for the use of modern environmentally friendly technologies, preferring the contractors that possess up to date, environmentally friendly technologies, was not clearly confirmed in Slovakia. Although when choosing a supplier, respondents take into account ecological factors to some extent, the price of the service is still decisive.

The results revealed that customers have specific requirements in relation to nature protection, usually the use of ecologically degradable oils in machinery. In some cases, specific requirements are related to forestry operations conducted in flysch zone, cableway terrain, and hygienic protection zone. In two cases, requirements resulted from forest certification.

Problems of forestry services market

One of the main problems of the forestry services market identified by the respondents was the quality of provided services. The forestry service market in Slovakia is characterised by oversaturated supply causing that not all entrepreneurs in forestry have the possibility to gain a contract on service provision. Due to prevailing supply of services over demand the bargaining position of forest owners is stronger in negotiation of price and other contractual conditions. Forestry services contractors are more or less forced to adapt to them. It is obvious that weak bargaining position of forestry contractors is a common problem of the market in several European countries as demonstrated by the studies of Bouriaud et al. (2011) and Rummukainen et al. (2006). Contract prices are in many cases low which restricts investments of contractors in new technology. Forestry contractors in Slovakia provide forestry services at minimal prices that barely cover their rising costs so they lack the financial resources for the renewal of machinery. Moreover, recently, short-term contracts predominate what leads to higher risk relating to purchase and repayment of new technology. Therefore, technological equipment of contractors is lagging behind the needs and requirements of modern forest management. The use of obsolete technology is reflected in the lower quality of provided forestry services which results in e.g. losses of harvested wood, reduced income from timber sale, low labour productivity, increased production costs, as well as increased damage of forest stands and inappropriate ergonomic parameters of work.

Development trend of the forestry service market will lead in the future to increased pressure on sustainable forest management and technological changes. Future development of the market will focus mainly on the improvement of services supply also because of high competition between...
contractors. In addition, the forestry services market is open also to foreign entrepreneurs. Currently, the subjects providing services to forestry in Slovakia are less competitive than foreign contractors which have up-to-date technology and equipment. This fact can adversely affect employment in rural areas.

A certain solution of this problem would be an active establishment of business entities through pooling of sole traders that become real partners for the supply of a complex of forestry activities. Another solution is an effort to conclude long-term contracts. The studies of Kaputa et al. (2011) and Paluš et al. (2011) reported a minimum period of five years to guarantee the return of investment.

A further problem of the forestry services market is imperfect legislation in the area of public procurement. The current system of public procurement is not satisfactory since even a company, who does not possess any equipment and is not able to provide the service, can obtain a contract. Therefore, in the Act on Public Procurement it is necessary to define exactly the extraordinary low bids which are unrealistic and do not guarantee meeting of deadline and required quality of service provision.

As follows from the results, the other problems of the forestry services market in Slovakia include weak law enforcement, lack of skilled workers and limited possibilities of implementation of environmentally friendly methods in the shelterwood management system mainly due to the insufficient forest road network.

3.3. Model of functioning of forestry services market

The basic decision of forest enterprises considering the mode of service provision is between externalisation and internalisation of services. It means that forest enterprises decide whether to carry out given forestry activities using their own capacities or transfer them to external contractors for remuneration. This decision problem is known in economic theory as “make or buy” decision. Based on the results obtained from the qualitative research a model of the functioning of the forestry services market was proposed. The model defines basic assumptions of outsourcing and insourcing utilisation. The model presented in Table 2 is guidance for forest owners or managers in decision making on the use of external or internal forestry services.

The level of production costs and production effectiveness is an important factor influencing decision making about forestry services. Reduction of production costs and achievement of higher effectiveness is one of the main reasons why forest enterprises use contracted services. If the costs of performing activities in-house are higher compared to costs of activities carried out by contractors, the enterprises decide for the externalisation of services, i.e. activities previously performed internally are transferred to independent organisations and are purchased as external services. Otherwise, if the costs of work performed internally are lower than the costs of contracted services, the internalisation of services is justified.

<table>
<thead>
<tr>
<th>Outsourcing assumptions</th>
<th>Insourcing assumption</th>
</tr>
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<tbody>
<tr>
<td>– lower price of external service than price paid for internal service</td>
<td>– higher price of external service than price paid for internal service</td>
</tr>
<tr>
<td>– minimal transaction cost</td>
<td>– assumption of high transaction cost</td>
</tr>
<tr>
<td>– lack of own capacities</td>
<td>– sufficient own capacities</td>
</tr>
<tr>
<td>– limited availability of financial resources</td>
<td>– availability of capital needed for equipment purchase</td>
</tr>
<tr>
<td>– inefficient use of own machines</td>
<td>– efficient use of own machines</td>
</tr>
<tr>
<td>– low work concentration</td>
<td>– high work concentration</td>
</tr>
<tr>
<td>– high levy burden</td>
<td>– low levy burden</td>
</tr>
<tr>
<td>– lack of proficiency in the given field</td>
<td>– sufficient expertise</td>
</tr>
<tr>
<td>– sufficient supply of services in the market</td>
<td>– insufficient supply of services in the market</td>
</tr>
<tr>
<td>– adequate legislation in the field of public procurement</td>
<td>– legal constrains</td>
</tr>
</tbody>
</table>

However, the costs savings due to the contracting do not always meet expectations. Besides traditional production costs, enterprises should take into account also transaction costs associated with the external provision of services. The amount of transaction costs can be ultimately decisive whether to outsource forestry operations or not. In some cases, transaction costs can go beyond the savings of production costs reached by contracting and finally, enterprises will pay for external service more when compared to internal service provision. Therefore, it is necessary to avoid service externalisation assuming high transaction costs, and rather, to carry out forestry operation in house. Otherwise, the lower the transaction costs are, the more convenient will be to perform forestry activities externally. The amount of transaction costs is influenced by several factors. One of them is the degree of centralisation or decentralisation of decision making processes.

High transaction costs can be expected in the case of state ownership where decisions about services are made at several levels of management. If the degree of decentralisation increased, organisational units at lower levels of management could make decisions independently, which would lead to lower transaction costs. On the contrary, centralisation of decision making rights causes limited possibilities and time intensity to obtain relevant information what results in increased costs of decision making and management as well. It is obvious that transaction costs are lower in the case of private ownership where there is an effort to simplify decision making processes.

It follows that contracting of services is more effective in case of low transaction costs and providing clearly defined property rights and ownership structure, clearly determined competencies of managing bodies and a higher degree of freedom in decision making processes. Otherwise, transaction costs are high, which is in contrary to contracting because cost savings resulting from outsourcing should not reach the level of transaction costs associated with contracted services. For this reason it is not convenient to carry out forestry activities by contractors but prefer internal performance of work.

Another factor influencing decision making about outsourcing and insourcing is the equipment of entities managing forests by necessary technology. Thus, enterprises decide whether they purchase their own machinery to carry out operations in timber harvesting in house or transfer them to external contractors. The availability of capital required...
for the acquisition of new technology plays an important role in investment decisions of enterprises. The use of a loan as a source of investment financing depends on its price, i.e. on the amount of interest rate. The increasing interest rates limit the access of forest enterprises to external financial sources, due to which enterprises reduce investments in machinery and prefer outsourcing of forestry operations. On the contrary, if interest rates decrease, the availability of financial sources will increase which will have a positive impact on investment activities of forest enterprises and, consequently, they will be able to carry out forestry activities internally.

In a decision whether to internalise or externalise forestry services, it is necessary to consider the size of enterprise or the area of managed forest land and the volume of performed work. Outsourcing of forestry operations is of great importance for small enterprises. The size of forest property plays a significant role in their cases which is related to the amount of finances from wood sale. Timber sale is the most important source of income to maintain employment in forest enterprises. The low volume of work performed in timber harvesting as well as the low volume of revenue from wood sale in small enterprises does not allow them to employ their own staff permanently (which was confirmed by the respondents in several cases).

In addition, in the case of enterprises managing forests of small areas there is a problem with insufficient use of own capacities. Due to the lower concentration of harvesting operations, the performance utilisation of own machinery is inefficient. The problem also lies in the unfavourable ratio between costs and benefits, especially in the case of expensive machines. For these reasons, for small enterprises it is more effective to have forestry operations in timber harvesting performed by contractors. As regards the enterprises managing forests of large areas, the utilisation of their own machines and equipment in felling and skidding operations is more efficient due to the possibility of higher volume of concentrated work. Therefore, for large entities it is more convenient to perform forestry activities on their own in comparison with small enterprises. In the case of extensive volume of work (e.g. due to salvage felling) when the enterprises’ own capacities are insufficient, the part of the operations may be performed by a supplier of forestry services.

A social factor, i.e. un/employment of own staff, has also a certain impact on decision making about forestry services. Decisions made by forestry enterprises whether to employ their own employees or rather to buy contractor services are significantly influenced by levy burden and the amount of labour costs. High levy burden and increased labour costs are the main barriers to employment which results in the reduction in the number of own employees. Due to this, enterprises transfer activities previously performed by their own staff to contractors and buy them as external services. On the contrary, reduction of levy burden allows enterprises to create new jobs and increase the number of their own staff which allows the enterprises to carry out forestry operations internally by their own employees. Other criteria of “make or buy” decisions include sufficient expertise and qualified workforce in forestry enterprises. The lack of expertise leads enterprises to carry out operations by contractors with necessary knowledge and experience in the given field. In any case, if enterprises decide for outsourcing, it is essential to ensure that concluded contracts on forestry services will include requirements for qualified and skilled staff as well as requirements relating to quality of performed work.

Outsourcing of forestry operations is appropriate if the adequate availability of services is ensured. The supply of forestry services depends on the number and the size of business entities providing services. When the supply of forestry services exceeds the demand, forest owners need not incur higher transaction costs of finding contractor which has a positive impact on contracting. On the other hand, when demand exceeds supply of services, customers have to make a greater effort to find service providers, which leads to higher transaction costs. Insufficient supply in the forestry services market therefore results in internalisation of services.

In case of state enterprises and trading companies established by municipalities, legislative restrictions resulting from the Act on Public Procurement may negatively affect contracting due to the difficulty of public procurement process and higher transaction costs of administrative security of public procurement. One of the major risks of public procurement is supplier selection based on the lowest bid price. Contractors may purposely underestimate real costs of service provision which, in case of obtaining a contract, could result in problems to provide services in required volume, quality and time.

4. Conclusion

The change of ownership relations in Slovakia during the transformation of economy has had a fundamental effect on the formation of the market with forestry services and the development of innovations activities in business based in the forestry sector.

The intensity of the demand for forestry services depends on forestry enterprises’ decision to internalise or externalise given services. The make or buy decision is influenced by a number of factors. Based on the results of questioning, several factors influencing enterprises’ decision making about forestry services, were identified. These key factors include forest enterprises’ machinery and technological equipment needed for performing timber harvesting activities. In most cases, current machinery and technological equipment used in the area of felling, skidding, bucking and transportation is physically old and out of date. The main reason of this state is the lack of internal financial resources and limited access to debt capital. The level of production costs seems to be the essential factor of such decision making. Not less important is the effect of transaction costs, which can exceed the savings from production costs reached by contracting. The level of transaction costs is significantly influenced by the type of ownership, or legal form of business. Besides economic criteria, social and environmental criteria or requirements have an impact on the demand for forestry services, as well. However, the effect of the social factor on forest enterprises’ decision making about services is negligible. Some environmental criteria are taken into consideration when choosing contractors, but the price of the service has still a strong impact on this decision.
On the basis of the questioning results and elaborated case studies, fundamental assumptions of functioning of the forestry services market were defined. In-house provision of forestry services require, first of all, sufficient own capacities, i.e. machinery and technological equipment, skilled workforce and expert knowledge in the given field. Limited availability of capital necessary for the purchase of machinery, inefficient use of machines, high levy burden as well as the lack of proficiency in the given field lead enterprises to buying of forestry services from external contractors. Outsourcing utilisation is effective in case of lower prices paid for external services compared to costs of operations performed internally, minimal transaction costs, sufficient supply of forestry services in the market and adequate legislation in the field of public procurement.

Acknowledgement

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References


Semiautomatic tree ring segmentation using Active Contours and an optimised gradient operator

Poloautomatizovaná segmentácia ročných radiálnych kruhov stromov s využitím metódy „Active Contours“ a optimalizovaného gradientového operátora

Michael Henke*, Branislav Sloboda

Department Ecoinformatics, Biometrics and Forest Growth, University of Göttingen, Büsgenweg 4, 37077 Göttingen, Germany

Abstract
This paper presents an easy and effective method to extract tree rings completely from images of tree discs independent of their source. The method uses Active Contours, often used in medical image processing to detect organs, in combination with an optimised image filter based on the Sobel operator to automatically outline the tree rings. Special attention is given to eliminate critical physical irregularities caused by branches, cracks or colourisations. The work resulted in the implementation of a platform independent, free and open source software solution for semiautomatic tree ring segmentation. Comparison to manual measurements shows that the system is dependable and the results are reproducible. The system has been applied to several conifer species.

Keywords: stem disc analysis; filter optimisation; segmentation tool; image analysis

Abstrakt
Článok prezentuje jednoduchú a efektívnu metódu pre extrakciu radiálnych ročných prírastkov z obrázkov získaných skenovaním diskov odobratých zo stromov. Metóda využíva techniku „Active Countours“, ktorá je často používaná pri spracovaní obrazu pre detekciu organov, v kombinácii s optimalizovaným obrazovým filtrom založeným na „Sobel“ operátore pre automatizované zvýraznenie ročných kruhov. Špeciálna pozornosť sa venuje eliminácii kritických fyzikálnych nepravidelností spôsobených vetvami, puklinami alebo zafarbením. Výsledkom práce je volne dostupný softvér pre poloautomatizovanú segmentáciu ročných radiálnych prírastkov na odobratých diskoch. Porovnanie s manuálnym meraním ukázalo, že systém je spolahlivý a výsledky sú reprodukovateľné. Systém bol preskúšaný na niekoľkých ihličnatých drevinách.

Keywords: analýza kmeňových diskov; filtrová optimalizácia; nástroj pre segmentáciu; analýza obrazu

1. Introduction
Tree rings can tell us a lot about climate variations over the last several thousand years. Generally, the precise determination of tree rings of a tree disc is an arduous and time-consuming matter. Therefore, one is in most cases satisfied with measuring the radii of the annual rings along single rays, e.g. obtained by a core sample. This is often done in a computer-assisted way and with the aid of a macroscope (Taube & Sloboda 1992). Other external systems like measuring stages, encoders, and readout units enable linear encoding of measurements. Such systems provided, e.g., by Metronics, Boecker boxes, Acu-Rite or Measucron are directly supported by commercial software systems like MeasureJ2X. For a great number of applications this restriction can lead to acceptable solutions, for example in the case of dendrochronological investigations where a destructive treatment of historical samples has to be avoided as far as possible. Later developments can process high-resolution images of tree discs or core samples. Commonly used, commercial representatives are WinDENDRO (Guay 2012) and LIGNOVISION™ (RINNTech e.K.).

However, if one is interested in precise statements about stem growth, e.g., to explore how a predominating wind direction affects the stem or how a slope situation is balanced by asymmetric growth, a complete extraction of all tree rings can hardly be avoided. Therefore, digitizing and processing of whole tree discs are required. Image analysis techniques have been applied already in several systems like TRESS (Conner 1999, Gopalan 2000). A watershed based transformation in combination with other morphological operations for measuring the areas of annual tree rings was introduced by Soille and Mission (2001). Zhou et al. (2012) presented another method based on watershed segmentation to detect and count tree rings. Norell (2011) used image filter based methods to analyse wood quality by counting the number of annual rings.

Since stem positions are fixed to the ground, asymmetric tree growth is an adaption in response to environmental conditions, e.g., plant density what influences light conditions or topo-graphical site conditions. The question of which influencing factor most prominently define such differences in growth is not trivial. Field experiments were already done by Gaffrey (2004) to investigate how influences of the elastomechanical behaviour of the stem, as well as the distribution of the assimilate crown production will affect the growth behaviour. The aim was to analyse, and then describe and model the expected resulting change in stem growth. In

*Corresponding author. Michael Henke, e-mail address: mhenke@uni-goettingen.de, phone: +49 (0)551 39 12109
functional-structural plant modelling of trees the focus also lies to physiological processes, because they are the driving force that determine growth and shape development of the stem in order to guarantee both mechanical stability and sufficient water supply to the foliage.

Calculations of ring area and the annual increment and furthermore estimations of volume and volume increment, what is possible when several sample disks are taken at different sections of the tree, are important information not only from a modelling or forest economic point of view.

2. Material and methods

The method which will be presented here and which was implemented in a software tool enables the complete extraction of tree ring information on the basis of images of tree discs. Data can be retrieved step by step from the disc to determine the precise dimensions of the annual rings.

In order to extract the tree rings from image data, well-known methods from image processing are used. First, the image will be improved qualitatively, then the proper extraction of the rings is carried out by means of Active Contours (Kass & Witkin & Terzopoulos 1987). This image processing method of course gives the best results if the tree rings are already well visible and distinguishable in the original sample. A (preferentially sharp) colour gradient between subsequent rings, however, does not occur in all tree species. In fact, in most deciduous tree species there is frequently the situation that some tree rings can hardly be identified. Thus our method is preferentially to be used for conifer species.

2.1. Description of the procedure

The primal material for our system are pictures of cross sections of a tree, in short tree discs, independent of which source they are origin, e.g., X-ray, photographs or scanned. The surface of the disc should be smooth and free of unevenness. Therefore, the discs should be planed or sanded using a grid 200 or higher in order to remove the damages caused by sawing. For pictures taken by a camera you need to make sure that the object plane is parallel to the camera in order to obtain an undistorted image.

Preparation of the base material is as important as image pre-processing including blurring and noise reduction can be to produce better results. A set of basic operations are also implemented for this reason in our software.

Besides quality of the image material, resolution of the image (dot density: number of individual dots per inch – dpi) plays a major role. This density directly limits the amount of informations that can be stored within an inch of an image and so it limits the number of rings and the minimal ring width that can be resolved. In order to distinguish more rings per inch a high resolution is recommended. At a density of 300 dots per inch 1 millimetre corresponds to 11.81 pixels.

A further problem that cannot be solved in such a simple way is a too weak contrast between early and late wood, which occurs frequently in some tree species. If there is the possibility before the images are taken, it is recommended to pre-apply colouring to the tree discs with specialised indicator colours, e.g., with a solution of hydrochloric acid and phloroglucinol, which colourises latewood darker than earlywood because of the higher concentration of Lignin. For coloured images it can be an advantage to split the original image into RGB channels and to use only the channel with the highest contrast for further analysis. Likewise, wood discolorations caused by fungal infection, e.g., by the Blue Stain, can cause errors in ring boundary detection. Besides colour and contrast problems, physical irregularities like branches or cracks in the wood represent further challenges. Another nontrivial problem comes from rings that are located so narrowly next to each other that with unaided eye their course is hardly tractable. In order to get as few problems as possible and thus to avoid time-expensive manual post-processing of the images, already in the phase of sample selection there should be paid attention to choose discs as immaculate as possible.

The described problems require new procedures for the semi-automatic tree ring extraction which exceed the standard image processing operations since the latter fail in difficult situations.

For the improvement of picture quality it is absolutely helpful to enhance the images using appropriate software in order to improve contrast or brightness before the extraction is carried out.

The extraction is based on the so-called edge image which is generated by means of gradient operators. This edge image serves as the basis for the segmentation by Active Contours.

The process of tree ring extraction can thus be split in the following steps: preparation of the disc → digitization → image pre-processing → edge recognition → segmentation → data post-processing.

2.2. Tree ring extraction = edge recognition

In order to identify a tree ring in a picture of a tree disc in a computer-assisted way, the here presented procedure uses the difference in colour or brightness, respectively, that occurs between the darker late wood and the brighter early wood. In the field of image processing, such an abrupt change is called an edge.

Technically seen, the problem of tree ring extraction can thus be reduced to that of edge recognition. If a grey-level gradient from black to white (Fig. 1a) is considered and the corresponding brightness values are plotted in a diagram where the value 0 is assigned to black and 1 to white, one receives Figure 1b. An edge can thus in the continuous case be defined by using the derivative of the brightness (or colour) function. The location at which the first derivative is maximal while the second derivative is zero defines the edge, see Figure 1.

From image processing a number of methods are known that approximate the derivative of an image, the so-called gradient procedures. Corresponding to the possibility to define an edge by primarily using the first or the second derivative, some gradient procedures approximate the first and some the second derivative.

In most procedures, one or several matrices, so-called convolution kernels, are shifted step by step over the initial
A more precise look at the edge image, however, reveals several unpleasant features which render the image almost useless for automatic edge detection. On the one hand every edge in the initial image is emphasized, including those generated by possibly existing branches or cracks in the wood (Fig. 2a). On the other hand sometimes double edges are generated (Fig. 3): This happens if the late wood appears only as a thin line that is enclosed by the brighter early wood. So the application of the Sobel operator gives two edges when the late wood is approached, one when coming from the centre and one when coming from outside.

These disadvantages make an optimisation of the filter necessary.

2.3. Filter optimisation

Purpose of the optimisation is to emphasize only the desired edges, in this case those corresponding to annual rings, and to weaken or to delete all other edges. Furthermore, the double edges should be reduced to a single edge. The basic idea of our filter optimisation is to consider the angles of the detected edges and to emphasize only those edges which are orthogonal to a ray through the marrow of the tree disc, taking a certain tolerance zone into account (Fig. 4). This condition is based on the property that tree rings expand in a more or less circular way around the pith and thus have tangents orthogonal to a ray through the centre.

As the basis of the filter optimisation the Sobel operator is used. While the convolution kernels are applied to the initial image step by step, in each pixel the angle between the tangent in this pixel and the ray through the centre is calculated according to equation 3.

\[
\theta = \begin{cases} \arctan \left( \frac{G_y}{G_x} \right), & G_x \neq 0, G_y \neq 0 \\ 90^\circ, & G_x = 0, G_y = 0 \\ 0^\circ, & G_y = 0, G_x \neq 0 \end{cases}
\]  

If the angle between the tangent and the ray to the centre lies now in a tolerance zone of up to five or ten degrees, the point will be intensified by 20 percent, otherwise the point is not included in the edge image. The reverse orientation of the dark and bright side of a “false” edge has the desired consequence that these false edges are refused by the modified operator. Thus the artefact of “double edges” (as in Fig. 3) is automatically avoided. Figure 5 shows the result of the optimization, applied to the example shown in Figure 2.
Precondition for the method is that the centre of the tree disc, more precisely: the position of the pith, is known. The exclusive strengthening of those edges which follow a nearly circular course around a centre has led us to the name “circular Sobel operator” for the optimized operator.

In the process of extraction of tree rings, the next step is the segmentation, i.e., the assignment of the detected edges to single tree rings and the extraction of their coordinates. The procedure which we have applied here is known under the name “Active Contours”.

2.4. Active Contours

The concept of Active Contours, also known as Snakes, was introduced by Kass (1987). A lot of optimizations and derived methods were subsequently developed, and their applications are today widespread. Basically the aim is to determine the contour of an object. A special feature of the method is its robustness against disturbances and noise in the initial image. Hence it is possible to identify even objects with very weak contours. This feature has led to a particularly widespread usage of the method in medical image processing where objects like organs or venation are to be identified in CT or MRT images. The method is also widely used in computer-aided object tracking and in face recognition.

The method makes use of a parametric curve, which is in most cases initialized manually. The slope of this curve is controlled by so-called internal and external energies. The internal energies are calculated solely from the form of the contour. They determine the tension and thus the tendency to the formation of loops, as well as the stiffness of the curve, or, expressed in a positive sense, its ability to adapt itself to fine details of the contour. The initial image determines the external energy via the edge (or gradient) image. An iterative optimization, which seeks to minimize the sum of the energies, deforms the contour until a stable state is obtained. The Snake curve thus seeks in the gradient image for maximal brightness values and adapts itself to their locations in the gradient image. An iterative method which seeks to minimize the sum of the external energy via the edge (or gradient) image. An iterative optimization, which seeks to minimize the sum of the energies, deforms the contour until a stable state is obtained. The Snake curve thus seeks in the gradient image for maximal brightness values and adapts itself to their locations in the best possible way, taking the internal energies into account.

2.5. Tree Ring Segmentation Tool – TriST

As a basis for the implementation of our software we have used the Java Extensible Snake System, JESS for short, which has been developed by Tim McInerney and his team at Ryerson University, Toronto (McInerney & Sharif & Pashotanizadeh 2005). It offers a hierarchically designed structure with various Snake implementations and a simple graphical user interface. Furthermore, the system allows an interactive manipulation of form and parameters while the Snake curve is optimized. To control the course of the curve, additionally so-called magnets can be defined which have impact on the form of the curve independently from the edge image and from the parameters.

We have extended JESS by the circular Sobel filter and by the necessary infrastructure for tree ring extraction. This includes all functionality that is used for processing the recognized rings, for automatic initialization of the new curve in relation to the recognized ring, and, ultimately, for storage of the recognized rings. Additionally, a toolbox of standard image processing routines for pre-processing of the scanned rings was implemented, which will not be discussed further here.

For standard image manipulation the free Java Advanced Imaging Library – JAI (version 1.1.3, Oracle Corporation) was used. Therefore, all common image formats, e.g., TIFF and PNG, are supported by our software. Our tool is platform independent and as open source software it is free of charge, available upon request from the first author.

3. Results

3.1. Tree Ring Segmentation

The process of tree ring extraction is started by the initialization of the first curve outside the innermost ring and by the definition of the centre. During the process of adaption of the curve the user can interact and manipulate the pathway of the curve at any time by simple pressing the mouse at one point where the curve should cross. When the first ring is seized correctly by the curve, the user gives a confirmation. Subsequently, the recognized ring is stored and a new curve, positioned in relation to the old one, is initialized. In addition approximations of average radius, circumference and the area enclosed are calculated (Fig. 6). So each ring, successively from the innermost to the outermost one, is processed until the bark is reached. Finally, the data can be saved in different plain text formats (e.g. coordinate based and polar coordinates). Images can be archived with or without their analysis.

Branch scars, injuries or contaminations, e.g., caused by fungal infestation, are a common problem which usually causes trouble and requires manual intrusions during the extraction of tree rings. Figure 7a shows a disc from a coast fir with a branch scar and a crack at the bottom. It is clearly
visible how the curves (highlighted in blue) have adapted to the courses of the tree rings, without having been significantly influenced by the branch scar or the crack.

The following example (Fig. 7c–d) of a spruce disc with 22 rings shows in a direct comparison the original disc and the extracted tree rings.

It is also possible to extract the rings from discs with a diameter of 50 centimetres and more with the here presented software TRiST. The problem in this case rather lies in the process of digitizing, which is restricted by the size of the maximal scanning area. A solution is offered by scanning in several steps with subsequent joining, the so-called stitching, of the partial images to a complete image, which then serves as the basis for tree ring extraction as described.

The largest tree disc which we have processed until now originated from a 21 years old coast fir (Abies grandis). It had dimensions of 45 to 38 centimetres and had to be scanned in four steps. Figure 7b shows the original disc as well as the extracted tree rings.

### 3.2. Accuracy of measurement and expenditure

For verifying the accuracy of measurement, a tree disc was measured exemplarily by hand and the results were compared with the data obtained from computer-assisted extraction. The object for this test was a disc from an approximately 25 years old coast fir (Abies grandis), taken from a height of 9.5 meters, with 9 tree rings. Starting with a fixed direction, at intervals of 10 degrees the radii of all tree rings in relation to the pith were determined.

The sample thus included a total of 324 measuring points (36 directions, each with 9 measurements). To check the quality of extraction, the differences between the manually measured points and the points obtained from computer-assisted extraction were calculated and plotted in Figure 8. The average deviation is about $\sim 0.184$ mm and shows a systematic error, which was probably caused by the conservative measuring by hand. The obtained errors are in an interval between $\sim 0.99$ and 0.95 millimetres. Altogether, 86% all of all differences are within a deviation of 0.5 millimetres or less around the mean.

Several test runs gave an average extraction time per ring of 60 seconds, with the required time increasing with larger radius. This results from the increase in perimeter and the resulting longer control time. For the complete analysis of a disc with 20 tree rings we got an average processing time of approximately 20 minutes.

### 4. Discussion

The key issue for successful, accurate and reliable measurements of whole tree rings with our system depend mainly on the quality and type of input material. As discussed above, the quality and success of extraction are proportional to the visibility of each ring within the image, consequently species where early- and latewood are clearly distinguishable

![Fig. 7. (a) Tree disc of a coast fir with a branch scar and a crack. The extracted tree rings are highlighted in blue. (b) Example of a 21 years old coast fir (Abies grandis), the largest tree disc analysed so far by our method. The extracted tree rings are highlighted in blue. (c–d) Example of a spruce disc with 22 tree rings. (c) Original disc, (d) Extracted rings.](image-url)
are preferred. In order to reduce false detections during the segmentation process caused by traces of the cutting process, e.g. sawing scratches, precedent preparations of the tree disc itself are advisable before scanning. During image processing common strategies to eliminate noise and enhance the contrast can be applied by the system if required. For our purpose, we can conclude that the technique of Active Contours produce reproducible and reasonable results.

The reliability of our system was evaluated by comparison with manually measurements performed on 324 measuring points (36 directions, each with 9 measurements). From Figure 8 we can see that the errors does not follow any pattern, while with increased ring number the variation are larger. The overall accuracy of measurement of our system might be low compared with touchstones applied in dendrochronology. While systems used in dendrochronology normally using light microscopes and consider only radial ring-width measurements, our system is designed to extract whole tree rings, what can compensate the errors to a certain extent. For deducing growth behaviour, the difference has no significant consequences.

While for common edge detection operators applied to wide latewood parts double edges, so called pseudo rings, are produced, it is found that our optimised Sobel operator does not face this problem. Cracks as well as branches can be nearly eliminate in the same way.

Our system reaches his limits when the contrast between early- and latewood is to low and following no edge can be identified. The same applies when a gradient instead of a sharp switch in colour is given. Very thin rings, low ring width and large image noise can lead to more user interaction and so increase the time for extraction.

5. Conclusions

A new software tool for the semiautomatic tree ring extraction by using Active Contours was developed. In order to enhance the tree ring recognition a new filter was designed and integrated into the software. The system is suitable for all kind of input images that fulfills a minimum requirement of a certain contrast, while the size of tree disks is only limited by the used recording equipment. To improve the accuracy of the interactive measurement process and to reduce its complexity, some exemplary studies have been conducted which gave promising results. The system provides an efficient, time-saving way for tree ring extraction. The resulting data can deliver plenty of information on how trees adapt growth to environmental conditions that further can be used to analyse wood quality or to describe and model changes in stem growth.

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References

Aktuálne problémy v ochrane lesa 2014 – 23. ročník medzinárodnej konferencie


linsky v lesných ekosystémoch, monitoring lykožrúta sever- 
ského, monitoring výskytu krasoňov Buprestidae, kde patri 
aj Agrius planipennis, ktorý napáda jasene v Rusku a 
širí sa do Európy. O práci rastlinolekárskej kontroly dovázaného 
rastlinného materiálu u tretích krajín bola prezentácia Ing. 
Marty Magdolínovej z ÚKSÚP-u Bratislava.

Posledný, šiasty blok prezentácií bol venovaný výskum-
ným aktivitám výskumníkov NLC - Lesnického výskumného 
ústavu Zvolen, Výskumné stanici ŠL TANAP-u v Tatran-
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lesných porastov na príklade javora horského a o ich ochrane 
pred zverou.

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cie o ochrane lesov, ktorú pripravujú pracovníci NLC-LVÚ 
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losti. Svedčí o tom vznik Kontrolnej a prognóznjej služby 
v roku 1959 a od roku 1970 aj vykonávánie porád o ochrane 
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Andrey Kunca

Národné lesnícke centrum – Lesnický výskumný ústav Zvolen, 
Stredisko lesníckej ochrannárej služby, 
Lesnica 11, SK – 969 01 Banská Štiavnica, 
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lizovaných sekcích a publikovaných boli stovky poste-
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Obr. 1. Na sympózium BIOGEO-
MON sa zúčastnilo vyše 400 
odborníkov z približne 40 štátov
vplyvy na toky rozpustných orgánických látok pre boreálne ekosystémy
• Melanie Vile a kol.: „Význam biologické fixácie \( N_2 \) v bažinných spoločenstvách podľa severnej zemepisnej širky“.
• Aaron Thompson: „Casové rámce pre narušenie ekosystémových funkcii pôdneho železa“.
• Thomas Hein a kol.: „Rekonštrukcia kľučových ekosystémových funkcií v záplavovej oblasti podľa riek rieky Dunaj“.


Dva veľkoplošné experimenty pre výskum biodiverzity sa prezentovali na exkurzii Experiment Jená v lúčnych spoločenstvách a experiment BIOTREE, ktorý predstavuje jeden z najrozľahlejších pokusov na sledovanie diverzity drevín v boreálnej krajinnej. Funkcia, dynamika a regulácia biodiverzity rastlín a fauna: Chýbajúce prepojenie vo výskume N2O?“.

Obraz. 2. Prof. Hjalmar Laudon (Švédsko) vystúpil s prednáškou o význame rozpustných orgánických látok v bažinných ekosystémoch.


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Tento sprievodca účastníkom sympózia prehľadnou formou priblížil program podujatia, obsah exkurzií, ako aj krátku biografiu vedcov prezentujúcich kľúčové prednášky.

Dôležitou skúsenosťou je pochopenie priorít súčasného ekologického výskumu. V osemdesiatych a čiastočne deväťdesiatych rokoch minulého storočia dominovala problematika vplyvu imisií na ekosystémy. Následne to boli otázky klimatickej zmeny a jej dosahov na prírodné prostredie. V súčasnosti sa táto tematika kombinuje so sledovaním (resp. hľadáním metód regulovania) biodiverzity ekosystémov. Ide aj o prioritu EÚ, preto treba do pripravovaných medzinárodných projektov zapracovať aj problematiku biodiverzity lesných spoločenstiev. Ďalšou prioritnou témou sa stáva zabezpečenie ekosystémových služieb v rôznych typoch rastlinných spoločenstiev.

Pozitívnou správou z podujatia je už spomínaná účasť výskumníkov zo Slovenska reprezentovaná pracovníkmi Národného lesníckeho centra, ktorí pripravili dva postery. Menovite to boli tieto: Bohdan Konôpka a kol.: „Príspevok jemných koreňov do čistej primárnej produkcie mladých porastov buka a smreka“, resp. Michal Bošeľa a kol.: „Dlhodobý vplyv environmentálnych faktorov na rast jedle bielej v strednej Európe“. Hoci relatívne skromnou, ale dôležitou účastou na podobných stretnutiach sa udržiava dôležitý kontakt nášho výskumu s európskymi a svetovými výskumnými pracoviskami. Sympózium bolo skvelou ukážkou a to nielen najnovších vedeckých poznatkov svetovej vedy, ale aj výborné organizácie takejto renomovanej medzinárodnjej akcie. Organizátori podujatia pripravili s príslovečnou nemeckou pedantnosťou a presnosťou, prítom prezentujúcim a všetkým účastníkom ponúkli bohatý vedecký a sprievodný program.


Poďakovanie

Tento príspevok vznikol aj vďaka podpore Agentúry na podporu výskumu a vývoja, v rámci projektov APVV-0268-10 „Komparačné štúdie štruktúry čistej primárnej produkcie v porastoch buka a smreka“ a APVV-0273-11 „Vplyv vnútrodruhových a medzidruhových kompetičných vzťahov na produkčno-ekologické vlastnosti porastov buka a smreka“.

Vladimír Šebeň, Bohdan Konôpka
Národné lesnícke centrum - Lesnícky výskumný ústav Zvolen, T. G. Masaryka 2175/22, SK – 960 92 Zvolen, Slovenská republika,

email: seben@nlcsk.org; bkonopka@nlcsk.org
KRONIKA – CHRONICLE

Profesor Rudolf Midriak – 75-ročné jubileum


Najprv veľmi stručný životopis jubilanta

Náš jubilant za posledných 5 rokov.

Prof. Midriak sa do svojej sedemdesiatky venoval najmä vedeckovýskumnnej činnosti, ako aj pedagogickej činnosti. Pripomína tiež, že výsledky vedeckého činnosti uverejnené v rámci celého Slovenska. Dielo má aj významnú dokumentáciu hodnotu, a to nielen ako výsledok vedeckovýskumnej činnosti, podporujúce práce jedného pracovníka výskumu, ale aj vtedajšieho VÚLH a práce jedného pracovníka výskumu, ale aj vtedajšieho VÚLH a prispel ku kvalifikačnému rastu odborníkov v rámci celého Slovenska.

Vedeckovýskumná činnosť jubilanta v posledných piatich rokoch

Výsledková publikácia 2009. Výsledky vedeckým projektom „Spustnuté pôdy, pustnutie krajiny Slovenska“, ktorého bol zdopovedným rišiteľom. Projekt bol jedinečný najmä jeho aktuálnouťou. Oslovil viaceré generecie a to od študentov (počas riešenia projektu študenti na tuto tému spracovali 33 záverečných práce) až po osemdesiatkovcov, ktorí spracovali ako externí experti. Zo zoznamu jubilantovej publikácie činnosti sme v súvislosti s riešením tohto projektu vybrali tieto najvýznamnejšie publikácie:


Cieľom práce bolo analyzovať terminológiu a činiteľy vzniku spustnutých pôd, charakter, rozsah a intenzitu erózie na niektorých druhoch spustnutých pôd Slovenska. Prítom venoval pozornosť aj vplyvu erózie na zhoršovanie vlastných spustnutých pôd a na struktúru krajiny v rámci pestrých pomorov na Slovensku. Autor spracoval tuto problematiku netradičnou formou. Striedajú sa v jej aspekty súčasných poznatkov s niektorými výsledkami výskumu vykonaného autorm v rokoch 1962 – 1965 (takmer pred 50 rokmi), resp. v 70. až 80. rokoch na vzorových územiach Malé Karpaty, Považský Inovec, Slovenský kras, Nízke Beskydy, Slovenské stredohorie, Juhoslovenská kotlina a nad hornou hranicou lesa. Išlo tu o prepojenie aspektov aplikovaných erodologickej metod výskumu a praktických protieróznych opatrení i zalesňovania. Zároveň sa poskytoval skupinám učidiel, ktorí pracovali ako externí experti. Zo zoznamu jubilantovej publikačnej činnosti sme v súvislosti s riešením tohto projektu vybrali tieto najvýznamnejšie publikácie:


Midriak, R. a kol., 2011: **Spustnuté pôdy a pustnutie krajiny Slovenska.** Banská Bystrica: UMB, FPV, 401 s., (vedecká monografia).


Midriak, R., 2011: **Implementácia lesov a lesného hospodárstva do prírodného a sociálneho prostredia krajiny a regionov.** In: Quo vadis lesníctvo? Zvolen, NLC, s. 56–68.

Midriak, R., 2011: **Pobľad na lesy a lesníctvo Slovenska z hľadiska prírodného a sociálneho prostredia.** In: Les & letokruhy: Lesmedium, 67, č. 9–10, s. 11–13.

Midriak, R., 2012: **Revitalizácia krajiny Slovenska ako vedecký problém.** In: Revitalizácia krajiny a integrovaný manažment povodí ako vedecký problém. SAPV, s. 64–71.


Nemalú pozornosť nás jubilant venoval **biosférickým rezerváciám** na Slovensku. Už 20 rokov organizuje každý dvojročne konferencie o biosférických rezerváciách Slovenska s medzinárodnou účastou. V posledných piatich rokoch zorganizoval tri a bol aj editorom zbierok:


Jubilant za posledných 5 rokov napsal sám, resp. v spoluautorstve úctyhodných 62 prác, z toho 5 vedeckých mongrafii, 3 odborné monografie, 4 zostavovateľské práce a 50 vedeckých a odborných príspevkov.

Pedagogická činnosť jubilanta v posledných piatich rokoch

Profesor Midriak pôsobil ako pedagóg. Na FPV UMB prednášal predmet Geoekológia horských a vysokohorských oblastí.

Celkové zhodnotenie doterajších aktivít jubilanta záver

Ak začneme vedeckovýskumnou činnosťou profesora Midriaka, musíme znovu pomenovať to čo sme povedali pri jeho predchádzajúcich jubileách, že táto bola veľmi široká. Profesor Šály ju výstižne pomenoval „Od ochrany pôdy k ochrane prírody“. V súčasnosti by bolo zrejmé možné jeho druhú časť ešte viac rozšíriť o ochrane prírody. Skutočne, jubilant začínal svoju vedeckovýskumnú činnosť od ochrany pôdy k ochrane prírody.

Podľa profesora Midriaka „netreba si dať zviazať ruky v poznávaní, bádaní javov a procesov, len kvôli tomu, že nie sme vyštudovanými odborníkmi v danej špecializácii“.1

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1 Podľa profesora Midriaka „netreba si dať zviazať ruky v poznávaní, bádaní javov a procesov, len kvôli tomu, že nie sme vyštudovanými odborníkmi v danej špecializácii“.
nia vedných odborov, ale problematiku riešil priznavo, teda tak, aby komplexne objasnil podstatu jednotlivých javov a ich vzájomných súvislostí. Je obdivuhodné, že ako lesník dokázal vniknúť aj do iných nelesnických odborov. Takéto komplexné riešenie problémov, je jediná cesta ako postupovať, najmä v aplikovanom výskume, aby sa dosiahli relevantné výsledky, aby si čiastkové výsledky navzájom neodporovali, a aby bola reálna šanca ich realizácie v praxi.¹

Prof. Ing. Rudolf Midriak, DrSc, sa veľmi významne zaslúžil o rozvoj vedy a výskumu. Išlo najmä o oblasti skúmania:

- eróznych procesov spustnutých pôd,
- deštrukcie pôdy vo vysokých pohoriaх Západných Karpát (kvantifikácia procesov nad hranicou lesa, najmä so zreteľom na jej rekonštrukciu a asanáciu kosodrevinového stupňa,
- geomorfologických procesov a foriem v horách Európy, Afriky, Ázie a polárnych oblastí,
- proti lavínovej funkcii ochranných lesov na Slovensku, vrátane vypracovania metodiky výskumu lavínových oblastí a overovania účinnosti proti lavínových opatrení,
- funkčne integrovaného lesného hospodárstva s osobitným prínosom na kvantifikáciu intenzity potenciálnej a reálnjej erózie pôdy vplyvom povrchovo tečúcej vody,
- obhospodarovania lesov vo flyšových oblastiach,
- krajinnokologických výskumov v horských oblastiach (potenciály, únosnosť a optimalizácia využívania krajiny),
- krajinnokologických vzťahov v biosférických rezervácích (racionálne obhospodarovanie z krajinnokologických a lesnokokologických aspektov),
- pustnutia krajiny.


Menovaný za svoju úspešnú činnosť dostal celý rad vyznamenávania. Aj to je dôkazom toho, že náš jubilant medzi významnejšie osobnosti, ktoré vytvorili hlbokú prácu pri rozvoji vedy a výskumu, ako aj v ostatných oblastiach našej spoločnosti. Z jeho charakterových vlastností treba vyzdvihnúť často časť, náročnosť a to v prvom rade na seba, ale aj na spolupracovníkov.

Menom všetkých jeho kolegov, spolupracovníkov a priateľov chcem vyjadriť presvedčenie, že jeho tvorivá činnosť dovŕšením 75. výročia nekončí. Že bude nadále pokračovať vo svojej doterajšej tvorivej činnosti.

Srdceňka vdaka za doterajšiu obetavú prácu. Veľa zdravia, síl a entuziazmu do budúcich rokov.

Jozef Konôpka
Národné lesnícke centrum - Lesnický výskumný ústav Zvolen, T. G. Masaryka 2175/22, SK – 960 92 Zvolen, Slovenská republika, e-mail: jkonopka@nlcsk.org