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SILVATICA  
&  
LIGNARIA  
HUNGARICA

AN INTERNATIONAL JOURNAL  
IN FOREST, WOOD  
AND ENVIRONMENTAL  
SCIENCES

VOLUME 15, NR. 2

2019

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UNIVERSITY OF SOPRON  
PRESS

ACTA SILVATICA ET LIGNARIA HUNGARICA

AN INTERNATIONAL JOURNAL IN FOREST, WOOD AND ENVIRONMENTAL SCIENCES

issued by the Forestry Commission of the Hungarian Academy of Sciences

*The journal is financially supported by the*

*Hungarian Academy of Sciences (HAS),*

*Faculty of Forestry, University of Sopron (FF-US),*

*Simonyi Karoly Faculty of Engineering, Wood Sciences and Applied Arts, University of Sopron (SKF-US),*

*National Agricultural Research and Innovation Center, Forest Research Institute (NARIC-FRI),*

*Sopron Scientists' Society of the Hungarian Academy of Sciences (SSS).*

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HU ISSN 1786-691X (Print)

HU ISSN 1787-064X (Online)

*Manuscripts and editorial correspondence should be addressed to*

TAMÁS HOFMANN, ASLH EDITORIAL OFFICE

UNIVERSITY OF SOPRON, PF. 132, H-9401 SOPRON, HUNGARY

*Phone:* +36 99 518 311

*E-mail:* [aslh@uni-sopron.hu](mailto:aslh@uni-sopron.hu)

*Information and electronic edition:* <http://aslh.nyme.hu>

The journal is indexed in the CAB ABSTRACTS database of CAB International; by SCOPUS, Elsevier's Bibliographic Database, by EBSCOhost database and by Sciendo (the brand of De Gruyter Open Sp. z. o. o. for publishing services)

*Published by* UNIVERSITY OF SOPRON PRESS,  
BAJCSY-ZS. U. 4., H-9400 SOPRON, HUNGARY

*Cover design by* ANDREA KLAUSZ

*Printed by* LÖVÉR-PRINT KFT., SOPRON

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# Environmental Life-Cycle Assessment of Arable Crop Production Technologies Compared to Different Harvesting Work Systems in Short Rotation Energy Plantations

András POLGÁR<sup>a\*</sup> – Zoltán KOVÁCS<sup>b</sup> – Veronika ELEKNÉ FODOR<sup>a</sup> – András BIDLÓ<sup>a</sup>

<sup>a</sup> Department of Environmental Protection, Institute of Environmental and Earth Sciences,  
Faculty of Forestry, University of Sopron

<sup>b</sup> Forest Research Institute, National Agricultural Research and Innovation Centre

**Abstract** – Environmental life cycle assessment (LCA) was developed as a tool for sustainable, decision-supporting environmental management. Applying agricultural sector-LCA in order to achieve both internal (comparative) and external (efficiency enhancing) benefits is a priority. Since the life-cycle assessment of products and processes attracts great interest, applying the method in agriculture is relevant. Our study undertakes a comparative environmental life-cycle assessment (LCA) of local arable crop production technologies used for the main cultivated plants: maize, sunflower, lucerne, cereals, and canola (environmental data in the territorial approach calculated on a 1 ha unit and in the quantitative approach calculated on 1 t of produce). We prepared an environmental inventory of the arable crop production technologies, constructed the life-cycle models, and executed the impact assessment. We also compiled an environmental ranking of technologies. In the impact interpretation, we compared the results with the values of short rotation energy plantations in each impact category. We analysed carbon footprints closely. The obtained results help better assess environmental impacts, climate risks, and climate change as they pertain to arable crop production technologies, which advances the selection of appropriate technologies adjusted to environmental sensitivities.

**environmental life cycle assessment / carbon footprint / arable crop harvesting technologies / global warming potential**

**Kivonat – Szántóföldi növénytermesztés környezeti életciklus elemzése.** A környezeti életciklus-elemzést (LCA) fenntarthatósági, döntéstámogató környezetmenedzsment eszköznek fejlesztették ki. Az LCA alkalmazása az agrárszektorban mind a külső (összehasonlító), mind a belső (hatékonyságnövelő) előnyök elérése érdekében is prioritás. Mivel a termékek és folyamatok életciklus elemzését nagy érdeklődés övezi, ezért e módszer mezőgazdasági alkalmazásának mindenképpen el kell terjednie. Kutatásunkban a hazai szántóföldi növénytermesztési technológiák (kukorica, napraforgó, lucerna, kalászosok, repce) összehasonlító környezeti életciklus-elemzésére vállalkoztunk (területi megközelítésben: környezeti adatok 1 ha-ra vetítve és mennyiségi megközelítésben: környezeti adatok 1 t-ra vetítve). Előállítottuk a szántóföldi növénytermesztési technológiák környezeti leltáradatbázisát, felépítettük az életciklus modelleket és elvégeztük a hatásértékelést. A technológiák környezeti rangsorát is felállítottuk. A hatásértelmezés során a kapott értékeket rövid vágásfordulójú energiaültetvényeknél tapasztalt értékekkel hasonlítottuk össze hatáskategóriánként. Kiemelt figyelmet fordítottunk a szénlábnyom elemzésére. Az

\* Corresponding author: [polgar.andras@uni-sopron.hu](mailto:polgar.andras@uni-sopron.hu); H-9400 SOPRON, Bajcsy-Zs. u. 4, Hungary

eredmények ismerete segíti a szántóföldi növénytermesztési technológiák esetén a környezeti hatások, a klímakockázatok és a klímaváltozásban betöltött szerep helyesebb identifikálását is. Ez segítheti a környezet érzékenységéhez illeszkedő megfelelő technológiák kiválasztását is.

**életciklus-elemzés / szénlábnyom / szántóföldi betakarítási technológia / globális felmelegedési potenciál**

## 1 INTRODUCTION

The fundamental economic performance changes in the production sector have been major causes of environmental problems since the Industrial Revolution. Nevertheless, the production sector, which includes the agricultural sector, would also be the easiest to control. Numerous regulatory principles have already been developed; of these, the voluntary principles (including life-cycle assessment, ISO (2006a), ISO (2006b)) are able to provide an effective, proactive approach to the management of environmental problems (Rédey 2011). Applying agricultural sector-LCA to achieve both internal (comparative) and external (efficiency enhancing) benefits is a priority. Since the life-cycle assessment of products and processes attracts great interest, applying the method in agriculture is pertinent.

Haas et al. (2000) examined the applicability of the LCA framework at the farm level. Numerous further studies proving the importance of applying LCA in the agricultural sector have been recognized (Nemecek et al. 2006, Rodrigues et al. 2009, and Dauguet et al. 2016). Several review articles address the challenges and perspectives involved in the application of the methodology (Hayashi et al. 2005, Harris – Narayanaswamy 2009, Caffrey – Veal 2013). Only 11–13% of the Earth's surface is cultivated; however, cultivation is not intensive in the majority of these areas. In contrast, 50% of Hungary's land area is intensely cultivated, while intensively managed forests cover another 20% of the country (Neményi – Milics 2010). About 75% of Hungary's surface area is occupied by primarily climate-dependent, non-irrigated land, which includes arable land, meadows, and forests. In addition to growing conditions altered by cultivation techniques and land cover effects, the specific environmental aspects of each utilized technology have to be considered for each land use type.

As noted above, crop production occurs on about half of Hungary's land area, which amounts to approximately 4.5 million hectares (KSH 2018). Nearly one-third of this area is poor-quality arable land where agriculture would be uneconomical. Energy plantations can be grown extremely well on poor-quality land. Currently, the carbon neutrality of wood as a raw material must also be justified, considering several factors (Polgár et al. 2018).

Yield fluctuations in the arable crop production in Hungary extend beyond what can be considered reasonable. These fluctuations can be attributed partly to climate, partly to soil quality, partly to technology, and partly to low irrigation capacity. Main crop yields are near levels recorded two or three decades ago (OTP 2017).

According to Nagy (2018), future agriculture will be characterised by the climate crisis, the increasing demand for food products, digitalisation, precision farming, and the spread of robotic innovations. The world will need 70% more food in 2050. This will coincide with the climate crisis, which could lead to a 30% decrease in arable land and a 40% decrease in potable water. Only science can address these challenges.

Maintaining an environmental balance and reducing damage caused by climate change anomalies are the two basic pillars of sustainable agricultural competitiveness. Therefore, irrigation, agrarian digitalisation, and the generational replacement of farmers will be more vigorously supported (Nagy 2019).

Nonetheless, several authors note that the arable production of biomass can only remain viable if the technologies applied meet environmental and sustainability requirements. Dinya

(2018) emphasizes the importance of long-term and supply chain-sensitive decision making, which prioritises technical aspects and is integrated into the wider system at both local and national levels. The life-cycle assessment method can be applied to environmental impact evaluations. This method provides accurate estimations for the emissions and energy balance of all biomass-producing and biomass-consuming methods (Heller et al. 2003). Hayashi et al. (2007) examined the schematic processes of agricultural production systems in the life-cycle approach. In addition to the environmental impacts of the primary processes, the study emphasised the need to identify background processes as well.

In our study, we have undertaken the comparative environmental life-cycle assessment (LCA) of the local arable crop production technologies used for the main cultivated plants (maize, sunflower, lucerne, cereals, and canola), taking environmental data into account in the territorial approach calculated on 1 ha unit and in the quantitative approach calculated on 1 t of produce.

Our research questions are as follows: What are the main environmental impacts of the cultivation technologies applied in the studied agricultural land uses? How does the environmental ranking of cultivation technologies evolve? To what extent do they contribute to the climate change? What is the expected carbon footprint of cultivation technology (in the territorial approach: 1 ha; and in the quantitative approach: 1 t)? How do these technologies relate to other biomass producing systems?

Polgár et al. (2018) forms the basis of comparison between cultivation technologies and other biomass producing systems. The study conducted a comparative environmental life cycle assessment for harvesting technologies of short rotation energy plantations (technology related to stands of 3 ha of poplar, 5–10 ha of willow, 20 ha of willow), specifically for the third year harvesting work system.

## 2 MATERIALS AND METHODS

The methodology applied for completing LCA corresponds to the requirements of ISO 14040: 2006 and ISO 14044: 2006 standards. The analysis was completed using GaBi 6.0 Professional (GaBi Thinkstep 2018) software. The required steps of LCA were the following: 1. Definition of goal and system boundaries. 2. Life cycle inventory analysis. 3. Impact assessment. 4. Impact interpretation (ISO 2006a, ISO 2006b).

*Goal:* The goal of the comparative LCA is to answer the preceding research questions in relation to the arable crop production technologies by applying the assessment methodology.

*System boundaries:* The examined life-cycle stages were determined by the specific technologies and the operational steps associated with them. The common field operations are: soil preparation – application – sowing – pesticide application – harvest – product transport – storage. In addition to the processes above, we also considered the background processes of fuel and lubricant oil production when calculating environmental impacts. The transport distance was uniformly considered as 10 tkm. A distance of 5 km of road travel in each direction was calculated for additional service transport.

*Detailed processes and operational steps included in the main cultivated plants:*

- Cereals (forecrop: sunflower): stubble cleaning by gruber – subsoil loosening – fertiliser application – seedbed preparation – sowing – top dressing – pesticide application – top-dressing – pesticide application – spica protection – harvest – product transport – storage
- Maize (forecrop: winter wheat): stubble cleaning by gruber – autumn deep ploughing – spring ploughing work – seedbed preparation – sowing + fertiliser application – pesticide application – row tillage – harvest – product transport – storage

- Sunflower (forecrop: winter wheat): stubble cleaning by gruber – autumn deep ploughing – spring ploughing work – fertiliser application – seedbed preparation – Sowing – pesticide application – row tillage – pesticide application – desiccation – harvest – product transport – storage
- Lucerne (forecrop: cereals): stubble cleaning by gruber – subsoil loosening – fertiliser application – seedbed preparation – rolling – sowing – fertiliser application – mowing – rotation – rotation – windrowing – baling – transport – storage – mowing – rotation – rotation – windrowing – baling – transport
- Canola (forecrop: cereals): stubble cleaning by gruber – subsoil loosening – fertiliser application – seedbed preparation – rolling – sowing – rolling – spraying – spraying – spraying – fertiliser application – spraying – spraying – spraying – spraying – harvest – transport

Our research did not cover the various processes associated with the grain drying life cycle stage. The reasons we did not analyse this in our work are many. On one hand, this stage belongs to a different economic partner, which made it difficult to discover the relevant data. On the other hand, our original goal was to detect the environmental impacts in connection to local agricultural land use only. If we had also studied grain drying, we would have been unable to make a comparison with other alternative local agricultural land use (in our case the short rotation energy plantations) because the system boundaries would have differed greatly.

*Life cycle inventory analysis:* The environmental inventory data of arable crop production technologies were collected according to the cultivated plants studied. We established the environmental inventory database (input-output, elementary flow) for the operational steps of technologies.

*Functional unit:* basically, the environmental data reference was applied to 1 ha of the cultivated area according to the territorial approach. Whereas with a view to a more nuanced presentation, the reference unit was 1 t of produce according to the quantitative approach. The *reference flows* related to specific cultivated plants are shown in detail in the inventory database of the territorial approach (*Table 1*).

With environmental inventory data, we considered the common period of process steps (for annual cultivated plants: 1 year) as a reference period. With the operational steps of the common three-year operational period of lucerne as a multi-annual crop, the whole period values of repetitive operations were divided into three parts to allow a comparison with annual plants.

*The reference period for the data:* 2016. *The geographical validity* of the data is national, specific to the area of Pápa.

The area of Pápa belongs to the Pápa-Devecseri Plateau (Pápa-Devecser sík), which is located between Bakony and Marcal valley. Brown forest soils are characteristic in the area (luvisols (36%); brown earth (21%); chernozem brown forest soil (13%). Meadow soils are typical in the floodplains. Most of the surface is covered by loess-muddy-sandy river water and slope deposits. Sand and pebble Pliocene material appears on the surface in many places. The northern region of this area is moderately warm and dry while the southern region is moderately wet (Dövényi 2010). Precipitation in the reference period was higher than average: 645 mm for the all whole year and 325 mm during the vegetation period. The average annual hours of sunshine is approximately 1950 hours. According to the Meteorological Database of US-FF-IEES (2016), the average temperature was 11.2°C in 2016. Temperatures averaged 17.6°C during the vegetation period. The aridity index is between 1.14 and 1.18. Days with snow cover numbered 40. The dominant wind direction is north. The arable crop production economic area was 140 ha (*Figure 1*). This type of climate is favourable for cereals, maize, sunflower and red clover.

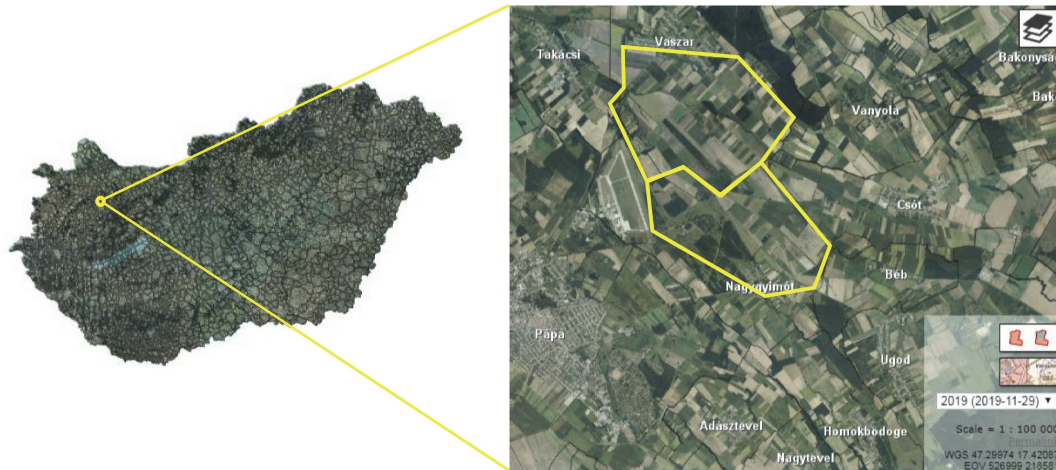


Figure 1. Economic area of arable crop production, Pápa area, Hungary (MePAR 2019)

The data sources stem from our own data (chemicals used: agri-business management log; fuel used: fuel bills), expert estimations (yields of crops), and published data (manuals). According to Gockler (2014), we also used average data, which were occasionally erroneous; however, their use is essential for the analysis.

In the absence of available information, the following are not included in the analysis: the environmental parameters in the machine and tool production needed for the technologies, and the impacts of road building and land use changes.

Based on the above, we constructed the software model for the life-cycle of the examined technologies.

*Impact assessment:* According to the standard, we first assigned the inventory results to impact categories according to the aim and frames of the LCA study. A wide range of impact evaluation methods exist. In our study, we applied the most widespread approach of the CML 2001 (January 2016) impact assessment method. This method is advantageous because it is specifically appropriate for representing carbon footprint (Simon 2012). We ranked the technologies based on the increasing values of their environmental impact.

As an impact assessment step recommended by the standard, we completed the normalisation to Central Europe with GaBi software according to the CML2001, Experts IKP (Central Europe) method in order to represent the overall environmental impact.

We also examined the CO<sub>2</sub> equiv. emission profiles of the related process step in order to analyse the operational contribution to the total technological carbon footprints of the specific cultivated plants according to field operation inventory results, product transport, and additional service transport.

*Impact interpretation:* In the last phase of the LCA, we verified the inventory analysis and impact assessment results; furthermore, we established our conclusions.

The results were examined according to both the territorial (1 ha) and the quantitative (1 t) approach. The cultivated plant values were compared to similar LCA results of other (wood) biomass producing agricultural land use technologies; namely, the observations in the 3rd year cutting age of the different (plantation size determined) harvest technologies in short-rotation energy plantations. Energy plantations provide a good opportunity for comparison because they grow extremely well on poor-quality land. Polgár et al. (2018) carried out their fieldwork in short rotation hybrid poplar and willow energy plantations in Hungary planted in single or twin rows. They separated the harvesting work systems based on the categories of the area, which are the following: large (above 20 ha), medium (5 to 10 ha) and small (below 3 ha). The plantations are harvested 3 to 5 times through a return period of 3 to 5 years

depending on site conditions and tree species. The study utilized the life cycle assessment to determine the common resulting environmental impacts of the harvesting work system at the 3-year cutting age. The study also analysed the most ideal conditions of mechanisation (Polgár et al. 2018).

### 3 RESULTS

In the life-cycle inventory analysis, we defined the process specific input-output data, i.e. the elementary flows. We have summarized both the input and output data. Environmental inventory data expressed per 1 ha in the territorial approach are displayed in tabular form (Table 1).

Table 1. Total input and output environmental inventory data of operations systems in the territorial approach (1 ha) by specific cultivated plants (area of Pápa, Hungary)

Factor	Unit	Cultivated plant					
		Cereals	Maize	Sunflower	Lucerne	Canola	
Reference period	year	2016	2016	2016	2016	2016	
Reference flow	t/ha	8	9	3	5	3	
<b>Input</b>							
Fuel	Diesel (operational + additional service)	kg	110.88	82.32	105.84	97.04	123.01
	Diesel (road traffic)	kg	35.70	26.88	29.82	44.10	50.40
	Total Diesel	kg	146.58	109.20	135.66	141.14	173.41
Lubricant	Lubricant	kg	0.59	0.58	0.59	0.18	0.61
Fertiliser	Urea (N 46%)		0.00	0.00	0.00	100.00	0.00
	Lime-ammon-saltpetre fertiliser, N (27%)	kg	500.00	300.00	0.00	250.00	250.00
	Complex fertiliser (NPK)	kg	300.00	0.00	0.00	0.00	400.00
	P fertiliser (superphosphate, P <sub>2</sub> O <sub>5</sub> 18%)	kg	0.00	0.00	200.00	0.00	0.00
	K fertiliser (KCl, K <sub>2</sub> O 60%)	kg	0.00	0.00	200.00	0.00	0.00
Pesticide application	Herbicide	kg	0.05	0.08	2.69	0.00	0.22
	Fungicide	kg	1.01	0.00	0.61	0.00	0.25
	Insecticide	kg	0.00	0.00	0.00	0.00	0.36
	Regulator (growth regulator)	kg	0.00	0.00	0.00	0.00	0.24
	Water	l	600.00	200.00	600.00	0.00	1400.00
<b>Output</b>							
Atmospheric emission	Carbon-dioxide equiv. (operational + additional service)	kg	349.80	259.70	333.90	306.14	388.06
	Carbon-dioxide equiv. (road transport)	kg	112.63	84.80	94.08	139.13	159.00
	Total carbon-dioxide equiv.	kg	462.43	344.50	427.98	445.27	547.06
Waste oil	Waste oil (recycled)	kg	0.59	0.58	0.59	0.18	0.61

The use of fuel and lubricating oil (to operate the machines), fertiliser (urea, lime-ammon-saltpetre, NPK, P, K), pesticides (herbicides, fungicides, insecticides, regulators), and water were significant on the input side in operations systems, while on the output side, the CO<sub>2</sub> equiv. emission and waste sump oil (recycled) were significant.

For comparison, according to Polgár et al. (2018), fuel and lubricating oil consumption were significant environmental factors in harvesting work systems on the input side per 1 ha of short rotation energy plantations during winter in third-year stands in 2015–2016 (on 100 m<sup>3</sup> of standing wood for harvesting). On the output side, the emission of CO<sub>2</sub> equiv. and waste sump oil (recycled) turned out to be significant. Timber is exclusively utilized for wood chips in the study. The study considered the CO<sub>2</sub> equiv. emissions from fuel, firewood, and slash burning. The amount of CO<sub>2</sub> equiv. emissions from firewood and slash burning is nearly three times higher than the amount of CO<sub>2</sub> equiv. emission from fuel.

The machines applied in arable crop production were mostly similar. Observable differences occurred in usage intensity of some crops (e. g. difference in soil preparation according to previous cropping).

In the following, we answer our research question through our obtained results.

Question: *What are the main environmental impacts of the cultivation technologies applied in the studied agricultural land uses? How does the environmental ranking of these technologies evolve?*

The following results were based on CML2001 (Jan. 2016) environmental life cycle impact assessment of work systems (Table 2).

Table 2. Environmental impacts of examined systems based on CML2001 (Jan. 2016) assessment method in the territorial approach (1 ha)

Environmental impact category (CML2001 – Jan 2016)	Cultivated plant				
	Cereals	Maize	Sunflower	Lucerne	Canola
Abiotic Depletion (ADP elements) [kg Sb eq.]	5.37E-05	4.00-05	4.97-05	5.16-05	6.35-05
Abiotic Depletion (ADP fossil) [MJ]	6.90E+03	5.13E+03	6.38E+03	6.62E+03	8.15E+03
Acidification Potential (AP) [kg SO <sub>2</sub> eq.]	0.26	0.19	0.24	0.25	0.31
Eutrophication Potential (EP) [kg Phosphate eq.]	0.05	0.04	0.04	0.05	0.06
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	2.87	2.14	2.66	2.76	3.40
Global Warming Potential (GWP 100 years) [kg CO <sub>2</sub> eq.]	505	376	467	486	597
Global Warming Potential, excl biogenic carbon (GWP 100 years) [kg CO <sub>2</sub> eq.]	535	399	495	515	633
Global Warming Potential (GWP 100 years), techn. processes only [kg CO <sub>2</sub> eq.] / 1 ha	462.43	344.50	427.98	445.27	547.60
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	20.20	15.00	18.70	19.40	23.90
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	7.20E+03	5.36E+03	6.67E+03	6.91E+03	8.51E+03
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.09-11	8.12-12	1.01-11	1.04-11	1.29-11
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	0.04	0.03	0.04	0.04	0.05
Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	0.99	0.74	0.92	0.95	1.17

Arable crop production technologies had the greatest impact on marine aquatic ecotoxicity pot. (MAETP) and abiotic depletion pot. ADP fossil had the second greatest impact. Technology impact on global warming (GWP 100) ranked third. Fuel and lube inputs and the environmental impact of fuel and lube production explains this. Due to the nature of the technologies, the impact categories of acidification pot. (AP), eutrophication pot. (EP), freshwater aquatic ecotoxicity pot. (FAETP inf.), photochemical ozone creation pot. (POCP)

and terrestrial ecotoxicity pot. (TETP inf.) were significant. The life cycle share of the technologies can be considered nearly equal (15–21%). We can establish the following increasing environmental ranking: maize (15%) – sunflower (19%) – lucerne (20%) – cereals (21%) – canola (25%).

In the total environmental impact calculation, the results of all impact categories can be demonstrated simultaneously in one dimensionless indicator per cultivated plant. We normalised the values we obtained in the compulsory impact assessment step for Central Europe (through the CML2001, Experts IKP method (Central Europe)) (Figure 2).

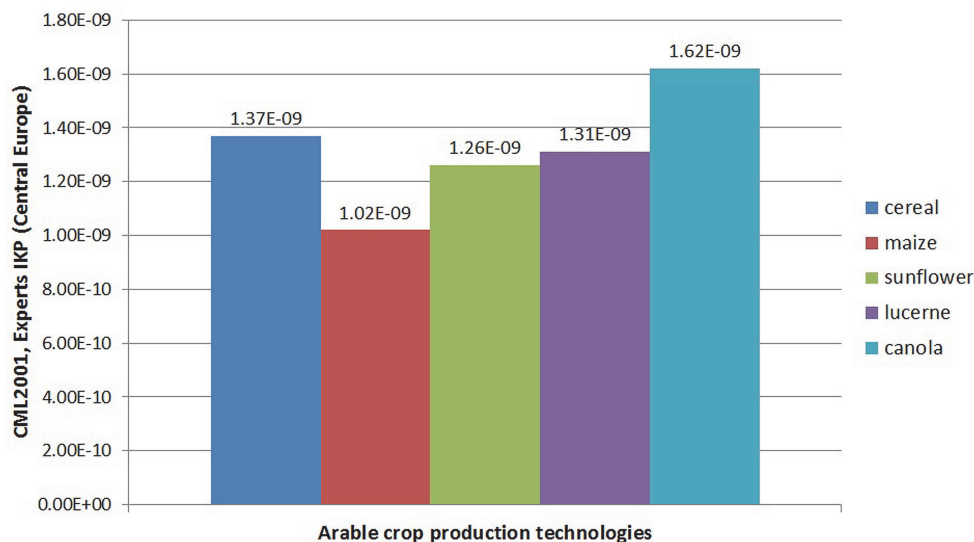


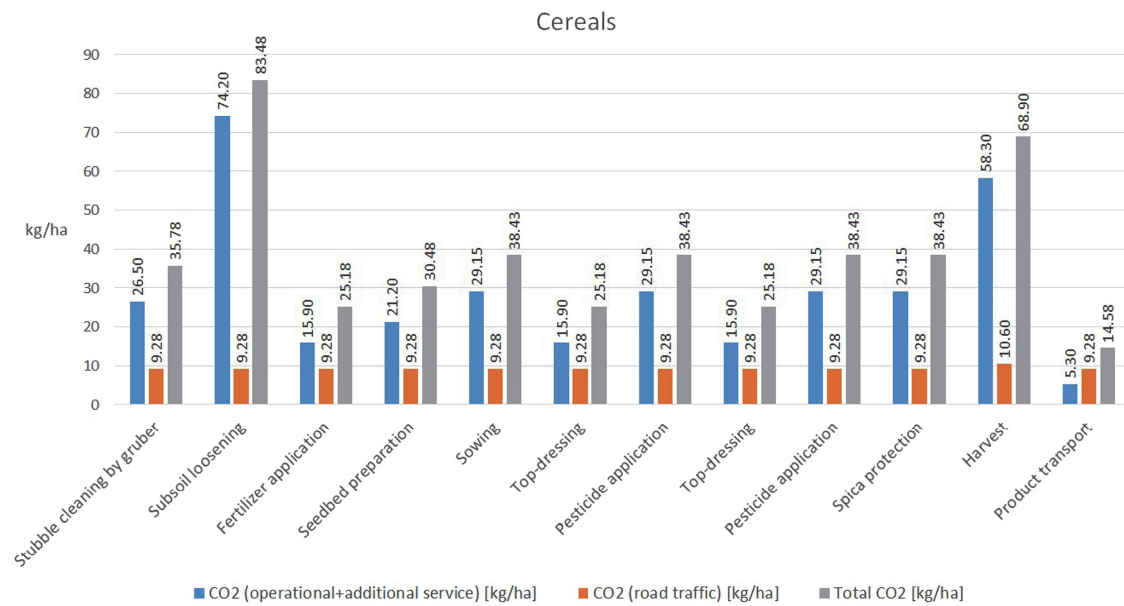
Figure 2. Total environmental impacts of the arable crop production technologies (by the method of CML2001, Experts IKP (Central Europe)) in the territorial approach (1 ha)

Through this, the previous environmental ranking of the contribution of specific cultivated plants was also confirmed as regards the total environmental impact: ‘maize (1.02E–09) – sunflower (1.26E–09) – lucerne (1.31E–09) – cereals (1.37E–09) – canola (1.62E–09)’.

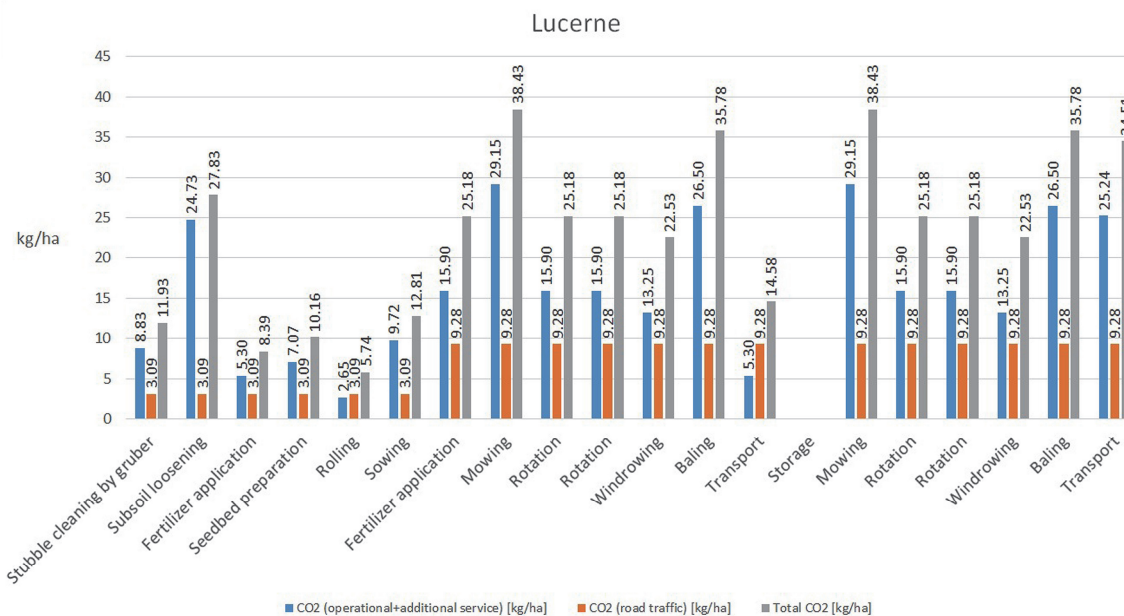
*Question: To what extent do they contribute to the climate change? What is the expected carbon footprint of cultivation technology (in the territorial approach: 1 ha)?*

To illustrate the contribution to climate change, we highlighted the global warming potential (GWP 100 years) values (carbon footprint) from the CML2001 (Jan 2016) impact assessment. When the carbon footprint contribution of cultivation technologies is expressed in percentages, the following increasing technological ranking emerges in the territorial approach (1 ha): maize (15%) – sunflower (19%) – lucerne (20%) – cereals (21%) – canola (25%). With the same expressed in measurement units [kg CO<sub>2</sub>-equiv./ha], we obtained the following increasing technological ranking: maize (376 kg) – sunflower (467 kg) – lucerne (486 kg) – cereals (505 kg) – canola (597 kg).

We gained a largely coherent picture when examining the CO<sub>2</sub> equiv. [kg/ha] emission profile of the specific process steps (Figure 3-4). *Emission group 1:* in the case of cereals, maize, sunflower, and canola, the emissions related to the process steps occurred in a larger extent during the preparation processes of the area and during the harvest. In contrast, the emissions and their images were smaller and balanced during the specific intermediate processes such as plant care and pesticide application. *Emission group 2:* We received a reversed image for lucerne when compared to the previous group. The emission values (calculated pro rata to 1 year) in the processes of preparation and harvest were smaller than the values derived during the specific intermediate processes (several mowing, rotation, windrowing, baling). The technological specificity of Lucerne could be the cause of this.



Emission group 1



Emission group 2

Figure 3-4. CO<sub>2</sub> equiv. emission profile of the process steps in the territorial approach (1 ha)

In Emission Group 1, the CO<sub>2</sub> equiv. [kg/ha] emissions ratio between soil preparation, harvest and intermediate processes is approx. 65–35%. In the Emission Group 2, this proportion was more balanced at approx. 55–45%.

In our models, the CO<sub>2</sub> equiv. [kg/ha] emissions were generally shared between the main operational and additional service steps versus road travel in the proportion of approx. 70-30%. It is interesting to compare the trend of the similarly examined CO<sub>2</sub> equiv. emissions to other agricultural land uses in the territorial approach. According to Polgár et al. (2018), in harvest technologies of short rotation energy plantations (SREP) of willow/poplar in the 3rd year cutting age, the contribution to CO<sub>2</sub> equiv. emission of the field operations was approx. 20–30%, while that of the road travel (transport) processes was approx. 70–80%. In the 3 ha> poplar and in the 5–10 ha poplar or willow stands we found that 20–30% of fossil CO<sub>2</sub> equiv.

emissions are caused by the work in the felling area, while 70–80% are due to the loading, transport, and unloading of wood. In the technology processes of the 20 ha < poplar stand the distribution is 50–50% (Figure 5).

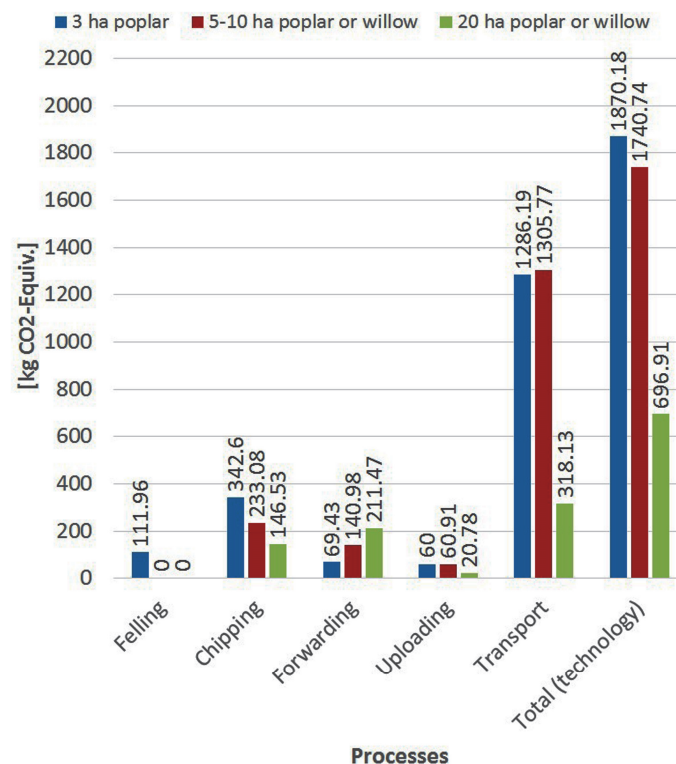


Figure 5. Contribution of processes in short rotation energy plantations to CO<sub>2</sub> equiv. emissions in fossil dimension of carbon footprint (Polgár et al. 2018)

Expressed as physical indicators in the case of arable cultivated plants (344.5–544.06 kg) in the territorial approach, we observed approx. CO<sub>2</sub> equiv. emissions that were two-to-three times smaller than in the case of SREP (697–1870 kg) (note: CO<sub>2</sub> equiv. [kg/ha] emission is counted only from fuel usage; the CO<sub>2</sub> equiv. emissions inherent in producing these is not included) (Polgár et al. 2018).

#### 4 DISCUSSION AND CONCLUSION

*Question: How do these technologies relate to other biomass producing systems?*

We compared the values received in the examination of the cultivation technologies to the values typical for SREP displayed above. To obtain a nuanced interpretation of the results, we applied the quantitative approach in addition to the territorial approach. The figure below compare the global warming potential values (GWP 100 years) (Figure 6).

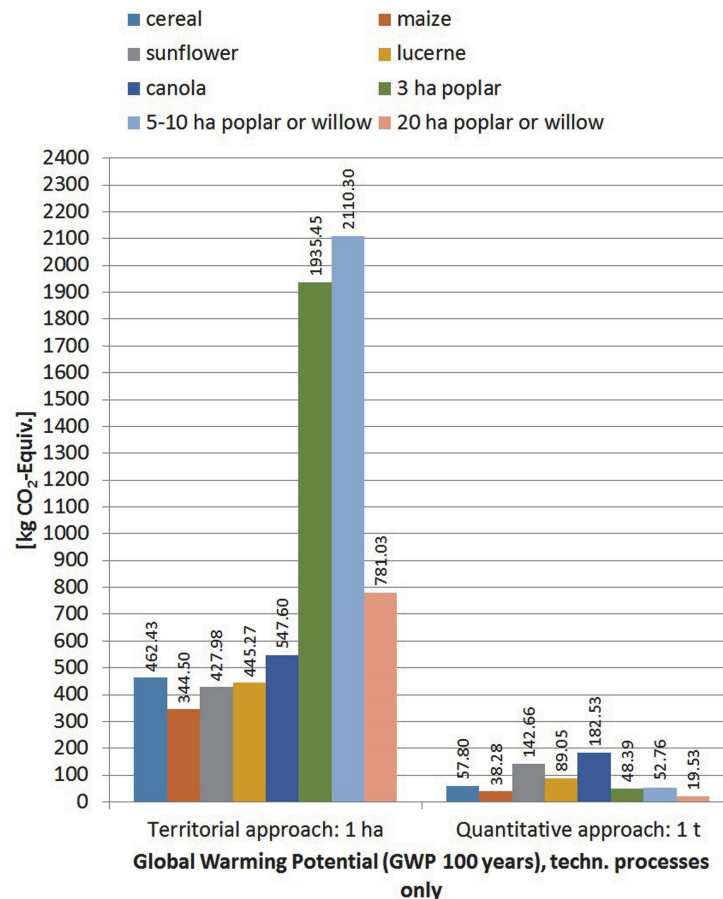


Figure 6. Global warming potential values (GWP 100 year) in territorial (1 ha) and quantitative (1 t) approach in the harvest operations systems of the examined cultivated plants and the short rotation energy plantings in the 3rd cutting age

The CO<sub>2</sub> equiv. emission profile analysis results were reflected in the territorial approach (1 ha). The analysis trends were valid in all additional impact categories; that is, they displayed 2–3 times smaller environmental impact values in cultivated plants than SREP.

*Question: What is the expected carbon footprint of cultivation technology (in the quantitative approach, 1 t)?*

When the carbon footprint contributions of cultivation technologies are expressed as percentages, we received the following increasing technological ranking in the quantitative approach (1 t): maize (8%) – cereals (11%) – lucerne (17%) – sunflower (28%) – canola (36%). With the same expressed in measurement units [kg CO<sub>2</sub>-equiv./ha], we received the following increasing technological ranking: maize (38.28 kg) – cereals (57.8 kg) – lucerne (89.05 kg) – sunflower (142.66 kg) – canola (182.53 kg).

We must emphasize that we achieved a more nuanced understanding in the territorial approach because cereals and maize presented almost equal, lucerne almost two times, sunflower almost three times, canola almost four times the carbon footprint values [kg CO<sub>2</sub>-equiv.] of the similar indicator of the SREP. This can be explained by the atmospheric emissions resulting from the larger quantities of fossil fuel produced and used in the quantitative approach (Table 3).

Table 3. Environmental impacts of examined systems based on CML2001 (Jan. 2016) assessment method in the quantitative approach (1 t)

Environmental impact category (CML2001 – Jan 2016)	Cultivated plant				Short rotation energy plantation			
	Cereals	Maize	Sunflower	Lucerne	Canola	3 ha poplar	5–10 ha poplar or willow	20 ha poplar or willow
Abiotic Depletion (ADP elements) [kg Sb eq.]	6.71E-06	4.44E-06	1.66E-05	1.03E-05	2.12E-05	2.87E-06	2.63E-06	1.08E-06
Abiotic Depletion (ADP fossil) [MJ]	8.63E+02	5.70E+02	2.13E+03	1.32E+03	2.72E+03	7.71E+02	7.01E+02	2.89E+02
Acidification Potential (AP) [kg SO <sub>2</sub> eq.]	0.03	0.02	0.08	0.05	0.10	0.05	0.04	0.02
Eutrophication Potential (EP) [kg Phosphate eq.]	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.01
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	0.36	0.24	0.89	0.55	1.13	0.50	0.46	0.19
Global Warming Potential (GWP 100 years) [kg CO <sub>2</sub> eq.]	63.13	41.78	155.67	97.20	199.00	1525.08	1543.39	1514.53
Global Warming Potential, excl biogenic carbon (GWP 100 years) [kg CO <sub>2</sub> eq.]	66.88	44.33	165.00	103.00	211.00	1528.63	1546.73	1515.88
Global Warming Potential (GWP 100 years), techn. processes only [kg CO <sub>2</sub> eq.] / 1 t	57.80	38.28	142.66	89.05	182.53	48.39	52.76	19.53

By comparing arable crop production values and SREP values, we highlight the experiences resulting from the quantitative approach (1 t) in a few significant impact categories below:

- Regarding the abiotic depletion (ADP fossil) category, the same trends were observable as those in the global warming potential (GWP 100 years) impact category in the comparison process
- When comparing the acidification potential (AP) values of arable crop production with similar SREP values, we must note that cereals and maize show nearly 0.6-times, lucerne almost equal, sunflower nearly 1.5-times, and rapeseed nearly double the values of SREP. The reason could be the ammonia and NO<sub>x</sub> emissions from fertilisation.
- Comparing the eutrophication potential (EP) values of arable crop production with the similar values of SREP, the values of cereals and maize are 0.33 times, the value of lucerne is almost 0.5 times, the value of sunflower is almost equal, and the value of canola is almost 1.5 times the values of the indicator of SREP. This can be due to differing rates of fertiliser and herbicide usage.
- Comparing the freshwater aquatic ecotoxicity pot. (FAETP) values of arable crop production with the similar values of SREP, cereals and maize values are 0.75 times, the lucerne value is almost equal, the sunflower value is almost 1.5 times, and the canola value is almost double the indicator SREP values. The reason for this could be differing rates of lubricant, fertiliser, and herbicide usage.

The research outcomes are only comparable with other LCA studies cases involving the same functional unit and system boundaries. A better understanding of environmental impacts can be improved by the extension of system boundaries and inventories, and the involvement of further primary and secondary processes.

**Acknowledgements:** We express our gratitude to AGROCLIMATE.2 VKSZ\_12-1-2013-0034 project for its support. This article was made in frame of the EFOP-3.6.1-16-2016-00018 - improving the role of research+development+innovation in the higher education through institutional developments assisting intelligent specialization in Sopron and Szombathely.

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# Stakeholder Analysis to Support Secondary Norway Spruce (*Picea abies* (L.) Karst.) Forest Conversion in the Ukrainian Carpathians

Oksana PELYUKH<sup>a\*</sup> – Alessandro PALETTO<sup>b</sup>

<sup>a</sup> Department of Ecological Economics, Institute of Ecological Economics and Management, Ukrainian National Forestry University, Lviv, Ukraine

<sup>b</sup> Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Research Center for Forestry and Wood, Trento, Italy

**Abstract** – Stakeholder analysis is a crucial step in the participatory process to involve all groups of interests in sustainable forest management. This paper aims to develop a method of stakeholder analysis to identify and classify stakeholders involved in secondary Norway spruce (*Picea abies* (L.) Karst.) stand conversions. The method is based on a questionnaire survey and structured into three stages: (1) stakeholder identification; (2) analytical characterization of stakeholders; and (3) stakeholder aggregation. Stakeholders are classified according to their interest level and importance while considering the relationships among them (social network analysis). Stakeholder analysis is applied in the Ukrainian Carpathians, which is characterized by cultural and economic dependence on forest resources. The results highlight seven “supporters” and six “opponents” as well as three key stakeholders and four primary stakeholders. We propose involving up to three stakeholders from each homogeneous group to balance stakeholder contributions and enhance the democratization of the forest conversion decision-making process.

**adaptive complexity / Norway spruce / forest management / questionnaire survey / social network analysis / public participation**

**Kivonat** – Az érdekelt felek elemzése az Ukrán Kárpátok mesterségesen létrehozott norvég lucfenyő (*Picea abies* (L.) Karst.) erdeinek átalakításához. Az érdekelt felek elemzése kulcsfontosságú lépés az összes érdekcsoport tartamos erdőgazdálkodásba való bevonásának folyamatában. A tanulmány célja a mesterségesen létrehozott norvég lucfenyő (*Picea abies* (L.) Karst.) állomány átalakításában részt vevő érintettek azonosítására és osztályozására kifejlesztett módszer bemutatása. A módszer kérdőíves felmérésen alapul, és három szakaszra tagolódik: (1) az érdekelt felek azonosítása; (2) az érdekelt felek analitikus jellemzése; és (3) az érdekelt felek összesítése. Az érdekelt feleket érdekeltségi szintjük és jelentőségük alapján osztályozzuk, miközben figyelembe vesszük a közöttük fennálló kapcsolatokat (közösségi hálózatok elemzése). Az érdekelt felek elemzését az Ukrán Kárpátokban alkalmazzák, amelyet az erdészeti erőforrásoktól való kulturális és gazdasági függőség jellemez. Az eredmények hét „támogatót” és hat „ellenzőt”, valamint három kulcsfontosságú és négy elsődleges érdekelt felet emelnek ki. Javasoljuk, hogy mindegyik homogén csoportból legfeljebb három érdekelt felet vonjanak be az érdekelt közreműködésének kiegyensúlyozása és az erdő átalakításáról szóló döntéshozatali folyamat demokratizálásának elősegítése érdekében.

**adaptív komplexitás / norvég lucfenyő / erdőgazdálkodás / kérdőíves felmérés / közösségi háló elemzés / a nyilvánosság részvétele**

\* Corresponding author: [pelyukh.o@ukr.net](mailto:pelyukh.o@ukr.net); UA-79057 LVIV, Gen. Chuprynyk 103, Ukraine

## 1 INTRODUCTION

Timber-based forestry systems are often motivated to reduce structural and functional complexity, which had negative consequences on the adaptability and resilience of forest ecosystems (Drever et al. 2006). An example of this practice is extensive Norway spruce (*Picea abies* (L.) Karst.) production, which has replaced native mixed or broad-leaved forests across Europe (Spiecker et al. 2004, Krynytskyy et al. 2014, Lavnyy – Schnitzler 2014). Beginning in the nineteenth century, more than 1,800 km<sup>2</sup> of even-aged spruce stands (secondary stands) were established on sites in the Ukrainian Carpathians that are naturally dominated by European beech (*Fagus sylvatica* L.) and mixed coniferous-broadleaved forests (Slobodiyanyan 2012, Parpan et al. 2014). Secondary spruce stands are vulnerable to many challenges today (Schutz et al. 2006), with climate change being chief among them (Zahvoyska – Pelyukh 2016). Recently, some studies have shown that spruce stand dominance will decline in the Ukrainian Carpathians over the next 500 years due to climate change (Hlásny et al. 2016, Shvidenko et al. 2017, Kruhlov et al. 2018). A sharp increase in the number of cumulative dry days, a significant decrease of precipitation during a growing season, and a higher frequency of extreme events (drought, windstorms, abundant rainfall within short periods of time) are regarded as the most detrimental factors facing Norway spruce.

The destruction of secondary spruce stand structure and functionality is related to natural, socio-economic, and institutional driving forces (Zahvoyska – Pelyukh 2016). This requires a complex response from forest managers. Promoting a more diverse and resilient array of potential forest ecosystem responses to disruptions can be achieved through the realization of “adaptive complexity” (Fahey et al. 2018) and “close-to-nature” (Krynytskyy et al. 2014) approaches in forest management. Both concepts are based on the creation of stable and resilient forest stands that possess more flexible and accommodative characteristics to manage current and future environmental changes and stressors (e.g., climate change, invasive pests). Silvicultural conversion of secondary spruce stands in the Ukrainian Carpathians is a forest management strategy that aims to stabilize and adapt forest ecosystems to current challenges (Slobodiyanyan 2012, Krynytskyy et al. 2014, Lavnyy – Schnitzler 2014, Parpan et al. 2014, Pelyukh et al. 2016, Pelyukh 2018).

Conversion is a silvicultural treatment that aims at gradual stand transition based on natural regeneration, which can transform pure stands to mixed forest stands and even-aged stands to uneven-aged stands (Krynytskyy et al. 2014). Many studies in the scientific literature describe the main techniques for forest conversion (Spiecker et al. 2004, Krynytskyy et al. 2014, Soloviy – Chernyavskyy 2011). Spiecker et al. (2004) advanced two main arguments confirming the need for secondary spruce stand conversions. Firstly, interest in numerous and diverse ecosystem services has been increasing in step with the increase in the quality of life in society. Secondly, forest management practices applied in the secondary spruce forests in recent decades have become untenable as these forests face serious and increasing threats from natural disasters and the spread of pathological processes.

According to several authors, forest conversions can provide a broad range of benefits: (1) increased drought resistance (Merlin et al. 2015); (2) improved soil conditions (Prescott 2002); (3) reduced landslide and windfall risks (Schutz et al. 2006); (4) reduced forest fire risks (Gonzalez et al. 2006); (5) improved hydrological regime and an increased water supply (Kulchytskyy-Zhyhaylo – Kulchytska-Zhyhaylo 2011); (6) reduced pathogen impact risk (Parpan et al. 2014); (7) higher resilience and resistance to natural and anthropogenic disturbances and better climate change adaptation (Soloviy et al. 2011); (8) increased biomass productivity (Pretzsch et al. 2014); (9) decreased financial risks due to forest species diversification (Hildebrandt – Knoke 2009); (10) enhanced biodiversity (Krynytskyy et al.

2014, Carnus et al. 2006); and (11) increased recreational value of forest landscapes (Grilli et al. 2014). However, forest conversion is only implemented on smaller sites in the Ukrainian Carpathians. This slow expansion of the forest conversion process is associated with a strong focus on short-term financial interests by businesses and local stakeholders. These financial interests conflict with a long-term perspective regarding the benefits of secondary Norway spruce forest conversions. This makes conversions unattractive from the macroeconomic perspective of resource allocation. Discrepancy and a lack of coherence in stakeholder activity hinder conversion projects (Zahvoyska et al. 2016, Zahvoyska et al. 2017).

Achieving a successful forest conversion requires an inclusive participatory process (Balest et al. 2016, Grimble – Wellard 1997, Paletto et al. 2010, Paletto et al. 2015, Reed et al. 2009, Zahvoyska – Pelyukh 2016) that incorporates an analysis of stakeholder interests and roles (Pelyukh et al. 2019c). A participatory process that aims to include differing stakeholder interests and point of view has the advantage of increasing social sustainability and reducing conflicts among interest groups involved in the decision-making process. In this context, an investigation of stakeholder interests and relationships is crucial for successful forest management (Sandström – Rova 2010). In the international literature, some authors have used the relationships between stakeholders as a tool to classify forest resource stakeholders. Paletto et al. (2015) used the social network analysis to support stakeholder analysis in two participatory forest plans in Italy (Matese and Arci-Grighine forest districts), while Krupa et al. (2018) mapped stakeholders in a case study in Alaska's Kenai Peninsula using social network analysis with the aim of increasing the transparency and legitimacy of the participatory process. Recently, Blanc et al. (2018) implemented participatory processes in forestry training in the Western Italian Alps (Piedmont, Liguria and the Aosta Valley) using social network analysis techniques.

Starting from these considerations, the main aim of this study is to develop an objective method of stakeholder analysis aimed at identifying and classifying stakeholders while considering their interests and relationships. The proposed method is based on selected stakeholder characteristics – ego-degree centrality and ego-betweenness centrality – identified through social network analysis. The proposed method identifies the main “supporters” and “opponents” of secondary spruce forest conversions in the Ukrainian Carpathians and seeks to involve these groups in the participatory decision-making process.

## 2 MATERIALS AND METHODS

### 2.1 Study area

The Ukrainian Carpathians is located in south-western Ukraine and covers a land area of 56,635 km<sup>2</sup> (*Figure 1*). The region includes four oblasts: Chernivetska Oblast, Ivano-Frankivska Oblast, Lvivska Oblast, and Zakarpatska Oblast with a population of 6.07 million inhabitants (population density of 108 inh./km<sup>2</sup>). The present research has been conducted in five towns (Lviv, Ivano-Frankivsk, Uzhhorod, Rakhiv, Skole) and four villages (Bogdan, Roztoky, Verkhnye Syn'ovyadne) located in the Ukrainian Carpathians.



Figure 1. The geographical location of study sites in the Ukrainian Carpathians

The altitude of the Ukrainian Carpathians is between 100 m and 2000 m a.s.l.; the climate is temperate with a moderate continental influence. The average annual precipitation range is between 900-1200 mm and the average temperature is from +20 °C to 6 °C in summer and from -3 °C to -10 °C in winter (Kuemmerle et al. 2009). The landscape in the Ukrainian Carpathians is characterized by glacier-shaped valleys and the slopes of different exposures and inclinations.

The forest area covers around 37% of the region (20,856 km<sup>2</sup>), out of which 70.9% belong to the Forest Resources Agency, 20.1% to the Ministries of Agricultural Policy, 3.8% to the Ministries of Ecology and Natural Resources, 0.4% to the Ministries of Education and Science, while the remaining 4.8% are private forests. State-owned forests (95.2% of the forested area) are managed by state forest enterprises. The main forest types in the Ukrainian Carpathians are Norway spruce (*Picea abies* (L.) Karst.) (41%), followed by European beech (*Fagus sylvatica* L.) (35%), pedunculate oak (*Quercus robur* L.) (9%), silver fir (*Abies alba* Mill.) (4%), and other forest types (11%).

Secondary spruce covers 28% of all spruce forests (184.3 thou. ha) in the Ukrainian Carpathians (Slobodiyani 2012). According to Parpan et al. (2014), 193 km<sup>2</sup> of these forests with a wood volume of nearly 6 million m<sup>3</sup> has experienced intensive drought. Most droughts in secondary spruce forests are distributed in the territory of Lviv (51.9% of all secondary spruce forests) and Ivano-Frankivsk (31.6%) oblasts.

## 2.2 Research framework

The research framework based on the questionnaire survey was developed in three stages: (1) stakeholder identification; (2) analytical characterization of stakeholders; (3) stakeholder aggregation.

### 2.2.1 Stakeholder identification

The first stage of stakeholder analysis is aimed at identifying all stakeholders who affect, and/or are affected by the policies, decisions, and actions of the system. Identifying stakeholders is an iterative process during which the preliminary list of relevant stakeholders is updated and integrated into subsequent steps (Reed et al. 2009).

In this study, the stakeholders were identified using the snowball sampling method. This method is a non-probability sampling technique used for the difficult task of defining and

accessing the population of interest. The snowball sampling method is applied to recruit a purposive sample (i.e. stakeholders thought to be most important to the issue under study), whereby the researcher asks respondents to identify other stakeholders the researcher may contact (Etikan et al. 2016).

In the present study, all respondents were asked to indicate the name of other potential stakeholders to be involved in the survey. The main criteria used to identify stakeholders were professional experience and skills in forest management and planning, biodiversity conservation, and forest economics and policy.

At the end of survey, 50 stakeholders were identified and directly contacted for the survey, but only 25 stakeholders were willing to participate (for a response rate of 50%). All identified stakeholders are strictly related to the problem of diminishing secondary spruce stands and possess knowledge about socio-ecological and economic features and consequences of the forest conversion process. The 25 stakeholders involved in the survey belong to the following organizations and institutions: Ukrainian National Forestry University (16%), Ivan Franko State University (4%), Ukrainian Research Institute of Mountain Forestry (4%), Carpathians Biosphere Reserve (8%), Zacharovanyi Krai National Park (4%), State Enterprises "Rakhiv forestry" (8%) and "Skole forestry" (4%), local people (8%), environmental Non-Governmental Organization "Ecosphere" (4%) and "Rakhiv. Tourist" (4%). The remaining respondents represent the following groups: forest harvesters (4%), paper manufactures (4%) wood processing companies (4%), local authorities (4%), pickers of non-wood forest products (4%), and hunters (4%).

### **2.2.2 Analytical characterization of stakeholders**

The second stage of stakeholder analysis refers to a set of methods aimed at characterizing and classifying the stakeholders based on certain attributes such as (Mitchell et al. 1997, Banville et al. 1998, Newman 2005, Paletto et al. 2015): urgency, legitimacy, influence, proximity, level of interest and influence, access to resources, relationships (cooperation/competition), and proximity to the resource.

In this study, stakeholders were characterized considering interests (benefits/loses) proposed by Lindenberg and Crosby (1981), and relationships between stakeholders proposed by Grilli et al. (2015). All identified stakeholders were contacted, and a semi-structured questionnaire was administered face-to-face. This administration system was chosen because it could provide a higher response rate, higher quality of acquired data, and a better opportunity to explain unclear questions to respondents (De Leeuw 1992, Goyder 1985). During this stage, all respondents provided important information and opinions about stakeholder interests, influences, and relationships in the context of secondary spruce conversions in the Ukrainian Carpathians.

A preliminary version of the questionnaire was developed and pre-tested. The final version of the questionnaire consists of four thematic sections concerning the following aspects: (1) personal information of respondents (2) assessment of forest conversion impacts on stakeholder well-being; (3) assessment of stakeholder influence on the forest conversion process; (4) relationships between stakeholders in the context of secondary spruce stand management.

The first part of the questionnaire focused on the respondent's personal information, such as name, location, and respondent's role in the organization/institution/association.

The second thematic section investigated stakeholder well-being in the context of secondary spruce stand conversions. A preliminary list of stakeholders developed by researchers from the Ukrainian National Forestry University was proposed for the respondents. The main question in this stage was: Who wins or loses as a result of forest

conversion impacts? The results of this thematic section have been used as an indirect indicator of stakeholder interests.

The third thematic section investigated stakeholder influence on the forest conversion decision-making process using the following question: Who influences and who are influenced by the forest conversion decision-making process?

A 5-point Likert scale format (from 1 = very low to 5 = very high value) was used in order to rate impacts of forest conversions on stakeholder well-being and influences in the decision-making process (Likert 1932).

In the fourth thematic section, relationships among stakeholders in the context of secondary spruce conversion were investigated and distinctions between strong and weak ties were drawn (Granovetter 1973). A 3-point Likert scale format (1 = very weak ties, 2 = weak ties, 3 = strong ties) was used in order to quantify the strength of ties.

This paper presents the results of the second and fourth thematic section. We used information from the second thematic section of the questionnaire to divide all identified stakeholders into two groups within the context of secondary spruce conversion: “supporters” and “opponents”. This division was done based on a comparative analysis of median value in the respondents’ estimates towards stakeholder benefits and costs. If the median value of stakeholder benefits was higher than the median value of losses, then the stakeholder belonged to the “supporters” group; if the reverse appeared, the stakeholder was classified in the “opponents” group. For this case, descriptive statistics were developed using XLStat 2012. Information from the fourth section of the questionnaire was used to analyze stakeholder relationships in the third stage of the research framework.

In addition, we collected comments and qualitative information the respondents provided for each question. It was assumed the comments would help to interpret the results. In our case study, this information was used to explain the results of the respondents’ estimations.

### **2.2.3 Stakeholder aggregation**

The third stage of stakeholder analysis sorts the previously identified stakeholders into homogeneous groups in order to choose the appropriate degree of involvement for each group (Paletto et al. 2015). This stage is crucial in the participatory process because the choice of an inappropriate degree of involvement for one or more stakeholders may compromise the process. The degree of involvement – from simply receiving information (referred to as the information level) to jointly deciding policy or activity (co-deciding) (Hare et al. 2003) – is closely linked to the stake and/or importance of the stakeholders in an issue or context.

In this study, stakeholder aggregation was completed based on the relationships between stakeholders. Relationships that exist between identified stakeholders were analyzed through social network analysis (SNA), which is a formal theory to define and analyze the relationships that stakeholders have with each other, focusing on the structural patterns of stakeholder positions (Wasserman – Faust 1994). SNA allows for an aggregation of stakeholders into three homogeneous groups of importance (ODA 1995): key, primary, and secondary. Key stakeholders can significantly influence or are important to the success of the project. Primary stakeholders are those who are affected, either positively or negatively, by project results. Secondary stakeholders are those who have a marginal effect on the results of the project results. This aggregation aims to choose the appropriate degree of involvement each stakeholder holds in the decision-making process based on the ability of a single stakeholder to represent the interests of their interest group.

The social network can be analyzed based on degree centrality, betweenness centrality, and closeness centrality and are defined by “complete” or “sociocentric” network data that provide information on relationships among all actors within a bounded social network (Freeman 1979). Conversely, the “egocentric” design does not require a priori enumeration of

a population of stakeholders and is often used to measure social networks in survey-based studies. (Marsden 2002). In addition, it is better to use an “egocentric” design to analyze a personal network in the immediate locality of a given actor (Marsden 2002). Ego-centric networks represent the respective relational communities of a set of actors that are not necessarily connected (Salpeteur et al. 2017). Two ego-network features (ego-degree centrality and egocentric betweenness) were applied to aggregate stakeholders into homogeneous groups within the context of secondary spruce conversions in the Ukrainian Carpathians. These features were calculated with UCINET 6.666 software.

Degree centrality is measured simply as the number of direct ties that involve a given node and reflects the direct relational activity of node  $p_i$  (Freeman 1979). A node with a high degree is therefore considered a hub in the network. There are no differences between degree centrality and ego-degree centrality (Marsden 2002). Since possible degree centrality can be considered an indirect indicator of stakeholder power (Grilli et al. 2015, Paletto et al. 2016), we use this measure of each stakeholder (ego) as an indicator of the personal power. The formula for calculating the ego degree centrality ( $C_d$ ) is (Marsden 2002):

$$C_d = \sum_{k=1}^N a(p_i, p_k) \quad (1)$$

where,

$C_d$  – the ego-degree centrality;

$a_i$  – the egocentric matrix;

$p_i$  – the "ego" node;

$p_k$  – nodes in the first-order zone of  $p_i$ , i.e. nodes  $p_k$  for which  $a(p_i, p_k)=1$ ;

$N$  – the total number of stakeholders.

The egocentric network  $A_i$  for stakeholder  $p_i$  includes all other stakeholders  $p_k$  such that  $a(p_i, p_k) = 1$ .

Betweenness centrality is calculated as the fraction of shortest paths between node pairs that pass through the node of interest (Freeman 1979). Betweenness centrality measures the influence that a stakeholder has over the spread of information through the network. Therefore, it evidences the stakeholders that possess real power in information control and that assume the roles of intermediates in the decision-making process (Mizruchi – Potts 1998, Paletto et al. 2010). Egocentric betweenness may often be a reliable substitute for Freeman’s sociocentric betweenness measure, which notes that some pairs ( $p_i, p_k$ ) may be connected not only via the ego node, but also through other nodes in the egocentric network that thereby share the intermediary position for that relationship with the ego node (Freeman 1979, Marsden 2002). The formula for calculating the ego-betweenness centrality ( $C_b$ ) is:

$$C_b = \sum_{u=1}^N \sum_{v=1}^N P_{uv}(f) / P_{uv} \quad (2)$$

where,

$C_b$  – the ego-betweenness centrality;

$u, v$  – the stakeholders in the ego network of stakeholders  $f$ ;

$N$  – the total number of stakeholders in the ego network;

$P_{uv}$  – the total number of network paths linking stakeholder  $u$  and stakeholder  $v$ ;

$P_{uv}(f)$  – the number of those paths that include stakeholders  $f$ .

Using the value of ego-degree centrality and ego-network betweenness, the Individual Index of Importance ( $I_i$ ) for each stakeholder in the network was calculated using the following equation:

$$I_i = C_d + C_b \quad (3)$$

where,

$I_i$  – the index of importance stakeholders  $i$ ;

$C_d$  – the ego-degree centrality of stakeholders  $i$ ;

$C_b$  – the ego-betweenness centrality of stakeholders  $i$ .

In order to aggregate the stakeholders into homogenous groups of importance, the stakeholders with an  $I_i$  higher than the third quartile are considered as key stakeholders, the stakeholders with an  $I_i$  between the third and first quartile are classified as primary stakeholders, whilst the remaining stakeholders are considered secondary stakeholders.

At the end of the aggregation stage, all stakeholders that were divided into groups of interest (“supporters” and “opponents”) and homogeneous groups of importance (key, primary and secondary stakeholders) within the context of their participation in decision-making regarding secondary spruce stand conversions in the Ukrainian Carpathians.

### 3 RESULTS

In the context of secondary spruce stand conversions, all respondents identified 13 stakeholders: nature conservation organizations (NCOs), state forestry enterprises, harvesting companies, wood processing companies, paper manufacturers (PMs), environmental non-governmental organizations (ENGOS), tourists (people who travel or visit a place for pleasure), recreationists (people who enjoy outdoor leisure activities such as hiking, camping, fishing), hunters, pickers of mushrooms, berries and other non-wood products (NWFPS), scientists, local authorities, and local people. Only respondents from Ukrainian National Forestry University and State Enterprise “Rakhiv forestry” indicated other stakeholders such as government organizations (Department of Ecology and Environmental Protection under the Regional State Administration, the Ecological Inspection and Ukrainian government organization, Lisovporyadne Production Association “Ukrderzhisproekt”).

Regarding stakeholder well-being, the common view among respondents was that almost all stakeholders receive mostly benefits rather than losses from forest conversions (*Table 1*). In accordance with respondent opinions, the main beneficiaries are: NCOs (mean value=4.17), tourists (4.10) and recreationists (3.74), scientists (3.631), ENGOS (3.57), local people (3.55), and authorities (3.33). These stakeholders can be considered as potential “supporters” of the forest conversion process.

Conversely, the respondents consider the main losers of the secondary spruce stand conversions to be: harvesting companies (mean value=3.42), pickers of NWFPS (3.00), state forest enterprises (2.90), wood processing companies (2.71), hunters (2.33), and PMs (1.75). These stakeholders can be considered potential “opponents” of the forest conversion process.

Stakeholders such as state forest enterprises and wood processing companies were included in a group of opponents in view of their explicit forest conversion costs. A more detailed explanation of their inclusion in this stakeholder group is provided in the Discussion chapter.

Table 1. Characterization of stakeholders by interest (benefits / losses).  
Value present on 5-point Likert scale (from 1 = very low to 5 = very high value)

Groups of stakeholders	Benefits			Losses			Interest
	Mean	Standard deviation	Median	Mean	Standard deviation	Median	
NCOs	<b>4.17</b>	1.17	5	1.33	0.58	1	Supporter
ENGOS	<b>3.57</b>	1.54	4	2.20	1.10	3	Supporter
Tourists	<b>4.10</b>	1.12	4	1.75	1.49	1	Supporter
State forestry enterprises	3.10	1.59	3	<b>2.90</b>	0.99	3	Opponent
Harvesting companies	3.00	1.73	3	<b>3.42</b>	1.00	4	Opponent
Hunters	2.17	1.53	1.5	<b>2.33</b>	1.63	2	Opponent
Pickers of NWFPs	2.90	1.51	3	<b>3.00</b>	1.41	3	Opponent
Recreationists	<b>3.74</b>	1.05	4	2.08	1.31	1.5	Supporter
Scientists	<b>3.63</b>	1.71	4	2.33	1.75	1.5	Supporter
Local authorities	<b>3.33</b>	1.50	3	2.00	1.20	1.5	Supporter
Local people	<b>3.55</b>	1.15	3	1.75	1.16	1	Supporter
Wood processing companies	2.86	1.88	2.5	<b>2.71</b>	0.95	3	Opponent
PMs	1.40	1.17	1.2	<b>1.75</b>	0.58	2	Opponent

The stakeholders with the highest value of both ego-degree centrality and ego-betweenness centrality are the state forest enterprises ( $C_d=12$ ,  $C_b=11.46$ ), local authority ( $C_d=12$ ,  $C_b=10.51$ ), local people ( $C_d=11$ ,  $C_b=6.41$ ), and NCOs ( $C_d=11$ ,  $C_b=6.29$ ) (Table 2). In other words, these stakeholders hold more power and ability to spread information compared to other stakeholders. Some stakeholders, such as tourists and recreationists, possess a high value of ego-degree centrality and a low value of ego-betweenness centrality ( $C_d=9$ ,  $C_b=0.17$ ) ( $C_d=9$ ,  $C_b=0.57$ ). These stakeholders hold much power, but their ability to spread information is low.

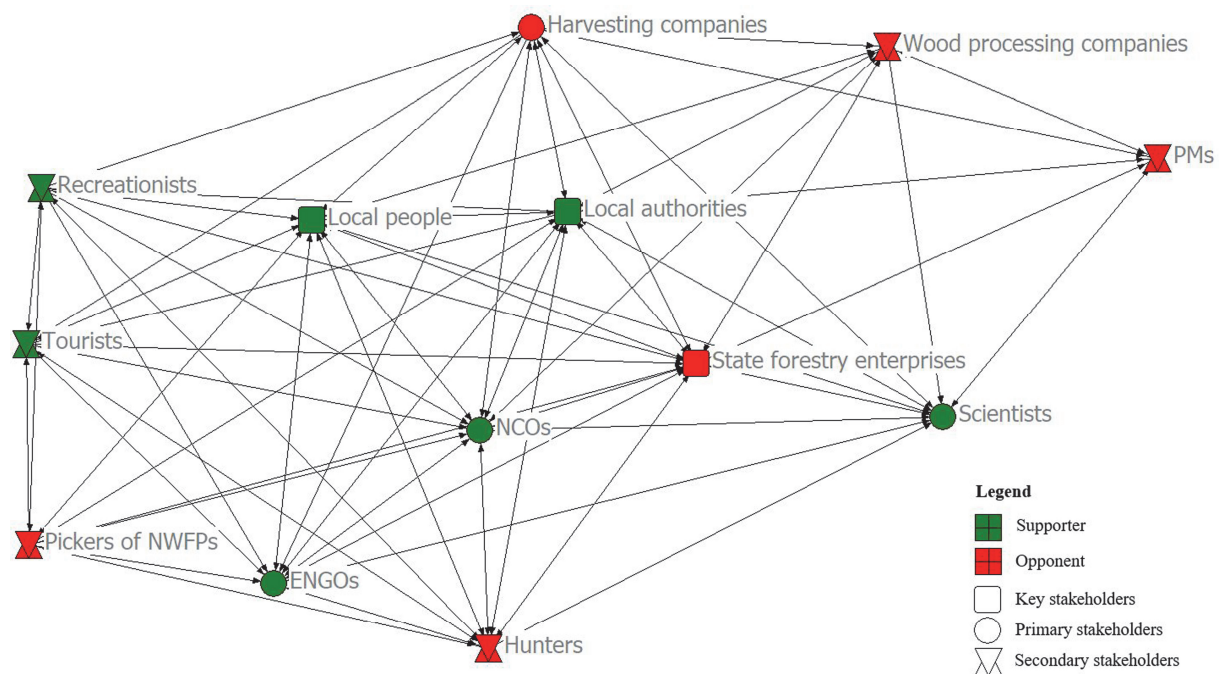
Table 2 Ego-degree centrality, ego-betweenness centrality and Individual Index of Importance of stakeholders in the context of secondary spruce stands conversion in the Ukrainian Carpathians

Groups of stakeholders	$C_d$	$C_b$	$I_i$	Aggregation of stakeholders
State forestry enterprises	12	11.46	23.46	Key
Local authorities	12	10.51	22.51	Key
Local people	11	6.41	17.41	Key
NCOs	11	6.29	17.29	Primary
Harvesting companies	10	4.23	14.23	Primary
ENGOS	10	2.44	12.44	Primary
Scientists	9	2.47	11.47	Primary
Hunters	9	2.20	11.20	Secondary
Recreationists	9	0.57	9.57	Secondary
Tourists	9	0.17	9.17	Secondary
Pickers of NWFPs	8	0.73	8.73	Secondary
Wood processing companies	7	1.23	8.23	Secondary
PMs	5	0.25	5.25	Secondary

Stakeholder aggregation based on the Index of Importance ( $I_i$ ) identified three key stakeholders: state forest enterprises, local authorities, and local people. Four other stakeholders are recognized as primary stakeholders (NCOs, harvesting companies, ENGOs, scientists), while the remaining six stakeholders (hunters, recreationists, tourists, pickers of NWFP, wood processing companies, and PMs) can be considered secondary stakeholders.

Key and primary stakeholders are mainly “supporters” (5 of 7 stakeholders), while secondary stakeholders are mainly “opponents” (4 of 6 stakeholders).

The SNA in the Ukrainian Carpathians (*Figure 2*) comprises 13 nodes (stakeholders) and 107 links (relationships). SNA results reveal no central stakeholder holds the key role in the decision-making process related to secondary spruce stand conversions. Instead, three stakeholders play key roles in the network: two of these three stakeholders are “supporters” (local authorities and local people) while the remaining stakeholder is an “opponent” (state forest enterprises). NCOs, important actors and primary stakeholders in this social network, are “supporters” of the forest conversion process. In addition, these stakeholders play the role of intermediaries with other stakeholders.



*Figure 2. Social network considering all identified stakeholders in the context of secondary spruce stands conversion in the Ukrainian Carpathians*

#### 4 DISCUSSION

The present study used respondent answers to identify all relevant stakeholders in the context of secondary spruce stand conversions in the Ukrainian Carpathians. According to Grilli et al. (2015), the proposed approach provides a realistic picture of the network and reveals some hidden stakeholders with lower importance. This approach has three main advantages in stakeholder analysis: it is simple, easy to apply, and requires small amounts of data.

The division of stakeholders into two groups (“supporters” and “opponents”) was based on the benefits or losses deriving from secondary spruce stand conversions. The qualitative comments provided by respondents during the questionnaire administration helped determine the appropriate group categorization for stakeholders with almost equal benefits and losses.

Costs of forest conversion are quite explicit for state forest enterprises, especially in the initial stages of this process. Forestry enterprises will bear significant financial costs due to higher harvest costs, logging equipment modernization, forest road network extensions, and additional training for forest technicians regarding the practice of forest conversion. Planting and protecting native tree species – such as European beech and silver fir – may be necessary in cases of poor natural regeneration. Planting and caring for seedlings increases forest conversion costs. Benefits for state forestry enterprises would be generated in the long-term rather than the short-term. More intensive financial investments over a conversion period of around 100 years with a questionable commercial return in a long-term perspective hinder the dissemination of forest conversion practices.

Hunters mainly lose from the secondary spruce stand conversions because the area under forest conversion should be fenced to avoid natural regeneration damage (Lavnyy – Schnitzler 2014). Thus, hunter benefits or losses depend on promoting the new generation on the sites under the conversion. Since most forest conversion sites are fenced, hunters and pickers of NWFPs must seek other forest sites.

The main “supporters” of forest conversion are NCOs due to the opportunities to eliminate the existing and massive dieback process of secondary spruce forests. These stakeholders are in the primary group of stakeholders (according to *Table 2*) because they are positively affected by the results of the forest conversion process.

Other potential “supporters” of forest conversion that are also key stakeholders are local people and local authorities. Their support of this silvicultural measure relates to revenue taxes from timber and firewood sales from conversion cutting, which increases the welfare of local people and authorities.

The high degree of power (ego-degree centrality) local people held in forest conversion decision-making relates to their involvement with Community Councils at the Regional Departments of Forestry and Hunting, which have been established with the aim of discussing important issues concerning the use of forest resources at regional and local levels.

The forest conversion process involves tree species composition and stand age changes that transform pure forests to mixed forests and even-aged forests into uneven-aged forests (Pelyukh et al. 2016, Pelyukh 2018). These changes could have a positive impact on the recreational attractiveness of this forest type. Investigations conducted in the Ukrainian Carpathians (Pelyukh – Zahvoyska 2018, Pelyukh et al. 2019a,b) confirm that people prefer mixed forests to coniferous forests and uneven-aged forests to even-aged ones. Other authors have obtained similar results in Italy and Poland (De Meo et al. 2015, Grilli et al. 2016, Paletto et al. 2017). Increasing recreational attractiveness through forest conversion contributes to an increase in the potential flow of tourists and local economic benefits.

Many tourist organizations operate in the territory of Ukrainian Carpathians: Tourist Association of Ivano-Frankivsk and Lviv region, Regional Tourism Organisation of Zakarpattia, Tourist Association of the Western part of Ukraine, Regional tourist alliances “Play” and “Chornohora”, Tourist alliance “Carpathian paths”, “Tourist Association of Recreational Development of Skolivshchyna”, “Rakhiv.Tourist”. These organizations coordinate the directions of tourism business. Many of them lobby to improve the recreational attractiveness of forests (increased tree species diversity, composition, and age structure) to attract more tourists to the Carpathian region of Ukraine.

Two primary stakeholders that “support” forest conversion are scientists and ENGOs. New opportunities to develop professionalism in the fields of adaptive forest management (i.e. forest conversion practice) are among the potential benefits for scientists, while the benefits for ENGOs are related to increased forest naturalness. Scientists should clearly articulate a holistic vision of the benefits from forest ecosystem services, close-to-nature

paradigms, and triggered conversion processes in the forestry curriculum. ENGO representatives should then promote this information to the local community.

Harvesting companies – classified as primary stakeholders – are negatively affected by the results of forest conversion processes. Conversion cutting (changes in age structure and tree species composition) is more complex than clearcutting. Since conversion cutting seeks to protect biodiversity and natural regeneration, it also requires greater attention, resources, and effort. Forest harvesting companies oppose these forest conversion challenges.

Other “opponents” that have a marginal effect on the forest conversion results are PMs and wood industries. The latter require many high-quality raw materials (roundwood), which places a higher value on coniferous stems with no branches and little crowns. Conifers in uneven-aged stands have a longer crown, which diminishes wood quality (Macdonald et al. 2009). A higher proportion of broadleaved wood leads to lower wood prices and, ultimately, financial losses. PMs also prefer coniferous species to broadleaved species because coniferous fibers are longer and pass through presses and other processing operations more easily (Andriyevska – Glushkova 2013).

In accordance with the results of the present study, in the participatory approach aimed to define the future of secondary spruce stands, we propose to involve up to three stakeholders from each homogeneous group of importance (key, primary and secondary stakeholders). This approach will help balance the differing stakeholder interests (“supporter” and “opponent”) during the decision-making process.

## 5 CONCLUSIONS

The interviewed respondents are stakeholders and experts in forest conversion processes, which is the main advantage of the proposed method. Consequently, respondents possess extensive knowledge about all aspects of the forest conversion process, especially concerning stakeholder interests, stakeholder relationships, and power in decision-making.

On the other hand, a disadvantage of the proposed method is the collected data, which are mostly quantitative. Therefore, more qualitative data collection concerning the interests, conflicts, and interactions between identified stakeholders is needed. In-depth interviews and focus groups with key and primary stakeholders could allow for the collection of qualitative information. These aspects require further research in the future.

Stakeholder analysis conducted from the perspective of secondary spruce stand conversions in the Ukrainian Carpathians allows us to identify potential “supporters” and “opponents” of forest conversion processes. Stakeholder analysis also predicts the relationships between stakeholders and the impact stakeholders have on the decision-making process. The presented results are significant to practitioners and decision-makers in two significant ways. Firstly, to understand the advantages and disadvantages of the forest conversion process for different stakeholder groups in the Ukrainian Carpathians. Secondly, to identify stakeholders who could be involved in forest conversion decision-making. This combination of findings provides some support for the conceptual premise of forest policy formulation aimed at sustainability achieved through close-to-nature silviculture in the Ukrainian Carpathians. Research questions for a future investigation could include examinations of how to multiply “supporters” synergies in forest conversion processes and balance trade-offs between stakeholder benefits and losses.

**Acknowledgments:** The authors would like to thank the respondents for participating in the survey of the study and contributing to the research project.

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## Combined Multi-assay Evaluation of the Antioxidant Properties of Tree Bark

Eszter TÁLOS-NEBEHAJ\* – Levente ALBERT – Eszter VISI-RAJCSI –  
Tamás HOFMANN

Institute of Chemistry, University of Sopron, Hungary

**Abstract** – Wood logging generates considerable amounts of bark by-product, which are a potential antioxidant source well worth extracting and using. The present work compares the antioxidant properties of the bark of the following selected Hungarian forest tree species: white poplar (*Populus alba* L.), black locust (*Robinia pseudoacacia* L.), sessile oak (*Quercus petraea* Liebl.), black poplar (*Populus nigra* L.), silver birch (*Betula pendula* Roth), European larch (*Larix decidua* Mill.), scots pine (*Pinus sylvestris* L.), wild cherry (*Prunus avium* L.), European hornbeam (*Carpinus betulus* L.) and sweet chestnut (*Castanea sativa* Mill.). Inner and outer bark were investigated separately. Total polyphenol content (TPC) was determined by the Folin-Ciocalteu method, whereas antioxidant capacity was assayed using the ferric reducing ability of plasma (FRAP), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) methods. The overall antioxidant power of the samples was evaluated using a scoring system that combined the FRAP, DPPH, and ABTS assay results. The TPC levels did not always follow the FRAP, DPPH, and ABTS assay values. Differing reaction mechanisms and sample compositions are possible reasons for this. The presented scoring evaluation was suitable for the assessment and comparison of complex antioxidant properties of tree bark samples. According to the scores, inner bark showed higher scores compared to outer bark for most species with the exceptions of black poplar, black locust, white poplar, sweet chestnut, and European larch. The highest overall antioxidant capacities were determined in the inner bark of wild cherry and the outer bark of sweet chestnut. The species with the overall lowest scores were black locust and black poplar.

**bark / antioxidant capacity / polyphenols / combined multi-assay evaluation**

**Kivonat** – Fakéreg antioxidáns tulajdonságainak felmérése kombinált többmódszeres kiértékeléssel. Az erdei fakitermelés során jelentős mennyiségű kéreg melléktermék keletkezik, mely nagy mennyiségben tartalmazhat kivonható és hasznosítható antioxidánsokat. A jelen cikkben kiválasztott magyarországi erdei fafajok (fehér nyár (*Populus alba* L.), akác (*Robinia pseudoacacia* L.), kocsánytalan tölgy (*Quercus petraea* Liebl.), fekete nyár (*Populus nigra* L.), közönséges nyír (*Betula pendula* Roth), európai vörösfenyő (*Larix decidua* Mill.), erdeifenyő (*Pinus sylvestris* L.), vadcsereznye (*Prunus avium* L.), közönséges gyertyán (*Carpinus betulus* L.) és a szelídgesztenye (*Castanea sativa* Mill.)) kérgének antioxidáns tulajdonságait mértük fel és hasonlítottuk össze. Külön vizsgáltuk a külső- és a belső kéreg szöveteket. Az összes polifenol tartalmat (TPC) a Folin-Ciocalteu módszerrel, az antioxidáns kapacitást a FRAP (vas(III)-ion redukálóképessége) a DPPH (2,2-difenil-1-pikrilhidrazil-gyök közömbösítése) valamint az ABTS (2,2'-azino-bisz(3-etilbenzotiazolin-6-szulfonsav gyök kation reakciója) módszerekkel vizsgáltuk. A minták "összesített" antioxidáns hatását egy pontrendszer segítségével értékeltük, amely kombinálta a FRAP, DPPH és ABTS módszerekkel kapott

\* Corresponding author: [nebehaj.esztella@gmail.com](mailto:nebehaj.esztella@gmail.com); 9072 NAGYSZENTJÁNOS, Arany János u. 38, Hungary

eredményeket. A TPC értékei nem mindig követték a FRAP, ABTS illetve DPPH értékeket, feltételezhetőleg a különböző mintaösszetételek, illetve a módszerek eltérő szelektivitása miatt. A bemutatott kiértékelő módszer alkalmas volt a kéregminták antioxidáns tulajdonságainak összehasonlító elemzésére. A pontszámok alapján a legtöbb faj esetében a belső kéreg magasabb antioxidáns tartalommal rendelkezett, mint a külső kéreg, kivéve az akác, fekete- és fehér nyár, vörösfenyő és a szelídgesztenye. A legmagasabb antioxidáns tartalmat a vadcseresznye belső kérgében és a szelídgesztenye külső kérgében mértük. Az összességében legalacsonyabb pontszámokkal jellemzett fajok az akác és a feketenyár voltak.

### **fakéreg / antioxidáns kapacitás / polifenolok / kombinált többmódszeres kiértékelés**

## **1 INTRODUCTION**

Waste products from the food, forestry, and agricultural industries are promising raw materials because they are inexpensive and their reuse provides environmental benefits (Vázquez et al. 2012). In this regard, forest tree bark is especially significant (Molnár 2004, Pietarinen et al. 2006, Diouf et al. 2009, Ekman et al. 2013, Ghitescu et al. 2015) because it is generated during the processing of wood logs in large amounts, with an estimated annual volume of 300-400 million m<sup>3</sup> (Pásztory et al. 2016). Of this amount, about 0.5-0.6 million m<sup>3</sup> are generated in Hungary alone (Molnár 2004). *Table 1* summarizes the proportion of different woody species by occupied area and by wood logging volume in Hungary in 2018.

*Table 1. The proportion of woody species by occupied area (KSH1 2019) and wood logging volume (KSH2 2019) in Hungary based on 2018 data*

Species	Occupied area (1000 ha)	Wood logging (1000 m <sup>3</sup> )
<i>Quercus petraea</i> and <i>robur</i> L.	389.3	1004
<i>Quercus cerris</i> L.	212.3	840
<i>Fagus sylvatica</i> L.	112.6	726
<i>Carpinus betulus</i> L.	97.1	259
<i>Robinia pseudoacacia</i> L.	454.2	1586
Other high density hardwood species	119.3	324
Hybrid poplar		1188
Indigenous poplar	197.4*	339
<i>Salix</i> spp.	n/a	61
Other low density hardwood species	97.3	273
<i>Pinus sylvestris</i> L.	110.9	n/a
<i>Pinus nigra</i> J.F.Arnold	59.2	1166**
Other conifers	17.8	n/a
<b>Total</b>	<b>1867.5</b>	<b>7766</b>

\* sum of poplars (*Populus* spp.)

\*\* sum of all coniferous species

Pásztory et al. (2016) recently reviewed potential fields for wood bark utilization. One of these fields is the extraction and use of natural antioxidants. Wood bark contains various types (enzymatic and non-enzymatic) of antioxidants. These compounds not only contribute to the protection of living tissues in trees, but have also beneficial health effects on humans as well.

Regarding tree bark antioxidant utilization, non-enzymatic antioxidants are considered more important and are better researched. The bark of *Cinchona* spp. contains the compound

quinine, which has been applied to cure malaria and was also evidenced to have antioxidant properties (Krishnaveni et al. 2015). The polyphenolic compounds present in high concentration *Acacia mangium* Willd. bark are a promising antioxidant source for cosmetic and pharmaceutical products (Rosdiana et al. 2017). The various types and mixtures of polyphenols in tree bark and bark extracts (e.g. in *Salix* spp.: salicin, catechins, procyanidins, in *Pinus pinaster* Aiton: catechins, procyanidins; and in the dragon blood tree *Draceana cinnabari* Balf. f.: flavylum compounds) were shown to have excellent-health improving and healing properties (Packer et al. 1999, Gupta et al. 2008, Sousa et al. 2008, Zaiter et al. 2016). In *Betula* spp., the triterpenoids contribute significantly to the antioxidant (Eom et al. 2016) and to the health-related effects of the bark extracts (Hordyjewska et al. 2019).

As seen from the previous examples, the polyphenolic compounds are the most important and abundant types of antioxidants in tree bark. Potential polyphenol uses are broad and include the production of natural food preservatives (Seeram – Heber 2007, Coté et al. 2011, Gyawali – Ibrahim 2014, Kobus-Cisowska et al. 2014), healthcare, and healthcare-related products (Packer et al. 1999, Dzialo et al. 2016, Watson et al. 2018), natural growth bioregulators (Popa et al. 2002, 2008, Vyvyan 2002), food and beverage products (Frydman et al. 2005, Sawalha et al. 2009), and silver nanoparticle production (Fahimirida et al. 2019, Ranzoszek-Soliwoda et al. 2019, Rolim et al. 2019). A recent global survey predicted a boom in the polyphenol market due to increasing demand and market size. An annual growth rate of 6.1% is expected (Ameer et al. 2017).

The present study aimed to provide a comparative antioxidant properties analysis of the bark of selected tree species: white poplar (*Populus alba* L.), black locust (*Robinia pseudoacacia* L.), sessile oak (*Quercus petraea* Liebl.), black poplar (*Populus nigra* L.), silver birch (*Betula pendula* Roth), European larch (*Larix decidua* Mill.), Scots pine (*Pinus sylvestris* L.), wild cherry (*Prunus avium* L.), European hornbeam (*Carpinus betulus* L.), and sweet chestnut (*Castanea sativa* Mill.). These important Hungarian industrial wood species either potentially yield large amounts of bark by-products or have not been investigated in detail to date. Although European beech is listed in the topmost section in *Table 1*, the species was not included in the present study as detailed investigations on the antioxidant and bioactive properties of beech bark extracts have recently been completed (Hofmann et al. 2015a,b, 2017, 2019, Tănase et al. 2018, Tanase et al. 2018, 2019, Coșarcă et al. 2019).

The primary functions of tree bark include assimilate storage and translocation as well as physical and physiological protection. Tree bark has two major parts: the inner and outer bark. The inner bark plays an important role in nutrient transport and storage as well as chemical protection, while the outer bark provides protection against mechanical impacts (e.g. chewing by wild animals, fire). As a whole, bark plays a crucial role in thermal insulation and water storage as well (Molnár 2004, Wagenführ–Scholz 2008). The present study investigated the inner and outer bark composition separately to provide detailed results on the antioxidant properties of each species studied. It must be noted, however, that in industrial practice, bark is usually collected as a whole without separating inner and outer parts.

The total polyphenol content (TPC) of the bark extracts was measured using the Folin-Ciocalteu assay, while the antioxidant capacity was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) and FRAP (ferric reducing ability of plasma) assays. Antioxidant capacity assays are varyingly selective to different types of compounds (Prior – Cao 1999). Therefore, the comprehensive measure of overall antioxidant properties for each sample was determined and compared by the combined evaluation of the results using a scoring system (Tálos-Nebehaj et al. 2017).

Using the scoring system, samples were ordered according to overall antioxidant power. The species/extracts with the best antioxidant parameters could be potential antioxidant sources for food, nutrition supplements, healthcare products, medical products, or other future applications.

## 2 MATERIALS AND METHODS

### 2.1 Chemicals and reagents

Double distilled water was prepared for the extractions using conventional distillation equipment. Methanol (HPLC grade) was obtained from VWR International (Budapest, Hungary). Quercetin, ascorbic acid, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (trolox), ABTS, potassium persulfate, DPPH, 2,4,6-tripyridyl-S-triazine (TPTZ), iron(III)-chloride, acetic acid, sodium acetate, hydrochloric acid, sulfuric acid, sodium carbonate, potassium hydrogen phosphate, and potassium dihydrogen phosphate were obtained from Sigma-Aldrich (Budapest, Hungary). Folin-Ciocalteu reagent was purchased from Merck (Darmstadt, Germany).

### 2.2 Bark material and extraction

Bark samples were collected from trees originating from the forests of the TAEG (Tanulmányi Erdőgazdaság) Forestry Company, Sopron (Hungary) during December 2015. As the specimens of each tree species were from the same plot, the climatic and other environmental effects were regarded as similar. The trees selected for sampling were mature and healthy, with a diameter at breast height of 30-50 cm. For each species, one representative tree was sampled immediately after felling. An axe was used to strip the bark from the trunk at heights between 1.5-3 meters. About 5 kg of bark material was collected from each tree. The bark samples were immediately taken to the laboratory and were dried for 2 days in the laboratory climate (18°C) in the dark. The inner bark was rasped from the whole bark pieces using a half round wood rasp (8 grain); the outer bark was also separated this way. With European hornbeam, the whole bark was investigated as the bark was too thin to be precisely separated into inner and outer parts. Bark powder in the amount of 0.15 g was extracted with 15 ml methanol:water 80:20 (v/v) solution using ultrasonication (Elma Transsonic T570 ultrasonic bath, Elma Schmidbauer GmbH, Singen, Germany) for 20 min at room temperature. The extracts were filtered using 0.45 µm cellulose-acetate syringe filters and were stored at -20 °C in amber glasses until analysis.

### 2.3 Spectrometric assays

All measurements were conducted in triplicate (the same extract three times) by using a U-1500 type spectrophotometer (Hitachi Ltd., Tokyo, Japan).

#### 2.3.1 Determination of the TPC

TPC determination was completed by applying the Folin-Ciocalteu assay (Singleton – Rossi 1965) using quercetin as the standard as follows: extract solution was mixed with 2.5 ml 10-fold diluted Folin-Ciocalteu reagent. After 1 min, 2 ml 0.7 M Na<sub>2</sub>CO<sub>3</sub> solution was added and the reaction mixture was heated for 5 min in a 50 °C water bath. Reaction was stopped by cooling to room temperature in a cold water bath. Solution absorbance was measured at 760 nm. The results were expressed as mg equivalents of quercetin/g dry bark units (mg QE/g d.w.).

### 2.3.2 Antioxidant assays

The ABTS assay was run based on the method of Stratil et al. (2007), using Trolox as standard and 10 min reaction time at 734 nm. The results were expressed as mg equivalents of Trolox/g dry bark units (mg TE/g d.w.). The FRAP assay was performed as described by Benzie – Strain (1996), using ascorbic acid as standard. Results were expressed as mg equivalents of ascorbic acid/g dry bark units (mg AAE/g d.w.). The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity of the extracts was determined using a slightly modified method of Sharma – Bhat (2009) as follows: methanol (2090  $\mu$ l), methanolic DPPH solution (900  $\mu$ l,  $2 \times 10^{-4}$  M) and 10  $\mu$ l of the extract were mixed. After incubation in the dark at room temperature for 30 min, the decrease in absorbance was measured at 515 nm. Results were calculated as  $IC_{50}$  (50% inhibition concentration) and expressed as  $\mu$ g extractives/ml assay ( $\mu$ g/ml) units, representing the amount of extractives that react with 50% of the added DPPH radicals in the total volume of the assay (3000  $\mu$ l) under the conditions used. The calculation was executed using equations 1 and 2 as follows:

$$I = \frac{100 \cdot (A_{DPPH} - A)}{A_{DPPH}} \quad (1)$$

$$DPPH (IC_{50}) = \frac{1000 \cdot E \cdot V}{3000} \cdot \frac{50}{I} \quad (2)$$

I: the rate of inhibition (%)

$A_{DPPH}$ : the initial absorbance of the reaction mixture

A: the absorbance of reaction mixture after the reaction

E: extractive content (mg/ml)

V: the volume of plant extract in the reaction mixture ( $\mu$ l)

3000: the final volume of the reaction mixture ( $\mu$ l).

### 2.4. Total extractives

The extracts (5 ml) were evaporated to dryness at 70°C in a laboratory oven and the remaining solids were weighed. The total extractive content was expressed as mg extractives/ml extract unit. Results were used to calculate the DPPH  $IC_{50}$  values.

### 2.5 Statistics

Analysis of variance (ANOVA) was performed using Statistica 11 (StatSoft Inc., Tulsa, USA) software, using Tukey's HSD test to compare the respective chemical parameters of the extracts. Prior to ANOVA, data was tested for normal distribution and the homogeneity of variances was checked using Bartlett's *Chi*-square test.

## 3 RESULTS AND DISCUSSION

### 3.1 Total amounts of polyphenolic compounds

Polyphenolic compounds are a major type of antioxidants, which are also found in large amounts in woody tissues (Popa et al. 2002, Molnár 2004, Vázquez et al., 2008, Wagenführ – Scholz 2008, Sathya – Siddhuraju 2012). First, the total amount of polyphenols was determined to see their contribution to tree bark tissue composition. TPC results are summarized in *Table 2*.

Table 2. The total polyphenol content (TPC) of inner and outer bark extracts

Species	TPC (mg QE/g d.w.)	
	Outer bark	Inner bark
European hornbeam*	25.2 ± 0.63 <sup>ab</sup>	25.2 ± 0.63 <sup>b</sup>
Black locust	29.4 ± 3.13 <sup>b</sup>	9.9 ± 0.05 <sup>a</sup>
Sessile oak	71.6 ± 1.20 <sup>d</sup>	46.2 ± 1.39 <sup>d</sup>
Wild cherry	70.0 ± 2.43 <sup>d</sup>	<b>139.0 ± 4.00<sup>h</sup></b>
Sweet chestnut	<b>89.0 ± 3.90<sup>e</sup></b>	61.4 ± 1.73 <sup>e</sup>
Black poplar	52.8 ± 2.83 <sup>c</sup>	36.3 ± 0.51 <sup>c</sup>
White poplar	49.2 ± 1.35 <sup>c</sup>	44.1 ± 1.71 <sup>d</sup>
Silver birch	57.3 ± 6.21 <sup>c</sup>	76.6 ± 0.54 <sup>f</sup>
European larch	<b>121.0 ± 4.11<sup>f</sup></b>	<b>106.9 ± 0.70<sup>g</sup></b>
Scots pine	16.4 ± 3.32 <sup>a</sup>	76.2 ± 3.15 <sup>f</sup>

Results were indicated in average ± standard deviation. Within a given column, the different superscript letters indicate a significant difference at  $p < 0.02$ . Bold values indicate the highest TPC values.

\* Whole bark was investigated as it could not be separated into inner and outer parts. The results for the inner and outer bark correspond here to the same (whole bark) sample.

In the distribution of polyphenolic compounds between inner and outer bark tissues, inner bark did not always possess a higher TPC than outer bark. Outer bark was found to be richer in polyphenolic compounds in black locust, sessile oak, sweet chestnut, black poplar, and European larch.

Outer bark sample comparisons revealed larch and sweet chestnut had the highest TPC. Earlier results, determined from the same extracts (Tálos-Nebehaj et al. 2018), indicated a high flavan-3-ol content in the outer bark tissues of European larch (20.0 mg (+)-catechin/g d.w.), and high flavonoid content (4.81 mg quercetin/g d.w.) was found in sweet chestnut. These compounds, together with other unmeasured compounds (e.g. hydrolyzable tannins in chestnut bark), may account for the high TPC in the mentioned tissues. The overall lowest TPC was determined in Scots pine, E. hornbeam, black poplar, and birch.

Wild cherry and European larch had the highest TPC levels in the inner bark while European hornbeam, and black locust had the lowest. The high TPC was accompanied by very high flavan-3-ol levels in both cherry (61.8 mg (+)-catechin/g d.w.) and larch (32.0 mg (+)-catechin/g d.w.) as determined by Tálos-Nebehaj et al. (2018) from the same extracts.

Comparing the inner bark of European beech (*Fagus sylvatica* L.), the TPC of the extracts gained with ultrasonic extraction and with methanol:water 80:20 v/v was 42.66 mg QE/g d.w., which is between the values of white poplar and sessile oak (Hofmann et al. 2015a,b).

Polyphenolic compounds are not the only compounds that influence the antioxidant power of bark tissues, especially in the inner bark where other types of reducing compounds can also be present in large amounts (e.g. sugars, organic acids, enzymes, etc.). These can influence the antioxidant power of the extracts significantly (Prior et al. 2005, Everette et al. 2010). This makes the application of other assays necessary, which are in turn also selective to various other types of compounds due to their specific working mechanism and reaction principle.

### 3.2 Antioxidant capacity

The DPPH, FRAP, and ABTS antioxidant capacity results of the outer bark samples are detailed in Table 3, while the respective results for inner bark are included in Table 4.

Table 3. The DPPH, FRAP, and ABTS antioxidant capacities of the outer bark extracts

Species	Outer bark		
	DPPH (IC <sub>50</sub> , µg/ml) <i>p</i> < 0.02	FRAP (mg AAE/g d.w.) <i>p</i> < 0.05	ABTS (mg TE/g d.w.) <i>p</i> < 0.01
European hornbeam*	6.2 ± 0.26 <sup>cd</sup>	30.1 ± 1.01 <sup>d</sup>	86.1 ± 0.81 <sup>ab</sup>
Black locust	5.1 ± 0.46 <sup>c</sup>	19.5 ± 0.86 <sup>b</sup>	103.3 ± 5.85 <sup>b</sup>
Sessile oak	<b>4.0 ± 0.10<sup>b</sup></b>	29.3 ± 0.76 <sup>d</sup>	86.5 ± 9.19 <sup>ab</sup>
Wild cherry	12.0 ± 0.32 <sup>ef</sup>	35.9 ± 0.89 <sup>e</sup>	207.7 ± 7.71 <sup>d</sup>
Sweet chestnut	<b>2.8 ± 0.11<sup>a</sup></b>	<b>82.8 ± 0.71<sup>g</sup></b>	<b>320.1 ± 5.73<sup>e</sup></b>
Black poplar	30.2 ± 2.89 <sup>g</sup>	18.3 ± 0.62 <sup>b</sup>	154.7 ± 10.75 <sup>c</sup>
White poplar	6.9 ± 0.60 <sup>d</sup>	38.1 ± 1.38 <sup>e</sup>	153.9 ± 2.53 <sup>c</sup>
Silver birch	12.8 ± 0.06 <sup>f</sup>	23.4 ± 0.30 <sup>c</sup>	205.2 ± 17.13 <sup>d</sup>
European larch	5.8 ± 0.16 <sup>cd</sup>	<b>51.4 ± 2.06<sup>f</sup></b>	<b>371.5 ± 18.53<sup>f</sup></b>
Scots pine	11.2 ± 0.61 <sup>e</sup>	10.9 ± 0.62 <sup>a</sup>	61.7 ± 4.37 <sup>a</sup>

Results are expressed as average ± standard deviation. Within a given column, the different superscript letters indicate a significant difference at the given significance level. Bold numbers highlight the best antioxidant values within a method.

\* Whole bark was investigated as it could not be separated into inner and outer parts. The results for the inner and outer bark correspond here to the same (whole bark) sample.

Comparing the *outer bark samples*, the best DPPH antioxidant activities (lowest IC<sub>50</sub> value) were measured for sweet chestnut and sessile oak, while black poplar obtained the poorest result. The difference between white poplar (6.88 ± 0.60 µg/ml) and black polar (30.2 ± 2.89 µg/ml) was remarkable and requires further evaluation and interpretation. It was also noteworthy that wild cherry, showing one of the highest TPC (70.0 ± 2.43 mg QE/g d.w.), was characterized with only moderate DPPH IC<sub>50</sub> (12.0 ± 0.32 µg/ml), while in the case of black locust, the low TPC (29.4 ± 3.13 mg Q/g d.w.) was accompanied by a fairly good DPPH antioxidant power (5.11 ± 0.46 µg/ml). The findings in these samples indicate two possibilities: it is not the polyphenolic compounds alone that determine the DPPH activity, or the DPPH reducing power of the polyphenols present in these samples is quite variable. The highest FRAP antioxidant power was present in sweet chestnut and larch; sessile oak showed only moderate FRAP activity; while the lowest activity was measured in black poplar, black locust, and Scots pine. When the DPPH and FRAP assays results were compared, a slightly different order was found, which was explained by the different selectivity and reaction mechanism of the two assays. The ABTS assay results were similar to the FRAP assay results, indicating similar selectivity: highest ABTS power was found for larch and sweet chestnut, while pine and hornbeam extracts demonstrated the lowest ABTS activity.

In *inner bark extracts*, cherry, sessile oak and sweet chestnut showed the best DPPH activity, while black locust and black polar produced the poorest results. Interestingly, the sessile oak sample showed one of the best DPPH radical scavenging activities (4.56 ± 0.13 µg/ml) even though it had only a medium TPC (46.2 ± 1.39 mg QE/g d.w.). Cherry, sweet chestnut, and larch inner bark extracts exhibited the highest FRAP, while black poplar the lowest overall FRAP. With the ABTS method, cherry showed an outstandingly high antioxidant capacity (533.3 ± 11.2 mg TE/g d.w.), which was almost double that of sweet chestnut (264.7 ± 13.9 mg TE/g d.w.). Larch and birch were also found to have excellent ABTS power, while black poplar, black locust, and hornbeam displayed the lowest values.

In scientific literature, researchers use various standard compounds for determining antioxidant capacity, and they can also indicate results in various differing units, which makes study comparisons quite difficult. Moreover, investigating inner and outer tree bark tissue

separately is quite common. Respecting these facts, the following, selected results found in the literature are presented and compared with the results of the present article. The examples are limited to those that are comparable in terms of standards and units of measurements.

Table 4. The DPPH, FRAP, and ABTS antioxidant capacities of the inner bark extracts

Species	Inner bark		
	DPPH (IC <sub>50</sub> , µg/ml) <i>p</i> < 0.05	FRAP (mg AAE/ g d.w.) <i>p</i> < 0.03	ABTS (mg TE/g d.w.) <i>p</i> < 0.05
European hornbeam*	6.2 ± 0.26 <sup>b</sup>	30.1 ± 1.01 <sup>b</sup>	86.1 ± 0.81 <sup>a</sup>
Black locust	13.3 ± 1.88 <sup>f</sup>	13.6 ± 0.12 <sup>a</sup>	63.7 ± 2.72 <sup>a</sup>
Sessile oak	<b>4.6 ± 0.13<sup>a</sup></b>	44.5 ± 0.12 <sup>c</sup>	138.4 ± 7.91 <sup>b</sup>
Wild cherry	<b>4.7 ± 0.05<sup>a</sup></b>	<b>80.1 ± 3.98<sup>f</sup></b>	<b>533.3 ± 11.20<sup>g</sup></b>
Sweet chestnut	<b>4.8 ± 0.17<sup>a</sup></b>	<b>70.9 ± 3.47<sup>e</sup></b>	264.7 ± 13.91 <sup>d</sup>
Black poplar	44.0 ± 2.41 <sup>g</sup>	17.6 ± 0.27 <sup>a</sup>	94.7 ± 4.48 <sup>a</sup>
White poplar	8.8 ± 0.27 <sup>c</sup>	34.6 ± 0.40 <sup>b</sup>	143.2 ± 4.31 <sup>b</sup>
Silver birch	6.6 ± 0.22 <sup>bc</sup>	32.9 ± 2.23 <sup>b</sup>	<b>300.4 ± 10.53<sup>e</sup></b>
European larch	6.7 ± 0.04 <sup>c</sup>	<b>62.3 ± 3.58<sup>d</sup></b>	<b>345.6 ± 9.28<sup>f</sup></b>
Scots pine	7.2 ± 0.09 <sup>d</sup>	42.4 ± 2.66 <sup>c</sup>	219.0 ± 13.98 <sup>c</sup>

Results are expressed as average ± standard deviation. Within a given column, the different superscript letters indicate a significant difference at the given significance level. Bold numbers highlight the best antioxidant values within a method.

\* Whole bark was investigated as it could not be separated into inner and outer parts. The results for the inner and outer bark correspond here to the same (whole bark) sample.

Hofmann et al. (2015a,b) determined  $11.12 \pm 0.90$  µg/ml DPPH IC<sub>50</sub> value for the methanolic extracts of inner bark from European beech, while Gao et al. (2007) measured inner and outer bark for Lawson cypress (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) at 10.31 µg/ml and 19.87 µg/ml respectively. According to Noriega et al. (2015), the DPPH IC<sub>50</sub> value of the ethanolic bark extract of red cinchona (*Cinchona pubescens* (Vahl)) was 42.00 µg/ml, which is comparable with the respective result of black poplar inner bark ( $44.0 \pm 2.41$  µg/ml). The DPPH IC<sub>50</sub> values of the bark extracts of Swiss pine (*Pinus cembra* L.) (71,1 µg/ml, Apetrei et al. 2011) and Australian pine (*Casuarina equisetifolia* L.) (101,69 µg/ml, Zhang et al. 2010) are also poorer compared to the present study results.

According to the data of Hofmann et al. (2015b), the FRAP ( $36.42 \pm 0.67$  mg AAE/g d.w.) and ABTS ( $146.65 \pm 2.48$  mg TE/g d.w.) values of the extracts of European beech inner bark can be considered as average compared to the respective results of this article.

The above comparison indicates that the species investigated in this study had quite variable antioxidant capacities, with some showing excellent results when compared to the bark extracts of other species. However, it is also apparent from the data that DPPH, FRAP, and ABTS methods have different selectivities, which is reflected by difference sample order when comparing highest and lowest values. In order to simplify evaluation, a method that combines the results of different antioxidant assays is presented.

### 3.3 Combined evaluation of antioxidant assays

Researchers usually apply at least three different antioxidant capacity methods to assess the antioxidant properties of plant extracts as none of the currently applied methods are alone suitable to determine overall antioxidant capacity. This is because each assay is specific to certain types of antioxidants; thus none of the methods evaluate the overall antioxidant power of a plant extract. The different selectivity of each method makes the combined evaluation of

different assays necessary (Hofmann et al. 2017). This was achieved in the present work through the use of a scoring system combining DPPH, FRAP and ABTS antioxidant assay results. Although in a broader sense the TPC method is also considered an antioxidant assay due to its reaction mechanism (Everette et al. 2010), it was excluded from the scoring evaluation in this study.

This combined multi-assay evaluation was completed as follows: samples were ordered according their antioxidant capacity value within each assay; a score of 1 was assigned to the highest antioxidant capacity; and a score of 0 was given to the lowest antioxidant capacity sample. Opposite scoring was used for the DPPH values because the lowest  $IC_{50}$  value (score: 1) represented the highest, while the highest  $IC_{50}$  (score: 0) represented the weakest antioxidant power. Scores were assigned proportionally in the range [1:0] for samples with intermediate antioxidant capacity values. Finally, scores were summed for each inner and outer bark sample. The maximum score was 3 (when a sample had the highest antioxidant capacity with all of the 3 methods, for example as with the inner bark of wild cherry). *Table 5* includes the calculated scores of the samples, a sum of scores for each sample, and the overall sum for species.

*Table 5. Evaluation of the DPPH, FRAP, and ABTS antioxidant capacities of the inner and outer bark samples using the scoring system, sum of scores for each sample (species/tissue type), and the overall sum for species*

Species	Inner bark				Outer bark				Overall
	DPPH	FRAP	ABTS	Sum	DPPH	FRAP	ABTS	Sum	
Sweet chestnut	0.99	0.86	0.43	2.28	1.00	1.00	0.83	2.83	<b>5.12</b>
European larch	0.95	0.73	0.60	2.28	0.89	0.56	1.00	2.45	<b>4.73</b>
Wild cherry	1.00	1.00	1.00	3.00	0.66	0.35	0.47	1.48	<b>4.48</b>
Silver birch	0.95	0.29	0.50	1.74	0.60	0.17	0.46	1.24	<b>2.98</b>
Sessile oak	1.00	0.46	0.16	1.62	0.96	0.26	0.08	1.29	<b>2.92</b>
White poplar	0.89	0.32	0.17	1.38	0.85	0.37	0.30	1.52	<b>2.89</b>
European hornbeam*	0.96	0.25	0.05	1.25	0.88	0.27	0.08	1.22	<b>2.48</b>
Scots pine	0.93	0.43	0.33	1.70	0.69	0.00	0.00	0.69	<b>2.39</b>
Black locust	0.78	0.00	0.00	0.78	0.92	0.12	0.13	1.17	<b>1.95</b>
Black poplar	0.00	0.06	0.07	0.13	0.00	0.10	0.30	0.40	<b>0.53</b>

\* Whole bark was investigated as it could not be separated into inner and outer parts. The results for the inner and outer bark correspond here to the same (whole bark) sample.

According to *Table 5*, the best overall antioxidant capacity for the inner bark samples was found in wild cherry (3.00), sweet chestnut, and European larch (2.28), while for the outer bark extracts sweet chestnut (2.83) and European larch (2.45) showed outstanding scores. The inner bark of wild cherry had the best antioxidant power with all three applied assays.

Combining the results of the inner and outer bark sample (not considering here the size and ratio of bark tissues compared to each other within one species), the best performing samples overall were sweet chestnut > European larch > wild cherry. The species with the lowest activity were Scots pine > black locust > black poplar.

Further analysis on bark tissue composition is required to reveal which compounds or combination of compounds are responsible for the antioxidant effects in the samples with the best antioxidant properties.

## 4 CONCLUSIONS

The present article conducted a comparative investigation of bark tissue antioxidant capacities of major Hungarian forest trees, focusing on the composition of the inner and outer bark tissues separately. Results were combined and compared using a scoring system. The TPC levels did not always follow the values of the FRAP, DPPH, and ABTS assays. The different reaction mechanisms were a possible cause of this. According to the scores, inner bark showed higher scores compared to outer bark for most species; black poplar, black locust, white poplar, sweet chestnut, and European larch were the exceptions. The highest overall antioxidant capacities were determined in the inner bark of wild cherry and the outer bark of sweet chestnut. The species with the overall lowest scores were black locust and black poplar.

According to the results, the presented multi-assay based antioxidant capacity evaluation method was suitable for tracking complex antioxidant properties in wood bark, and can be also applied to other tissues such as cones or leaves. Samples with the best results need further evaluations to determine possible future uses.

**Acknowledgements:** This research was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences

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## Guide for Authors

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## Contents and Abstracts of the Bulletin of Forest Science

Bulletin of Forest Science (Erdészettudományi Közlemények) is a journal supported by the Hungarian Forest Research Institute and by the Faculty of Forestry of the University of Sopron. The papers are in Hungarian, with English summaries. The recent issue (Vol. 9, 2019) contains the following papers (with page numbers). The full papers can be found and downloaded in *pdf* format from the journal's webpage ([www.erdtudkoz.hu](http://www.erdtudkoz.hu)).

### Vol. 9, Nr. 1, 2019

Péter KOTTEK and Éva KIRÁLY:

#### **Climate change can be detected in the national forestry database...7–18**

**Abstract** – From 2006 to 2016 a noticeable change can be observed in the climatic classification of forest stands in the National Forestry Database (NFD). As the polygons of forest stands cannot be fully matched between the 2006 and 2016 state of the NFD, climate transitions were studied along a one hectare resolution sample grid. This sampling pattern allowed large scale comparison of climatic categories and the description of local changes occurred between the two periods (2006 state of NFD consists of field surveys between 1996 and 2005; 2016 state between 2005-2015 accordingly). The sample grid also facilitated the statistical evaluation. The results show that climate classification has changed in 5.4 percent of the forest area, and the distribution of climate categories in 2016 shows a statistically significant difference compared to the 2006 state. Accordingly, the concept of climate change is strongly supported by data of the official forest inventory. The speed of climate shifts may be considered fast and the direction is warning as changes are generally unfavourable. We also analysed the sampling grid nodes where the forest land use changed to another land use type between 2006 and 2016. We found that 44 percent of these sampling points were in the “forest steppe” climate category (the most arid one of the 4 possible classes). This shows that in forest stands under this climate category land use change is more likely to be undertaken. On the other hand the major part of newly afforested area is under “forest steppe” (37%) and “sessile oak – Turkey oak” (34%) climate which shows that new forests are planted under dry conditions.

Ferenc Péter ROZOVITS, Zsolt MAGYAR, Péter KOTTEK and Sándor BORDÁCS:

#### **Modeling pollen capacity of forest areas based on tree species and pollen data ...19–33**

**Abstract** – Model maps were constructed for estimating pollen capacity of Hungarian forests, based on meteorological pollen monitoring and forestry database information. Model maps are continuously updated and directly linked to the National Forest Database (NÉBIH

Forestry Directorate) which are publicly available at NÉBIH website (URL 4). Based on the model maps the flowering period of tree species can be forecasted in different region of Hungary. Data and information of the model maps can be used for annual seed crop prognoses and indirectly for planning of forest regenerations and silvicultural works. Model maps also provide an opportunity for more conscious planning of bee keeping and preparation of public health measures taken for pollen sensitivity.

Ágnes FÜRJES-MIKÓ, Sándor CSÖSZ and György CSÓKA:

**Role of red wood ants (*Formica rufa* group) in forest protection in Europe – a literature review ...35–50**

**Abstract** – Red wood ants are generalist predators. They prey on many insect groups, so may significantly influence their abundance. Species in *Formica rufa* group obtain their food mainly from tree canopies, so they can effectively reduce the herbivore pressure. European literature gives wide ranges for their food spectra. Based on investigations, almost half of their food consists of insects, including species considered “forest pests”. Honeydew of different Hemiptera species also plays an important role in their nutrition. The ant-aphid mutualistic relationship and its impacts on the health of trees and forests have been discussed for a long time. The ants may also have a positive effect on soil since their nest material contains concentrated minerals bound to organic materials. The trees near the nests can utilize these organic nutrients that can result in accelerated growth. In this paper we review the related Hungarian and European literature.

Szabolcs SZANYI, Attila MOLNÁR, Lajos KOZÁK, Tímea SZALÁRDI, Zoltán VARGA, Miklós TÓTH and Antal NAGY:

**Study on the Macroheterocera assemblages of the Nyírség (Northeast Hungary) using volatile traps...51–68**

**Abstract** – The unique biota of the Nyírség region is known mainly on basis of its flora, however, its fauna is poorly studied especially in case of insects, for the Lepidoptera fauna we have only more than 20-years old data collected by light traps. In 2014 and 2015 we carried out samplings with volatile traps near Debrecen-Nagycsere, in the southern part of the Nyírség. We attempted to compare comparing the efficiency and selectivity of phenylacetaldehyde based (FLORAL) and isoamyl-alcohol based (FERM) lures, and to collect faunistical data from the region. During the two-years long study we caught 226 Macroheterocera species belonging to 7 families. Considering the number of caught species the FERM bait was more effective and the different selectivity of the lures was also proven. We characterised the studied fauna on the basis of their composition and ratios of faunal types and faunal components.

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Tivadar BALTAZÁR, Ildikó VARGA and Miloš PEJCHAL:

**Investigation of relationship between dendrometric variables of infected host trees by European mistletoe (*Viscum album* L.) with dependence of infection intensity...69–85**

**Abstract** – The aim of our study was modeling the relationship between the tree height and diameter at breast height (DBH) with dependence of host taxa and mistletoe infection intensity. Ten woody species have been selected for this study from 5 genera (*Acer*,

*Crataegus*, *Juglans*, *Robinia* and *Tilia*) representing more than 3,000 individuals whereof about 1400 are already infected. The examined host taxa can be found in the castle park of Lednice in Czech Republic. The park is in the centers of the mistletoe distribution in this region. Logarithmic regression was chosen characterizing this relationship because these two dendrometric variables relatively accurately and simply. From the obtained result, it can be clearly established that as the infection intensity increases, the relationship between the height and DBH decreases proportionally. The difference was also statistically significant for several other host species. However, the exact modelling of this relationship is more complicated, because the negative effect of mistletoe may differ within host species too.

András SZABÓ, Zoltán GRIBOVSZKI, Bence BOLLA, Kitti BALOG, Péter CSÁFORDI and Tibor TÓTH:

**Effect of *Robinia pseudoacacia*, *Populus x. euramericana* and *Quercus robur* plantations on groundwater and iontransport at the northern Hungarian Plain...87–97**

**Abstract** – The role of forests in hydrological processes on the Great Hungarian Plain is still a subject of debate. Among the causes there are numerous and highly variable local factors taking part in the processes. This research investigated the impact of forests on groundwater levels and ion transport of the soil since 2012 on 108 study sites, using one-time soil sampling, forest stand measurements and groundwater monitoring. Results in general supported the assumptions of the hypothesis in correlation with groundwater depression and ionaccumulation under forest stands. Meanwhile the same results highlighted that different water-uptake strategies of different tree species and other local factors (topography, soil texture) highly influenced the processes. Consequently it is not correct to evaluate the impact of forest stands exclusively by their increased evapotranspiration. For this purpose complex approach is necessary in which groundwater monitoring and investigation of ion transport also could be used as useful instruments.

László BALI, Dániel ANDRÉSI, Róbert FERKA, Katalin TUBA and Csaba SZINETÁR:

**Pitfall trapping arachnological survey in the Szalafő Forest Reserve...99–112**

**Abstract** – During our research, we surveyed the ground-dwelling spider fauna of the Szalafő Forest Reserve (ER-53, Hungary) by pitfall trapping. The research was conducted in 2014 from April to October. We collected data from three different habitats: mixed deciduous stand, mixed deciduous stand with Scots pine (both in the core area), and mixed Norway spruce stand in the protective zone. Our goals were to assess the ground-dwelling spider assemblages of the habitats, compare their spider fauna regarding species composition, diversity indices and guild structures. We determined that the two deciduous forest patch had the most similar ground-dwelling spider assemblages, while the communities of the spruce stands were somewhat different.

Zoltán BÖRCSÖK, Péter ADAMIK and Zoltán PÁSZTORY:

**Review of the possibilities of bark utilization...113–138**

**Abstract** – Approximately 300-400 million cubic meters of bark are produced each year during wood processing. Most of this, however, remains unused or burned. The structure and composition of the bark are special, and differs from the wood, which features a number of utilization possibilities. Agriculture, power engineering, medicine, woodpanel industry, insulation and chemical industry can successfully use and utilise the bark of different trees.

This study provides an overview of the structure, properties, and utilization potential of the bark.

Péter PRIMUSZ, Péter KALICZ, Balázs KISFALUDI and József PÉTERFALVI:

**Determining the bearing capacity of lime-treated soils by the CBR method...139–157**

**Abstract** – In this research a set of tests were performed to determine the effect of lime addition and water content on the bearing capacity of cohesive soils. The bearing capacity was measured by the CBR method. Four types of soils were included in the research. Soil samples were prepared from each type by 6 different water content, 4 dosage of lime addition and 3 duration of curing time. It was found, that each soil is suitable for the construction of lime-stabilized pavement layers. As a result of the lime treatment the bearing capacity of each soil was increased. Repeated CBR tests were performed on the treated and untreated soil samples after 4 days of soaking. It was confirmed that the water-sensibility of the treated soils decreased significantly. A regression tree model was applied to create practice-oriented rules for predicting the bearing capacity. Our results support the idea that the bearing capacity of lime-stabilized soil layers can be counted in the total bearing capacity of forestry and agricultural road's pavement.



