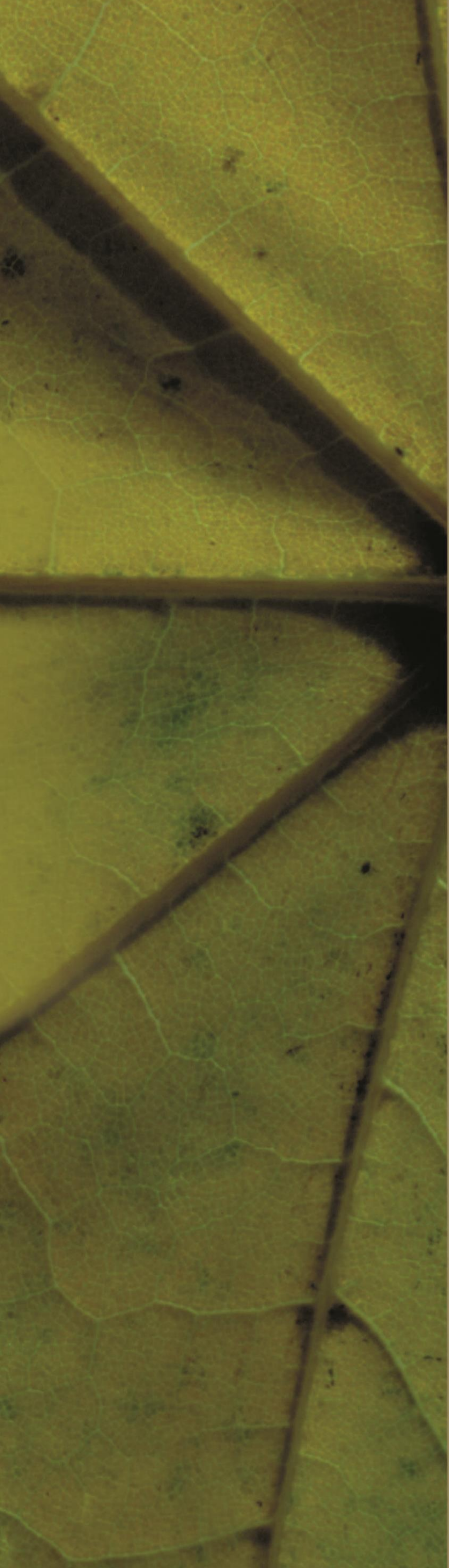

Acta Silvatica & Lignaria Hungarica

An International Journal in Forest, Wood and Environmental Sciences

Volume 13, Nr. 1

2017

ACTA SILVATICA
&
LIGNARIA
HUNGARICA

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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).

HU ISSN 1786-691X (Print)
HU ISSN 1787-064X (Online)

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E-mail: aslh@nyme.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 De Gruyter Open Sp. z. o. o., Warsaw

Published by UNIVERSITY OF SOPRON PRESS,
BAJCSY-ZS. U. 4., H-9400 SOPRON, HUNGARY
Cover design by ANDREA KLAUSZ
Printed by LŐVÉR-PRINT KFT., SOPRON

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ACTA SILVATICA ET LIGNARIA HUNGARICA

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Tartalomjegyzék

Economic Assessment of European Beech and Turkey Oak Stands with Close-to-Nature Forest Management

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Abstract – The paper analyses the complex economic models of continuous cover forestry based on the 'Dauerwald' principles in the early transformation period and in the traditional rotation system both in European beech (*Fagus sylvatica* L.) and Turkey oak (*Quercus cerris* L.) stands in central Hungarian study sites. The analysis was carried out on both the stand and estate-levels, and the performances were compared as well. We found that continuous cover forest management (CCF) can achieve at least the same economic efficiency as traditional rotation forest management (RF) in both beech and in Turkey oak stands. The regeneration problems occurring in poor quality sites in Turkey oak stands made visible the economic differences between the two management systems investigated.

European beech / Turkey oak / continuous cover forest management / rotation forest management / annuity

Kivonat – Természetközeli erdőgazdálkodás ökonómiai értékelése bükk és cser állományokban. A tanulmány bemutatja az örökerdő elvek szerint folyamatos borítást biztosító erdőgazdálkodással kezelt bükkösök (*Fagus sylvatica* L.) és cseresek (*Quercus cerris* L.) kezdeti átvezetési időszakának adataiból, és a hagyományos vágásos erdőgazdálkodás adataiból felállított komplex ökonómiai modellek elemzését a Közép-Magyarországon található vizsgálati területeken. Az elemzés erdőrészlet és erdőtömb (üzemi) szinten hasonlítja össze a gazdasági teljesítményeket. Megállapítható, hogy a bükkösökben és a cseresekben örökerdő-gazdálkodás mindkét szinten legalább olyan ökonómiai teljesítményre képes, mint a hagyományos vágásos üzemmód. A gyenge termőhelyű cseresekben jelentkező felújítási problémák rövid idő alatt láthatóvá tették a két gazdálkodási rendszer közötti ökonómiai különbségeket.

bükk / cser / örökerdő-gazdálkodás / vágásos erdőgazdálkodás / annuitás

1 INTRODUCTION

A topical question in contemporary forestry is the comparison of the continuous cover forest management system (CCF) (Pommerening – Murphy 2004, Knoke 2012) and traditional rotation forest management (RF) methods. From an economic point of view, the most important advantages of CCF (the English translation of 'Dauerwaldwirtschaft') are the stability of uneven-aged forests and evenly distributed logging, which has a positive effect on

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profitability and is also able to mitigate the fluctuation of wood prices (Knoke 2010, 2012). Based on the research of Knoke (2010) carried out in twelve European (German-speaking) regions as a comparative analysis, 'Dauerwald' forest management methods never showed a disadvantage; when comparing 'Dauerwald' forest management in English-speaking areas, a disadvantage was found only three times out of twelve sites.

As was the case in the rest of Europe, many professionals in Hungary turned their attention to this topic at the end of the nineteenth century and in the twentieth century; however, Hungarian professionals did so in theory rather than in practice. Objections and resistance to CCF, which has been considered inferior to RF mainly for economic reasons, have lingered until now (Knoke 2012).

Hungarian silviculturists (Jablánczy 1953, Roth 1958, Majer 1986) showed great concern about the 'Dauerwald' idea in the 1950s and early 1960s. Therefore, a selective cutting experiment was initiated in 1954 on 22.98 ha of the Visegrád 77A subcompartment (Madas 1956). Today, Pilis Park Forestry Company (PPF) manages this site. It is one of the few forerunners of CCF in Hungary mentioned by Roth (1958) and Majer (1986), in addition to the selection forest managed by Roth in Sopron (Koloszár 2013). However, the development wound down by the late 1960s, and there was no further progress until the 1990s.

Criticism over the use of traditional RF methods increased in the 1990s among nature conservationists and the Hungarian public alike. To address this criticism, some private forest owners, state forestry companies, and the PPF especially, began to revive CCF approaches.

According to official statistics (NÉBIH 2016), the total forested area in Hungary is 1,940,700 hectares, of which 55% belongs to the state, 1% to local communities, and 44% to private owners. The PPF is one of the twenty-two state-owned companies that manage state forests. The PPF manages 58,051 hectares of state forests in the Pilis, Visegrád, Gerecse, and Buda Mountains, Gödöllő Hills, on the Danube islands of Szentendre and Csepel, and on the Csepel Plain. These forests represent an invaluable resource for Hungary's capital city Budapest as well as the surrounding urban areas as they provide recreational possibilities and facilities to millions of visitors. The proportion of protected areas (including Natura 2000) is 74%, which is among the highest in Hungary.

The first step of resuming CCF was the establishment of an exemplary area based on Pro Silva principles. This came to be in 1999 in the subcompartment of Pilisszentlélek 25A, a 9.74 ha mixed beech stand. The company level introduction of CCF began in 2002 when the most suitable areas – mainly beech forests – were gradually marked out (Csépányi 2012, Csépányi 2016). PPF's vision regarding the introduction of CCF is to make it large scale enough to help integrate higher-level nature conservation (Boncica 2011) and public welfare aspects into forestry practices as these are important to the community.

This paper deals with the economic valuation derived from the already gathered practical experience of CCF introduced on a company level in European beech (*Fagus silvatica* L.) and Turkey oak (*Quercus cerris* L.) stands managed by PPF. The CCF management at PPF is based on the so-called 'Dauerwald' concept defined by Möller (1922) (Troup 1927, Thomasius 1996, Helliwell 1997) and on the principles of Pro Silva (1996, 2012).

The most important criteria of CCF are:

- Avoidance of clear cuts or final cuts and a rotation age. Felling of single trees, tree groups, or trees standing in gaps is done due to their individual maturity. There is no regular, traditional felling area. However, groups or gaps can be made according to the light demand of given species. Uneven-aged mixed forests provide protection for the soil and sustain maximal productiveness with continuous forest cover.
- The basis of regulation in a given subcompartment is the actual increment determined periodically as well as the relation between the optimal and actual living stock (control method).

- Single trees or groups have to be harvested at the peak of their value; well performing ones have to be kept and poorly performing ones can be felled.
- Regeneration is a secondary aspect; it appears spontaneously. However, it has to have high density and good quality to complement the trees and tree groups harvested from the area.
- The consideration of biological aspects, dead wood, and biodiversity during forest management practices.

The subject of our research was a model-based economic analysis and comparison of forests managed with the RF and CCF systems. Beech forests cover the company's good sites where the CCF system has been easier to implement after it was successfully introduced in 2002. In the poor sites where Turkey oak stands dominate, mainly on the sandy soils of the Gödöllő Hills, the common cockchafer (*Melolontha melolontha* L.), the forest cockchafer (*Melolontha hippocastani* F.), and periodic drought inflicted severe damage on the regeneration. This damage made RF methods very expensive. The possibility of introducing CCF in these sites, considering that light-demanding tree species are dominant, has not been generally admitted among professionals. Therefore, it was particularly interesting to compare the CCF and RF systems to investigate what kind of effects can be observed both at better and at poorer sites. At the international level, studies comparing CFF and RF systems in beech or in silver fir-Norway spruce-European beech mixed stands exist; however, assessments of this kind in Turkey oak stands are rare.

2 MATERIALS AND METHODS

2.1 Study sites

The 58,051 hectares state forest managed by PPF *(Figure 1)* includes 32% oak (*Quercus petraea* Liebl., *Quercus robur* L., *Quercus pubescens* Willd.), 25% Turkey oak, 6% beech, 7% hornbeam (*Carpinus betulus* L.), 10% black locust (*Robinia pseudoacacia* L.), 3% ash (*Fraxinus excelsior* L., *Fraxinus ornus* L., *Fraxinus angustifolia* Vahl. *subsp. pannonica* Soó et Simon), 9% other hardwoods, poplar 2%, conifers 6%). Due to the consequent process of introducing CCF in 2002, the forest areas managed with different systems at the end of 2016 were as follows: 7,157 ha were CCF system, 7,175 ha were transitional management system (transition from RF to CCF), 36,149 ha were RF, and 7,570 ha were non-timber production forests.

The assessment area in 2nd yield class beech stands between CCF and RF systems was at the Pilisszentkereszt Forestry Unit and the Pilismarót Forestry Unit of PPF in the Pilis and Visegrád Mountains, 300-700 m above sea level. Its climate is moderate with a mean annual temperature between 9.3-9.7 C°, and an annual precipitation of 600 mm. The 44 subcompartments were situated in the administrative area of settlements Pilisszentkereszt, Pilisszentlélek, Pilismarót, and Dömös; the total area was 359.8 ha. The RF system was investigated in a total area of 183.5 ha according to the management plans of Pilismarót Forestry Unit 1981-2011 (in subcompartments: Dömös 5B, 6A, 26E, 29A, 30C, 39C; Pilismarót 54 B, 55C, 57A, 61B, 63D,F, 124A, 125B, 126A,B,C,D, 128A, 129B, 134A, 136A, 139A, 140A). The CCF system was assessed in a total area of 176.3 ha according to the management plan of Pilisszentkereszt Forestry Unit 2002-2011 (in subcompartments: Pilisszentkereszt 3A, 4B, 6C, 8B, 9A, 11A, 14A,C, 15A, 16A, 29B, 30C; Pilisszentlélek 16B, 23A, 24A,B, 26A, 27A, 28A,B).

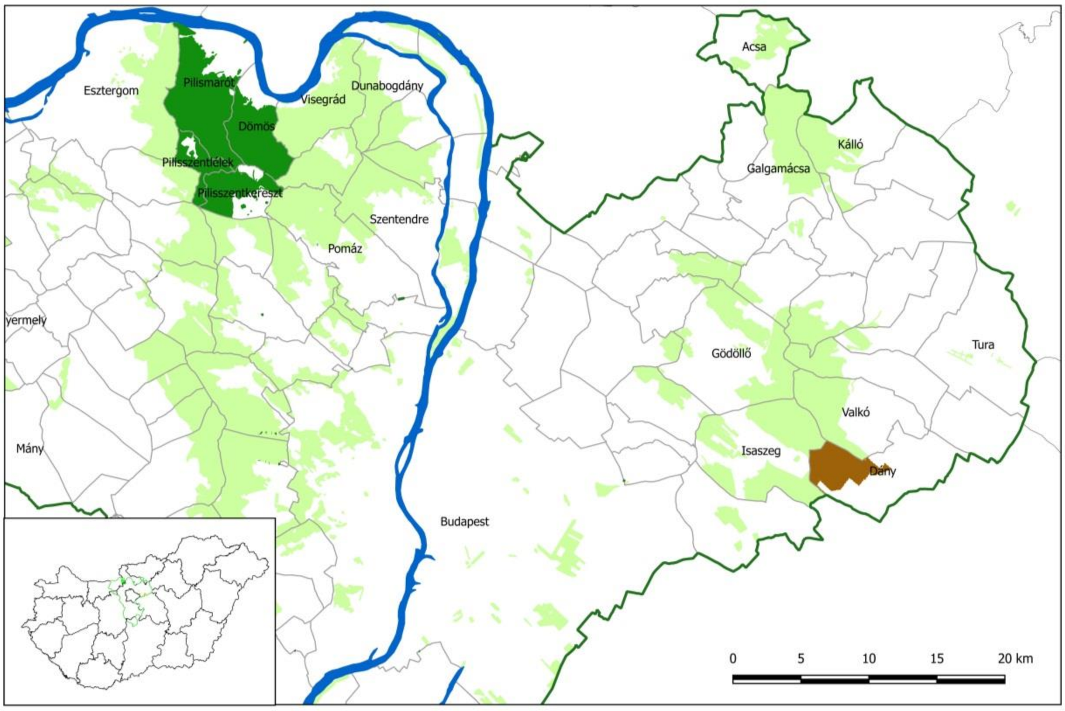

Figure 1. Location of assessment area by Pilis Park Forestry Company in Hungary. (The green line is the border of the company; the pale green areas: state forest managed by PPF; the dark green area is the administrative area of the Pilismarót, Dömös, Pilisszentlélek, Pilisszentkereszt settlements: beech assessment, the brown area marks the administrative area of Dány settlement: Turkey oak assessment)

The assessment area in 4th yield class Turkey oak stands between CCF and RF systems was situated at the Valkó Forestry Unit in the Gödöllő Hills, 150-250 m above sea level. The annual mean temperature here is 10.2 °C and the annual precipitation is 540 mm. Severe heat and drought occur here annually in July and August; artificially planted seedlings are often scorched at this time. The six subcompartments were in the administrative area of the Dány settlement and the total area was 43.4 ha. The RF system in the clearcutting with artificial regeneration in the Dány 25B, 40A, 40C subcompartments has an assessment area of 15.1 ha. The RF system in regeneration cutting with natural regeneration has an assessment area of 16.3 ha in the Dány 11C, 44E subcompartments, and the CCF system has a 12.0 ha area in the Dány 28A subcompartment. The subcompartment data originate from the management plan of Valkó Forestry Unit 1990-2011.

2.2 Methods of economic analysis

To carry out the economic analysis, the method of complex economic models (Márkus and Mészáros 2000, Marosi 2005, Marosi and Juhász 2011) was applied using the management data of PPF. The data of exploited gross volume by the different cutting methods and by subcompartments were collected from the registering part of management plans.

During the establishment of the RF model in the case of beech stands, 2nd yield class beech forests at the Pilismarót Forestry Unit between the ages of 24 and 123 years (183.5ha) that have an approximately similar mixture were used.

The empirical model of CCF was created from the data collected in the management plan period of 2002-2011 at the Pilisszentkereszt Forestry Unit. In this system, the last ten years of interventions were examined in beech stands in the 2nd yield class in a similar area (176.3 ha);

their ages were between 49 and 109 years. The cutting method was a combination of single tree and group selection.

Contrary to the calculation made in beech forests (Schiberna et al. 2012, Csépányi 2013), in the case of Turkey oak stands (Csépányi - Csór 2014) the comparison was simplified and only deals with the examination of the different methods of RF and CCF beyond middle age and regenerations including the first cleaning. This way the data of the further cleanings and thinnings in young and middle-aged stands are lacking and can be viewed as the same respectively. Subcompartments (43.4 ha) that were situated close to each other where the process of regeneration had already begun were examined. Due to the negligible distance, the site conditions and yield classes were equal (4^{th} yield class). The development phase of regenerations was not the same; thus, the cost analysis is based on the data originating from the six subcompartments with different development levels. In this way, practical models were assembled from the given subcompartments. The area within the Valkó Forestry Unit (Dány settlement) suffers especially from regeneration problems because of the damage to seedling roots caused by the grubs of the cockchafer species or the climatic and soil condition issues mentioned above. The stands mostly contain Turkey oak, but they also have a few per cent of other oak species.

Basic data gathered for the analysis are as follows: exploited volumes are taken from the registering part of the management plan, while net prices and costs are taken from the financial accounts of the PPF. The data collected from the management plans and the accounting system were uploaded on Microsoft Excel worksheets and the calculations were carried out by means of the software.

The economic evaluation is done on two levels: firstly on the stand-level, which can be important for smallholding forest owners, and secondly on the estate or enterprise-level (Schiberna et al. 2012) in order to have sufficient areas to represent the conclusions derived from the calculations.

2.2.1 Stand-level analysis

To be able to process the data at the stand-level, the method of determining equal annual cash flows is used for analysis; based on earlier professional literature, this is known more commonly as annuity (Schiberna et al. 2012, Márkus and Mészáros 2000), which is a series of equal cash flows over a fixed period time (rotation period, return cycle of single tree or group selection). If this time limit is infinite, we get to the definition of perpetuity. By comparing the annuity of different management systems the economic performance of the two management types can be compared on a stand-level.

Periodic annuity of RF system:

$$PA_{RF} = \sum_{t=1}^{f} CF_t (1+r)^{f-t} \tag{1}$$

where:

PA_{RF}: Periodic annuity of the RF system at the end of the rotation
CF_t: net cash flow of the tth year, balance of the incomes and expenses during management processes (logging, regeneration, silviculture)
f: harvesting age
t: year of forest management interventions
r: interest rate

Annuity of forests managed with the RF system:

$$A_{RF} = PA_{RF} \frac{r}{(1+r)^f - 1} \tag{2}$$

where:

A_{RF}: annuity with the RF system
PA_{RF}: Periodic annuity of the RF system at the end of the rotation
f: harvesting age
r: interest rate

Annuity of forests managed with the CCF

$$A_{CCF} = CF_c \frac{r}{(1+r)^c - 1} \tag{3}$$

where:

A_{CCF}: annuity in the given cycle of CCF
CF_c: net cash flow of the c^{th} year, balance of the incomes and expenses during management processes (logging, regeneration, silviculture)
c: cycle, return period of CCF felling interventions
r: interest rate

2.2.2 Estate-level analysis

The comparison of forest estates on a large-scale is also done by defining annuity. In this case – assuming regular conditions – the annual revenues equalize, and interest plays no role in the calculations. The forest estates in the RF system are considered as a fully regulated 'normal forest'.

Annuity of the management system in the case of a regular forest estate

$$A_E = \sum_{i=1}^{m} CF_i \tag{4}$$

where:

A_E: annuity of the forest estate
CF_i: net cash flow of the i^{th} age class, balance of the incomes and expenses during management processes (logging, regeneration, silviculture)
i: number of the given age-class
m: number of all age-classes

3 RESULTS AND DISCUSSION

Basic data in the tables were gathered for complex economic models, and results were provided by the processing methods mentioned above.

3.1 Beech stands RF system – regeneration cutting with natural regeneration

For a beech stand in the RF system (*Table 1, Table 2*), the average gross yield per hectare can be calculated on 786 m^3 and the average net yield can be calculated on 698 m^3 with a 120 year old harvesting age. Each ten-year age class had enough area. Depending on the age, subcompartments from 2011 dating back thirty years were examined (1981–2011).

Data about the date of interventions were sorted as follows: the age of the stand at the intervention, cutting methods, and logged gross timber volumes. With the help of these data, an empirical model could be set up. The cutting method in these beech stands is gradual regeneration cutting with a rotation of 120 years where the initial intervention is mostly done by a uniform shelterwood cutting and later interventions are mainly done in a group pattern or combined. The data about timber assortment structure were taken from the period between 2005 and 2011 net selling prices, and net costs were taken from the last two years (2010, 2011). Sales data are collected only from the prices of beech products; therefore, the incidentally present differences in species composition do not disturb evaluation. Forest regeneration expenses were calculated using the 2011 costs based on the regeneration practices used in the Pilismarót Forestry Unit.

Table 1. The empirical natural model of the RF system in beech stands without regeneration (1ha)

Age classes	yr	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120
Management methods	–	Cleaning	Cleaning	Cleaning/ Thinning	Thinning	Thinning	Thinning	Thinning	Thinning / Regeneration cut	Regeneration cut	Regeneration cut	Final cut
Timber yield	(Gross m^3/ha)	2.1	6.1	31.3	40.8	29.4	36.7	104.7	37.9	72.7	73.5	351.1
	(Net %)	69%	69%	69%	69%	83%	83%	88%	93%	93%	93%	93%
	(Net m^3/ha)	1.5	4.2	21.6	28.2	24.3	30.4	91.8	35.1	67.3	68.1	325.1
Specific revenues	(HUF / net m^3)	10,400	10,400	12,400	12,400	13,360	13,360	13,360	15,070	15,070	15,070	15,070

The following complex model (*Table 2*) could be set up for the thirty years preceding 2011 in the beech stands of the RF system.

A benefit of the RF system is that later harvesting damage to regeneration does not need to be dealt with. Nonetheless, the lack of shade from older generations creates a constant need for nursing and other interventions to control mixture rates and stem number.

Table 2. The empirical economic model in beech stands (2nd yield class) managed by the RF system, cash flow and annuity (r=0.02)

Intervention	Age	Yield	Unit prices, fees		Cash flows				Annuity
			Price	Logging fee	Income	Logging cost	Regeneration cost	Balance	
	(yr)	(m^3/ha)	(HUF/m^3)		(HUF/ha)				(HUF /ha/yr)
Cleaning	20	2	10,400	0	20,800	0	26 000	–5,200	–77
Cleaning	30	4	10,400	0	41,600	0	24 000	17,600	214
Thinning	40	22	12,400	3,600	272,800	79,200	0	193,600	1,933
Thinning	50	28	12,400	3,600	347,200	100,800	0	246,400	2,018
Thinning	60	25	13,360	3,500	334,000	87,500	0	246,500	1,656
Thinning	70	30	13,360	3,500	400,800	105,000	0	295,800	1,631
Thinning	80	92	13,360	3,500	1,229,120	322,000	0	907,120	4,102
Thinning/ Regeneration cut	90	35	15,070	3,400	527,450	119,000	0	408,450	1,515
Regeneration cut	100	67	15,070	3,400	1,009,690	227,800	0	781,890	2,380
Regeneration cut	110	68	15,070	3,400	1,024,760	231 200	0	793,560	1,981
Final cut	120	325	15,070	3,400	4,897,750	1,105,000	270,000	3,522,750	7,215
Total 120 years	–	698	14,478	3,406	10,105,970	2,377,500	320,000	7,408,470	24,569

3.2 Beech stands the CCF system

In the CCF system (*Table 3*), based on the facts of the ten-year period, a 744 net m^3 volume was calculated for a 120-year period. The data of gross timber volume harvested in the ten-year period were collected. In this period, the total yield in the assessment area was 13,435 gross m^3, 76 gross m^3, 62 net m^3 per hectare. The return cycle of logging interventions was five years with 31 net m^3 per hectare. The method of determining assortment structure, prices, and costs was the same as for the traditional RF system.

Table 3. The empirical economic model in beech stands (2nd5 yield class) managed by the CCF system, cash flow and annuity (r=0.02)

Intervention	Cycle	Yield	Unit prices, fees		Cash flows				Annuity
			Price	Logging fee	Income	Logging cost	Regeneration cost	Balance	
	(yr)	(m^3/ha)	(HUF/m^3)		(HUF/ha)				(HUF/ha/yr)
Selection cut	5	31	14,350	3,400	444,850	105,400	2,500	336,950	
Total 120 years	–	744	–	–	10,676,400	2,529,600	60,000	8,086,800	64,748

According to the results, the income in beech CCF forests kept up with the forests managed in the RF system. In the long term, the expected income can increase for CCF because single-tree or group selection concentrates on obtaining the highest value of each stem (Knoke 2010, 2012). The income counts as a good performance since in the early stage of CCF the removal of stems with lower performance dominated. In the next 20-40 years, quality loss in the mother stand will not be a consideration (Tarp et al. 2000). This is confirmed by the fact that the specific income of the subcompartment Visegrád 77A, consisting of an uneven-aged stand (24-159 year old trees mainly in the 3rd yield class), was

14,285 HUF/m^3 in 2012. It is worth starting the establishment of CCF prudently in time. When CCF starts in 50-70 year old forests, the quality loss of the mother stand will not have a significant impact on the average income for the next 70 years (Tarp et al. 2000). Thinner stems of good quality are usually present on a greater scale in the main and lower layers at CCF, which grow valuable yield faster after removing thicker trees that have already reached their highest value. A possible explanation for this is that leaving thicker stems in the RF system is more observable due to bigger seed producing crowns and the prevention of felling damage (Froehlich 2011), which makes the exploitation of maximal value of individual stems more difficult. Another consideration in the RF system is the lack of thicker timber in young and medium age classes, which has a negative impact on income. However, based on practical experience, it is notable that the timber volume of felled trees bigger than 50 cm DBH in beech stands managed by CCF exceeds 50% of the total timber volume logged (Wobst 2006).

The logging costs for CCF did not exceed the usual costs for traditional RF (*Table 2*). The logged timber volume per hectare during the interventions is similar to a thinning volume; but the average thickness of the timber is significant. Evaluation of harvesting cost by RF systems is deceptive as the specific costs of final or clearcutting were commonly taken into consideration without considering the higher logging costs of cleanings and thinnings (Price – Price 2008). At the establishment of uneven-aged forests, logging requires greater preparation; this incurs a cost increasing effect. However, the question is how the positive effect of thick average stems can balance this out. Forest accessibility was good in the examined areas; during logging works we supplemented the already established forest roads with permanent extraction lines every 40-50 meters. During logging, the trees are felled onto or towards the lines. After debranching and chopping, the winching of further stems is done first. This makes the work of forwarders easier and more effective as they do not have to search for the timber and just work on the previously marked extraction lines.

There were no regeneration or cleaning costs in beech CCF forests during the examined period; nevertheless, a high abundance of good quality beech regeneration became established, so a significant part of the area is covered with regrowth of various density of 30-50 thousand pcs/ha and often 5-6 meter high mixed young beech groups of good quality. The explanation for this is the natural regeneration occurring during biological rationalization (Turckheim 2006, Schütz 2011, Froehlich 2011) and later the natural selection and decrease in stem numbers due to the shading of higher layers. However, the regeneration cost shown in Table 3 serves as a financial security for unforeseen cases such as securing the quality of regrowth, for example.

3.3 Turkey oak stands in RF system – clearcutting with artificial regeneration

In the case of Turkey oak clearcutting (*Table 4* and *Table 5*), the regeneration was intended to start naturally, but the seedlings completely perished because of cockchafer grub damage. Therefore, a total soil preparation was done and artificial regeneration was initiated. The soil was sterilized with pesticide concurrently with a deep ploughing. A further goal of the total soil preparation was to improve the hydrology of the dry sand. Primary planting was done with one-year-old Turkey oak seedlings mixed with sessile oak and small-leaved linden. On top of this, grey poplar (*Populus x canescens* Sm.) was planted as a shading layer because practice showed that grub damage ends after the closure of the regeneration. Due to the faster growth rate of grey poplar and interrow discing, the shading layer became established in the second year, which prevents the sand from heating up lessening the damage of heat demanding grubs. Soil sterilization was done in a part of the area in the fourth year; during the replacement of grub damaged seedlings, pesticide was applied to the root zone. Root development of the rapid growing poplars is more intensive as well, so they can provide an alternative food source under the ground, thereby protecting the target species of the stand from total destruction. The shading layer of grey poplar is gradually cleaned out during the development of the reforestation; the grey poplar can also disappear completely by the age of 15–20 years. Continuous soil cultivation between the rows of the reforestation is important as it aids the growth of trees by supressing weeds. Establishment regeneration cost values in the case of RF systems exceed the national average on a bigger scale in the case of artificial regeneration because of the site conditions and different damage types (Nagy 2013). Based on the references, the establishment cost value of reforestations on terrain accessible with machines was 522,000 HUF/ha in case of acorn planting (7th year). In our examination the cost of artificial regeneration with seedlings was 1,680,000 HUF/ha (in 7th year). These values can be found elsewhere as well, mainly in cockchafer grub damaged areas (Babics 2014).

Table 4. The model of artificial reforestation (after clearcutting) in Turkey oak stands (4th yield class) in the RF system

Year	Intervention	Expenditures for 1 ha				
		Material/Energy			Work costs	Total
		Name	Quantity	Cost		
			pcs/kg/ work hours	Thousand HUF	Thousand HUF	Thousand HUF
0	Total soil preparation				330.0	330.0
	Soil sterilization	Force 1.5 G	25 kg	45.0		45.0
1	Primary planting with seedlings	Turkey oak, sessile oak, small-leaved linden, grey poplar	10,000 pcs	150.0	150.0	300.0
	Hoeing 2x				160.0	160.0
2	Supplement with seedlings (30%)	Turkey oak. sessile oak. grey poplar	3,000 pcs	45.0	45.0	90.0
	Weeding of plates				30.0	30.0
	Sickling				35.0	35.0
	Discing 3x				45.0	45.0
	Hoeing				80.0	80.0
3	Discing 3x				45.0	45.0
	Hoeing				80.0	80.0
	Sickling				45.0	45.0
4	Protection against larva damage	Force 1.5 G	8.33 kg	15.0	15.0	30.0
	Supplement with seedlings (15%)	small-leaved linden grey poplar	1500 pcs	22.5	22.5	60.0
	Weeding of plates				15.0	15.0
	Discing 3x				45.0	45.0
	Sickling 2x				70.0	70.0
5	Discing 3x				45.0	45.0
	Sickling 2x				70.0	70.0
6	Discing				30.0	30.0
7	Discing				30.0	30.0
10	Shoot control				35.0	35.0
13	Shoot control				35.0	35.0
23	Cleaning				25.0	25.0
	Total					1775.0

Table 5. The empirical economic model in Turkey oak stands (4th yield class) managed by the RF system (clearcutting with artificial regeneration), cash flow and annuity (r=0.02)

Intervention	Age	Yield	Unit prices, fees		Cash flows				Annuity
			Price	Logging fee	Income	Logging cost	Regeneration cost	Balance	
	(yr)	(m^3/ha)	(HUF/m^3)		(HUF/ha)				(HUF/ha/yr)
Clearcutting	100	225	13,500	2,900	3,037,500	652,500	1,775,000	610,000	
Total		225	13,500	2,900	3,037,500	652,500	1,775,000	610,000	1,954

3.4 Turkey oak stands in RF system – regeneration cutting with natural regeneration

In the Turkey oak regeneration cut with the shelterwood system (*Table 6 and Table 7*), seedlings disappeared after the completion of the first preparatory cut (resulting in a 70–75 % closure). A grub exploration was done; sample ditches showed a high number of larvae (2–4 pcs/m^2). An artificial replacement was also essential with acorn and seedlings, as well as soil sterilization. The first preparatory cut was done very early compared to the time of the final cut (normally 3-5 years); the reason for this was the annual development and recession of the regeneration layer. This experience showed more mother trees in a shelterwood system had to be maintained as they are necessary until the regeneration layer reaches high closure; otherwise, it is possible that the seedlings disappear due to cockchafer grubs. Accordingly, the harvesting of the mother stand was carried out in several steps considering the development of regeneration. Establishment regeneration cost values in the case of RF natural regeneration is higher than the national average in a smaller scale (Nagy 2013), which in the case of natural regeneration was 510,000 HUF/ha in the 9th year old regeneration. For natural regeneration, we got a reduced initial cost of 721,500 HUF/ha (in 9th year) due to the extremities of our sites.

Table 6. Natural regeneration model with gradual regeneration cuts and with replacement planting in Turkey oak stands (4th yield class) in the RF system

Year	Intervention	Expenditures for 1 ha				
		Material/Energy			Work Cost	Total Cost
		Name	Quantity (pcs/kg/ work hours)	Cost (thousand HUF)	(thousand HUF)	(thousand HUF)
–11	Bush clearing	MS-Fergusson	4 work hours	22.0		22.0
–8	Direct sowing	Turkey oak acorn	300 kg	30.0	65.0	95.0
–7	Bush clearing	MS-Fergusson	4 work hours	22.0		22.0
0	(final cut) Shoot control				50.0	50.0
1	Shoot control				35.0	35.0
2	Protection against grub damage (20%)	Force 1.5 G	5 kg	7.5	10.0	17.5
	Strip soil preparation				35.0	35.0
	Supplement with seedlings (35%)		3500 pcs	52.5	52.5	105.0
	Shoot control 2x				70.0	70.0
3–10	Shoot control 7x				315.0	315.0
13	First cleaning				25.0	25.0
23	Total					791.5

Table 7. The empirical economic model in Turkey oak stands (4th yield class) managed by the RF system (gradual regeneration cut with natural regeneration), cash flow and annuity (r=0.02)

Intervention	Age	Yield	Unit prices, fees		Cash flows				Annuity
			Price	Logging fee	Income	Logging cost	Regeneration cost	Balance	
	(yr)	(m^3/ha)	(HUF/m^3)		(HUF/ha)				(HUF/ha/yr)
Regeneration cut	89	70	13,500	3,100	945,000	217,000		728,000	2,899
Regeneration cut	95	75	13,500	3,100	1,012,500	232,500		780,000	2,758
Final cut	100	80	13,500	2,900	1,080,000	232,000	791,500	56,500	181
Total		225	13,500	3,029	3,037,500	681,500	791,500	1,564,500	5,838

3.5 Turkey oak stands CCF system

The Turkey oak CCF management at the beginning of the 1990s was started as a natural regeneration with the shelterwood system. Afterwards, however, the regeneration under the stand disappeared almost completely in more opened up areas due to drought and cockchafer grub damage; in more closed spots it became thinner, so the natural seedling cover decreased significantly. Due to these conclusions in the early 2000s, the continuation of further operations used CCF principles (*Table 8 and Table 9*) in order to minimize risks. A few years later, new seed produce appeared and regeneration patches in smaller openings showed improvement and development. A regeneration patch is only opened up fully if a dense, well-developed, and closed Turkey oak regrowth is present. Nursing of the regeneration patches and cleaning-like intervention in more developed groups, removal of wolf-trees, or non-native and invasive tree species like black cherry (*Prunus serotina*) are only required in some parts of the area. In the CCF system, trees in the upper layer were harvested gradually one by one or in small groups (2-3 trees) of single-tree and group selection, which results in spontaneous establishment of natural regeneration. It can be proved that by using this method the high additional costs caused by cockchafer grubs and drought damage can be avoided in the permanently present shelter of the mother stand, which provides protection through shading and seed production.

Table 8. The model of natural regeneration of Turkey oak stands (4th yield class) in CCF system

Year	Intervention	Expenditures for 1 ha				
		Material/Energy			Work Cost	Total Cost
		Name	Quantity	Cost		
			(pcs/kg/work hours)	(thousand HUF)	(thousand HUF)	(thousand HUF)
1	Shoot control				45.0	45.0
3	Shoot control				45.0	45.0
5	Shoot control				45.0	45.0
8	Chemical shoot control (50%)	Lontrel	0.5	12.0	20.0	32.0
12	Shoot control, cleaning (60%)				21.0	21.0
15	Chemical shoot control (20%)	Lontrel	0.2	4.8	7.0	11.8
18	Chemical shoot control (20%)	Lontrel	0.2	4.8	7.0	11.8
23	Shoot control, cleaning (60%)				21.0	21.0
	Total					232.6

In the case of the CCF model for Turkey oak (*Table 9*), we took an even-aged forest where the transition to an uneven-aged stand starts at the age of 50 years and lasts into the next 50 years as a starting point.

Table 9. The empirical economic model in Turkey oak stands (4th yield class) managed by the CCF system (selection cut with natural regeneration), cash flow and annuity (r=0.02)

Intervention	Age	Yield	Unit prices, fees		Cash flows				Annuity
			Price	Logging fee	Income	Logging cost	Regeneration cost	Balance	
	(yr)	(m^3/ha)	(HUF/m^3)	(HUF/m^3)	(HUF/ha)				(HUF/ha/yr)
Selection cut	60	45	13,500	3,100	607,500	139,500		468,000	3,310
Selection cut	70	45	13,500	3,100	607,500	139,500		468,000	2,715
Selection cut	80	45	13,500	3,100	607,500	139,500		368,000	2,227
Selection cut	90	45	13,500	3,100	607,500	139,500		468,000	1,827
Selection cut	100	45	13,500	3,100	607,500	139,500	232,600	235,400	754
Total		225	13,500	3,100	3,037,500	697,500	232,600	2,107,400	10,833

3.6 Stand-level comparison

Unlike in other cases (Marosi and Juhász 2011, Schiberna et al. 2012), the results presented in this paper are not theoretic models. They were created by analysing natural and financial data from real forestry practice; however, during their evaluation the fact that the CCF is still only in its early stage has to be taken into consideration.

Based on the results summarized in *Table 10*, it can be confirmed that, at the stand-level, the CCF system performs at least as well as those managed with the RF system (Zing et al. 2009). For beech stands, the whole cycle of the RF system was compared with the CCF system; however, only the data of the final harvest and the regeneration period to the first cleaning were analysed for Turkey oak stands.

Table 10. Stand-level comparison of the traditional RF and the CCF system (r=0.02)

Management system – Stand	Annuity for 1 ha (HUF/ha/year)
RF in beech stands	24,569
CCF in beech stands	64,748
RF in Turkey oak stands (clearcut, artificial regeneration)*	1,954
RF in Turkey oak stands (gradual regeneration cut, natural regeneration)*	5,838
CCF in Turkey oak stands *	10,833

* except of revenues and costs from second cleaning to all the thinnings

According to practical experiences, the Turkey oak stands provide firewood quality wood; thus, the exclusion of further cleanings and thinnings from the model does not distort the differences between the CCF and RF systems. Moreover, these interventions of cleanings and thinnings can be considered as equal in all the cases. The incomes were calculated with the prices of Turkey oak only, so that the different mixture proportion did not distort comparability. We considered the timber yields as equal, because our viewpoint was that in the case of the CCF system, the presumably smaller volume due to earlier cuts is equalled out by greater increment; furthermore, we have no data to analyse this.

The costs of reforestation greatly depend on the silviculture systems used. Because of the cockchafer grub and drought damage present in the Gödöllő Hills, we had the opportunity to try out several methods and to compare them at the same time. In the sandy areas of the Gödöllő Hills, the occasional twenty year lack of regeneration success after traditional clearcutting with partial soil preparation could be frequently observed. There are always great numbers of cockchafer grub in these regeneration areas, which neither allows spontaneous regeneration nor the development of the reforestation until the grub damage disappears with the canopy closing. Based on the cost analysis and the management methods described above, it is readily apparent how many additional regeneration costs the technologies with large clearcut and final cut areas generate.

3.7 Estate-level comparison

According to Schiberna et al (2012), cash flow can be made consistent in time as well in bigger forest estates with a normal age-class distribution (‘normal forest’), so the management system makes no difference in profitability. However, the examinations resulted in similar conclusions here as well as on a stand-level: CCF gives an appropriate alternative from an economic point of view. This is obtained from the models that assumed forest estates are considered as fully regulated ‘normal forest’ in the RF system (Knoke 2012). If this is given for a 120 ha beech, or a 100 ha Turkey oak forest estate, then the total rubric of the balance column in the mentioned tables equals the income of the total area for one year (*Table 11*).

The differences between the models are primarily the result of the different regeneration costs and the different timing characteristics of cash flows. The income and the cost of logging cause fewer differences. Economic comparison between different forest management systems not only shows the remarkable economic competitiveness of CCF in beech stands through the presented examples, but also in Turkey oak stands mainly used for producing firewood.

Table 11. Estate-level comparison of the RF and CCF system

Management system – Estate	Annual cover for estate (HUF/year)
RF in beech stands on 120 ha	7,408,470
CCF in beech stands on 120 ha	8,086,800
RF in Turkey oak stands (clearcutting, artificial regeneration) on 100 ha*	610,000
RF in Turkey oak stands (gradual regeneration cut, natural regeneration) on 100 ha*	1,564,500
CCF in Turkey oak stands on 100 ha*	2,107,400

* except of revenues and costs from second cleaning to all the thinnings

4 CONCLUSIONS

According to the research it can be stated that beech and Turkey oak stands managed with the CCF system do not lag when compared to even-aged RF systems either on a forest stand-level (smallholding) or on a forest estate-level (enterprise-level), even according to the comparison based on classical economic analysis. The economic ranking between different management methods was defined by regeneration costs, which reflected their significantly different ecological-economic risks well.

The research showed that the permanent shading effect of the mother trees kept in the upper layer - which we also modulate by taking the light demand of the regeneration of main tree species into consideration during CCF – also reduces costs significantly in stands under poorer site conditions. Shelter trees reduce the damage caused by cockchafer and drought through shading and the appearance of regeneration. Through frequent seed production, they continuously supplement the seedlings lost due to damage. In the poor quality sites, the climatic extremities and periodic appearance of cockchafer grub damage did not worsen comparability, but they magnified the performance differences of each management system and made these visible in a short time period as well.

From both a silvicultural and economic perspective, the results presented in this paper show that CCF can be successfully applied in high quality beech sites and poorer quality Turkey oak sites where the regular appearance of natural regeneration is ensured in suitable quality and quantity.

By minimising damage and reducing silviculture costs, CCF proved to be a suitable management option in Turkey oak stands that suffered cockchafer grub damage and drought.

In conclusion, it can be stated that employing CCF in Hungary's mountainous and hilly regions would be more desirable than the proportions of its current practice and utilization indicate.

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10.1515/aslh-2017-0002 *Acta Silv. Lign. Hung., Vol. 13, Nr. 1 (2017) 25–40*

Light Conditions, Soil Moisture, and Vegetation Cover in Artificial Forest Gaps in Western Hungary

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Abstract – One of the greatest challenges of continuous cover forest management is to find a suitable gap size in a given forest stand that will help the regeneration of economically significant tree species, and possibly control competitor species. This paper summarizes the results of a two-year intensive mapping of various bearing artificial gaps at two sites in western Hungary: a sessile-oak-hornbeam and a Turkey oak forest. Light conditions and soil moisture were measured in the gaps as abiotic variables. Hemispherical photography and a Field Scout TDR 300 Soil Moisture Meter were used. Vegetation cover as well as quantity and height of the regeneration were measured as biotic variables. There are significant differences between the middle of a gap and the closed canopy forest stands. The maximum light intensity below the canopy shows a slight northward dislocation. Correlation analysis results showed that a gap's slight, northward irradiation surplus effected soil moisture, regeneration heights, and total vegetation cover less than a gap's real shape and size, ergo, its openness did.

gap / continuous cover forest management / light conditions / soil-moisture / regeneration / plant cover

Kivonat – Talajnedvesség, fényviszonyok és a vegetáció borításának térbeli változása mesterséges lékekben a Nyugat-Magyarországon. A folyamatos erdőborítást biztosító erdőgazdálkodás egyik legjelentősebb kihívása egy adott erdőállomány esetében megtalálni azt a megfelelő lék méretet, amely segíti a gazdaságilag értékes fafajok felújulását, azonban lehetőség szerint korlátozza a kompetitorokat. A tanulmány összefoglalja egy két éves időtartamú intenzív felvételezés eredményeit különböző tájolású mesterséges lékekben két kísérleti területen, Nyugat-Magyarországon: egy gyertyános-kocsánytalan tölgyes és egy cseres-tölgyes erdőrészletben. A lékekben fényviszony és talajnedvesség mérések történtek, mint abiotikus változók. Hemiszférikus fényképezést és Field Scout TDR 300 talajnedvesség mérőt használtunk. Biotikus változóként vegetációborítást, az újulat mennyiségi és magassági méréseit végeztük el. Szignifikáns különbségek találhatóak a lék középpontja és a zárt lombozatú erdőállomány között. A fénybesugárzás maximuma a lombkorona alatt csekély északi irányú eltolódást mutat. Az korreláció vizsgálati eredmények kimutatták, hogy a lékek csekély északi irányú besugárzástöbblete kisebb hatással bír a talajnedvességre, a csemetemagasságra és a teljes növényborítottságra, mint a lék valós alakja és mérete, tehát annak nyitottsága.

lék / folyamatos erdőborítást biztosító erdőgazdálkodás / fényviszonyok / talajnedvesség / újulat / növényborítás

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1 INTRODUCTION

A major question in Hungarian forest management is "how to transform a clear cutting forest to a selection cutting forest" (Koloszár 2005). The selection cutting forest is a special forest stand shape (forest scape) established by prolonged continuous selection cutting (harvesting or intervention of stems) (Solymos 2000). Adequate environmental parameters such as light and water are indispensable for seedling growth.

There is a great debate in Hungarian silviculture literature about which woody species are suitable for selection cutting and which are suitable for silviculture under continuous forest cover. At the beginning of the twentieth century, Roth (1935) wrote about the light demands of woody species and that light-demanding and shade-tolerant species can be differentiated. Oaks are described as light-demanding species but with significant differences amongst the various oak species. Koloszár (2005) states that only shade-tolerant species, such as European silver fir (*Abies alba*), Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) are suitable for selection cutting The regeneration of light-demanding oaks theoretically contradicts the decreased light quantity of gaps, but in many cases the idea of selection cutting silvicultural system overwrites these (Pro Silva 1999, Bodonczi et al. 2006, Csépányi 2008, Reininger 2010). Csépányi (2008) shows several examples for oak regeneration and proposes how to choose the required gap size, shape, and bearing. Gálhidy et al. (2005, 2006) makes intensive studies in beech stands. Török (2006) fully assays the methods of exposure-orientated regeneration in beech forests; however, such a detailed work does not exist for oaks yet. A law passed in 2009 requires forest managers to use gaps for natural regeneration in every type of forest, even in oak dominated forests where scientific research has not yet been completed and established.

Mountain areas with beech and coniferous species are highly representative in international silviculture literature (Clinton 2003, Gagnon et al 2004, Page – Cameron 2006, Naaf – Wulf 2007, Ritter et al 2005, Cater et al 2014). Tropical forests are also frequently studied with basic gap dynamics (Brown 1996, Van Dam 2001, d'Oliveira – Ribas 2011). Oak species are less studied, especially in mixed forests (Aikens et al 2007, Petritan et al. 2013).

Since it is difficult to express the light-demand of tree species, finding more accurate indices than gap size is required. The conventional subjective canopy closure estimation cannot be used in the case of gaps because a regular gap is theoretically open, while the surrounding forest stand has the average closure of the forest sub-compartment; therefore, it is reasonable to use other measurements. Describing a gap by its size measured on the ground cannot provide adequate answers about the light conditions dominating the gap (Kollár 2013). Studies of light conditions using hemispherical photography have their history already back in the age of analogous cameras (Frazer et. al. 1999, Brunner 2002), but photography techniques and digital processing have advanced greatly since then.

Soil moisture is changing and the gaps become watered when gaps opened in closed forest stands. Soil moisture content variability is high between the gap centre and the surrounding closed forest stand (Van Dam 2001). More measurements are required to show the variability of soil moisture at the temporal and spatial scale. Extensive studies of gap regeneration and its hydrological consequences are conducted in Hungary mostly in beech stands, which are preferred for continuous-cover forest management purposes. Manninger (2008) states that there are differences in absolute value of soil moisture in the gaps and in the surrounding closed forest, but the directions and values of change are similar. Gálhidy et al. (2006) claim there are no significant soil moisture differences in a small or large gap, but the values in a large gap are more diverse. Moreover, soil moisture was higher in gaps than it was under a closed stand. The presence of soil moisture indicator herbaceous species is generally a good indicator for soil moisture determination in the absence of instrumental measurements. Tobisch (2010) said that the height of the tallest sessile oak and hornbeam seedlings was related mainly to the cover of soil moisture indicator plants.

The research aim is to discover whether there are differences between closed canopy control parcels and young, early-staged gaps and gap regions. This paper was a primer study of a long duration research project where the development of artificial gaps has been examined in reasonable periods. The gaps will be increased in the future, and further comparisons could be studied with greater gap sizes, and developed regeneration.

Our questions are the following:

- Are there significant differences in soil moisture, regeneration, or herb coverage between the brighter gaps and the closed canopy control plots?
- Have the gaps become watered and affected regeneration and vegetation coverage?
- Are there correlations between the measured abiotic (light and soil moisture) and biotic (regeneration, plant cover) factors?

2 MATERIALS AND METHODS

2.1 Research sites

The research took place in Central Europe, in Vas County in western Hungary. Two sites were involved (*Table 1, Figure 1*) and the temporal range covered the vegetation period of 2013 and 2014. The study sites are flat; gaps were opened in each sub-compartment in 2011. There are three parcels in both sites, each with an area of 0.25 ha (50 × 50 metres) including two similar-sized artificial forest gaps and one control area with closed canopy. The elliptical gaps are about one-tree height long and half-tree height wide (approximately 30 × 15 meters), with one orientated north-south, and the other east-west.

Table 1. Research sites (H: Average Height, $D_{1.3}$: Average diameter at breast height, N: Number of Stems per Hectare, at the Bejcgyertyános 13 A site, for sessile oak's data first, than hornbeam's data)

Forest sub-compartment	Forest stand type	Age	H	$D_{1.3}$	N	Soil type	Hydrology	Soil texture
		in 2011 (gap opened)						
		years	m	cm	n/ha			
Bejcgyertyános 13 A (N47° 11.304', E17° 0.626')	Sessile oak-hornbeam	81	26.0 17.5	33 11	302 172	Lessivated brown forest soil (Vertisol)	Water-losing sites	Loam
Vép 32 D (N47° 13.667', E16° 47.307')	Turkey oak	67	26.4	28	459	Surface water gley brown forest soil (Vertisol)	Water-losing sites	Loam

In each gap and the surrounding closed forest stand, 41 grid points were set in a regular pattern, while in the control area 16 grid points were set (*Figure 2*). The grid points are 5 meters apart in the middle of the gaps, and 10 meters apart at the sides and under closed canopy in order to get a similar number of samples. During data processing, grid points in the parcels were categorised into three gap regions: middle of the gap (Gap, n=11), sides of the gap (Sides, n=12), and under closed canopy (Closed, n=18).

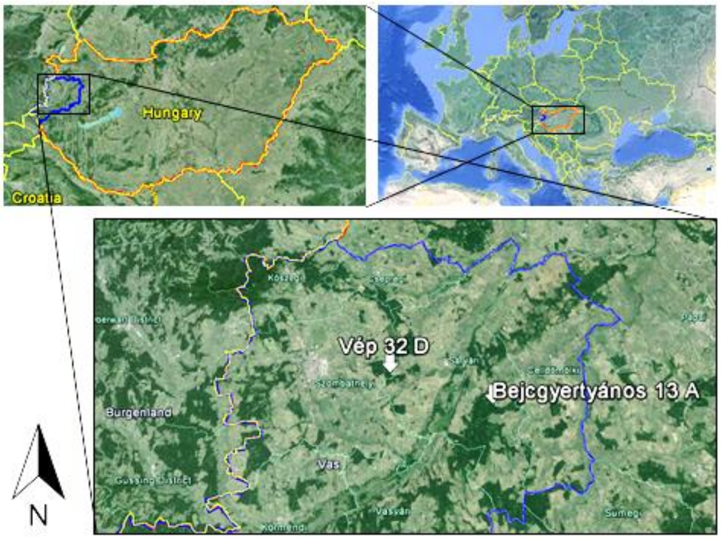


Figure 1. Research sites, Vas County, western Hungary, Central Europe

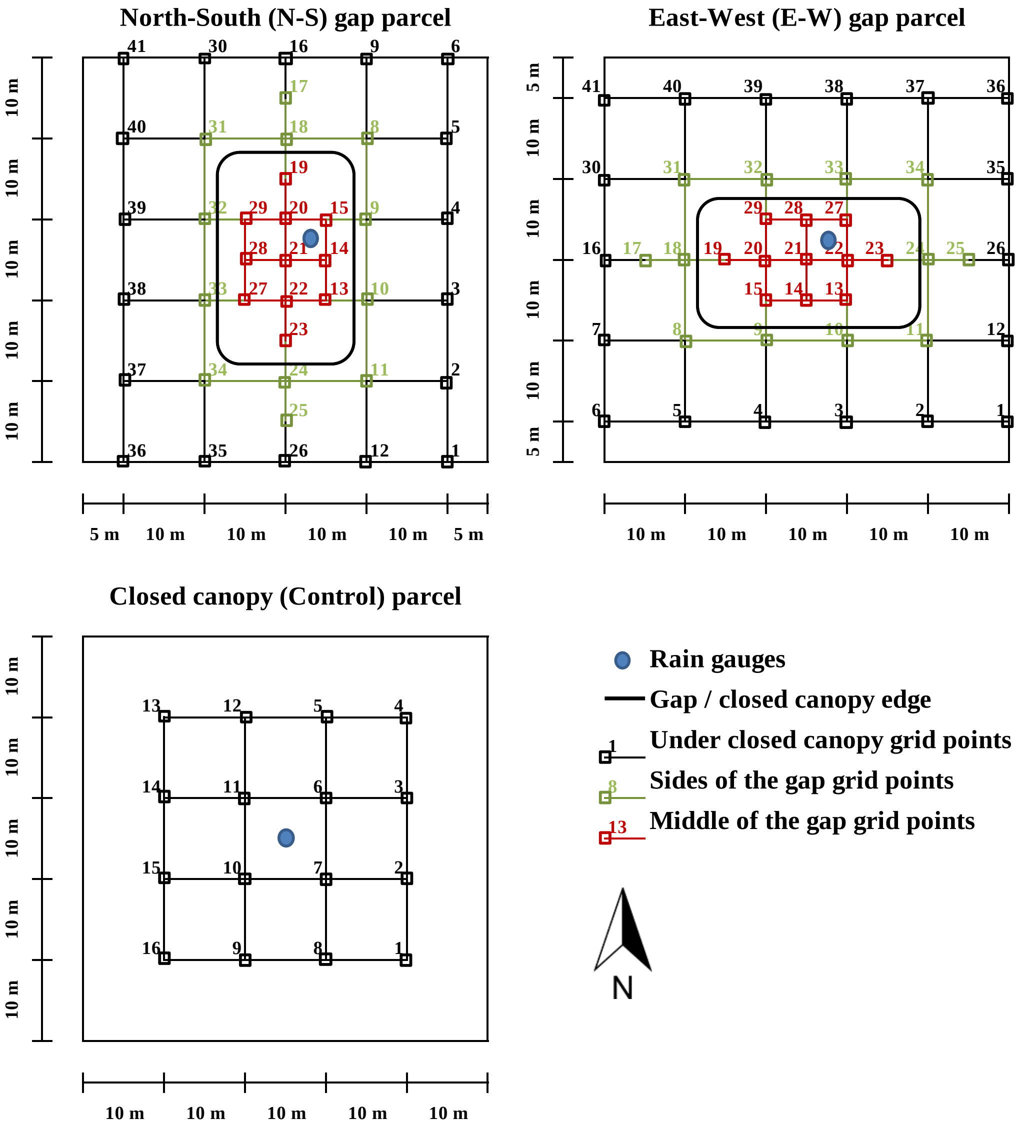


Figure 2. Experimental designs of the two gaps and control parcel in the research sites

2.2 Field methods

2.2.1 Light condition measurements

A Sony NEX-7 24 MP DSLR camera with calibrated fish-eye lens in automatic program settings was used in the experiment. The camera was inside a levelling mount with North Finder, in a 170 cm high position. Two sets of hemispherical photos were taken at every grid point of the sites, during sunny sky conditions at the end of August 2013 and 2014. Photos were evaluated with WinSCANOPY 2013a software (Guay 2012). As input data, the geographical position (GPS coordinates), altitude, height of the camera, slope, aspect, time of the growing season, and the orientation of the photo are required for photo analysis. It is necessary to have sharp, high-resolution photos in order to differentiate the celestial sphere from the vegetation (or other covering objects). Interactive pixel classification was used to separate sky and covered pixels. With this method, sun spots can be eliminated; therefore, photos taken in imperfect sky conditions can be used.

In the study, openness and total site factor data were used from photo evaluation. Openness is the fraction of open sky (unobstructed by vegetation) in a specified region of the real canopy above the lens. It is similar to the canopy closure used by foresters, but hemispherical photography monitors sideward irradiation also. The total site factor is the fraction of total (direct and diffuse) photosynthetically active flux density under and over canopy average for the growing season (Guay 2012). In the evaluation, the growing season was set as it lasted from 1st April to 30th September. Therefore, the irradiation of the entire growing season can be estimated by taking one photo with maximum leaf area as the program computes the irradiation at all hours of all days in the growing season. Using all photos of a parcel, spatial models were made.

2.2.2 Soil moisture measurements

Field Scout TDR 300 Soil Moisture Meter was used in the research (Spectrum Inc., 2009). Data collection mode was set to default calibration for standard soils. During measurement campaigns, four repeats of measurements were taken at each grid point. Depending on weather conditions, measurements were taken between one- to two-week periods. Between April and October 2013, 23 measurement campaigns were undertaken in 2013 and 16 in 2014. We used different rod lengths (20 cm, 12 cm, and 7.6 cm) at the beginning of the research. The most reliable was 7.6 cm; therefore, we used this as the standard (see Appendix).

2.2.3 Regeneration measurements and cover estimations

In each year of the study between 11th August and 19th September, one set of regeneration measurements and cover estimations (abundance) were made at every grid point in the parcels. Seedlings of every tree species were counted in four 1 m^2 quadrants. The heights of the tallest seedlings per species were measured in all quadrants. Cover estimations of the dominant species were taken by visual assessment in these total 4 quadrant areas with an accuracy level of 1% to 5%, then 5% accuracy with higher coverage values. In this paper, only total vegetation coverage was examined, which is the sum of all species cover. It is also equal to 100% minus the vegetation non-covered ground.

2.2.4 Statistical analyses and visualisation

Spatial changes of measured variables are visualised with categorised box and whisker plots. Categorised variables were the sites, bearing of the gaps or control, and gap regions inside a parcel. T-tests were used to find significant differences between variables within a parcel.

Spatial distributions of the data were presented with 3D contour plot diagrams, which were created with the least squares fit options and minimum stiffness.

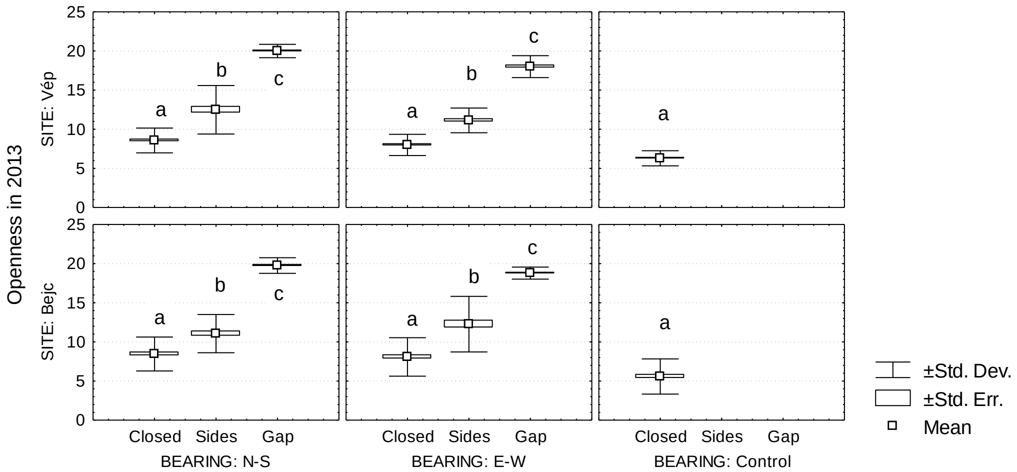
In the case of soil moisture measurements, the first step of the analyses was to standardize the soil moisture data that came from different soil depths (*see Appendix*). Demonstrating the temporal change of soil moisture, average values of daily soil moisture data were presented in diagrams, trend lines were fitted, and R^2 calculated to find out how well the model fits the data (*Figure 5*).

Relationships of individual data were searched using a Pearson Product-Moment correlation matrix. For statistics and visualisation, Microsoft Excel 2010 and StatSoft Statistica 2000 programs were used.

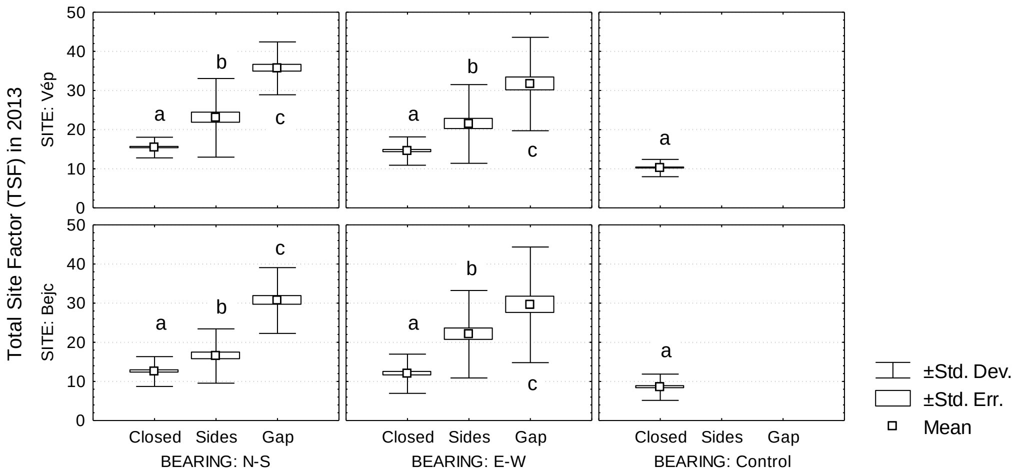
3 RESULTS AND DISCUSSION

3.1 Spatial changes of light conditions

In *Figure 3*, light condition differences in gap regions can be seen for year 2013. Light conditions in 2014 showed slightly higher data. T-tests ($p < 0.05$) for openness and also total site factor in 2013 and 2014 show less than 0.3%, but significant differences in average.



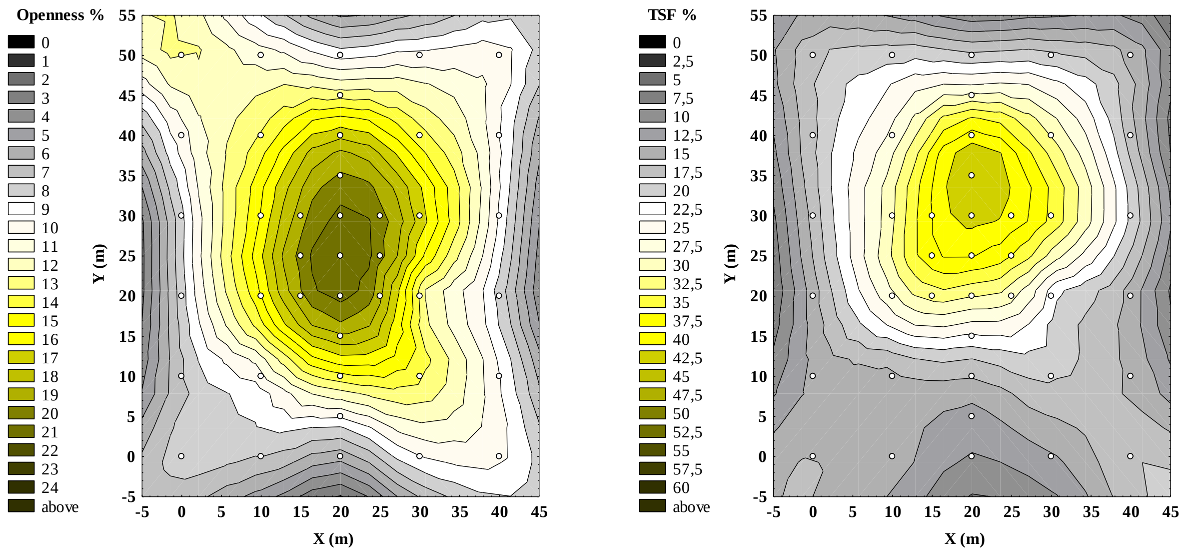
(a)



(b)

Figure 3. Openness (a) and total site factor (b) values in 2013, different letters indicate significant differences (p<0.05) between means inside a parcel

It is nearly impossible to make gaps that are exactly the same size even in artificial opened gaps. There are traceable differences between the sites, and between gaps within the sites (*Figure 3*). In the case of openness, the gap regions show apparent differences, but the openness values under closed canopy areas were significantly different compared to the control parcel. This means that the parcels should be greater and have denser grid points to model the whole range of canopy closure from the middle of the gap to the closed canopy forest stand.



(a) Openness % *(b) Total Site Factor %*

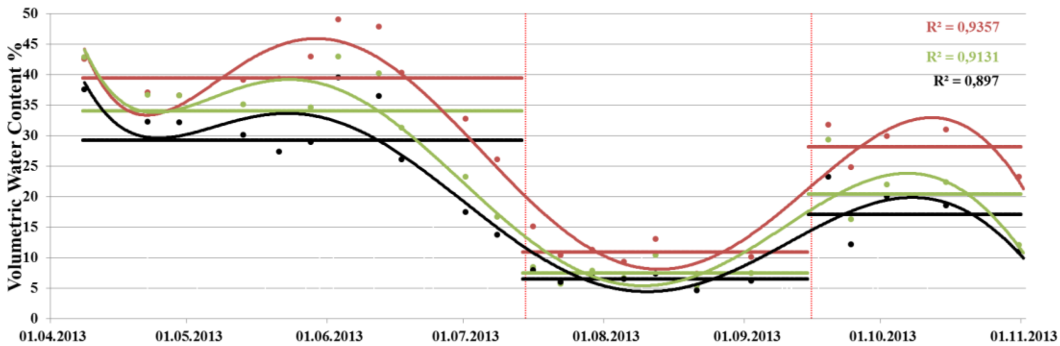
Figure 4. Vép 32/D, north-south gap Openness (a) and total site factor (TSF) (b) in 2013

Figure 4 (a) shows the symmetry of the gap in a 3D contour plot diagram as the viewer moves from the gap centre towards the closed canopy. The effects of nearby gaps are visible at the corners. Nearby gaps are also too close to each other and, thus, affect each other. In *Figure 4 (b)*, the maximum light intensity below the canopy shows a slight northward dislocation. This light effect is similar to what Csépányi (2008) noted. A similar dislocation occurred in the case of a gap with an east-west orientation. It is important to note that even the most illuminated area within the investigated gaps recorded only about 40–50% of the above canopy light quantity, and this decreases rapidly when nearing the closed forest canopy. At the sides of the gap, about 20–30% of the above canopy light reaches the surface, while under closed canopy it is only 10–15%.

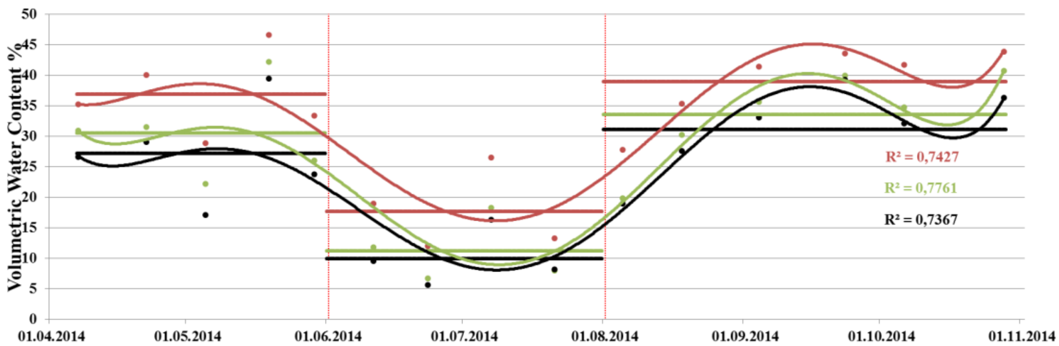
3.2 Temporal and spatial changes of soil moisture

The two vegetation periods had a great precipitation variance, which had a big influence on soil moisture. Precipitation was measured in the six parcels with rain gauges during the research. There was an average of 250 mm of precipitation in Vép and 319 mm in Bejcgyertyános from the beginning of April to the end of October 2013; however, in same period in 2014, precipitation was 466 mm in Vép and 525 mm in Bejcgyertyános.

In *Figure 5 (a-b)*, trend lines show the modelled temporal changes of soil moisture. These trend models were divided into three periods a year: the beginning of vegetation season, drought period, and the end of vegetation season; the periods' average soil moisture values were presented with horizontal lines.



(a) 2013



(b) 2014

Figure 5. Vép 32/D, north-south gap average soil moisture (Volumetric Water Content) data in 2013 (a) and in 2014 (b) (middle of the gap: red line, sides of the gap: green line and under closed canopy: black line)

The soil moisture fluctuation is marked in the two different years (*Figure 5 (a-b)*. In 2013, an extended drought period was observed between the middle of July and the middle of October. Then in the winter, the soil could not reach the saturated phase; consequently, the 2014 vegetation season began in less moist conditions. In 2014, June was the only virtually rainless month and the soil moisture dropped during this time. After that short dry period, soil moisture increased rapidly. There was no real so-called drought period, while the decreased soil moisture phase started one-and-a-half-months earlier than the previous year's drought and lasted the same two months. By the beginning of September, soil moisture reached its maximum as it had at the beginning of 2013.

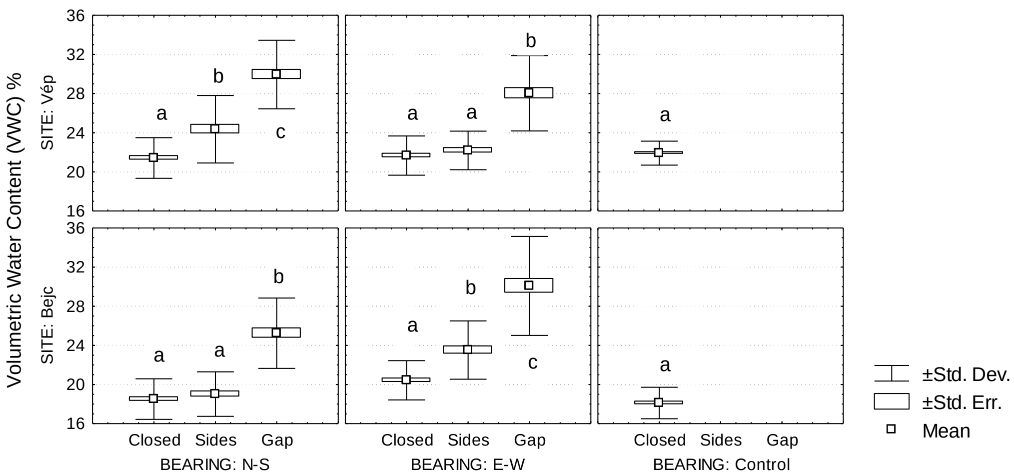
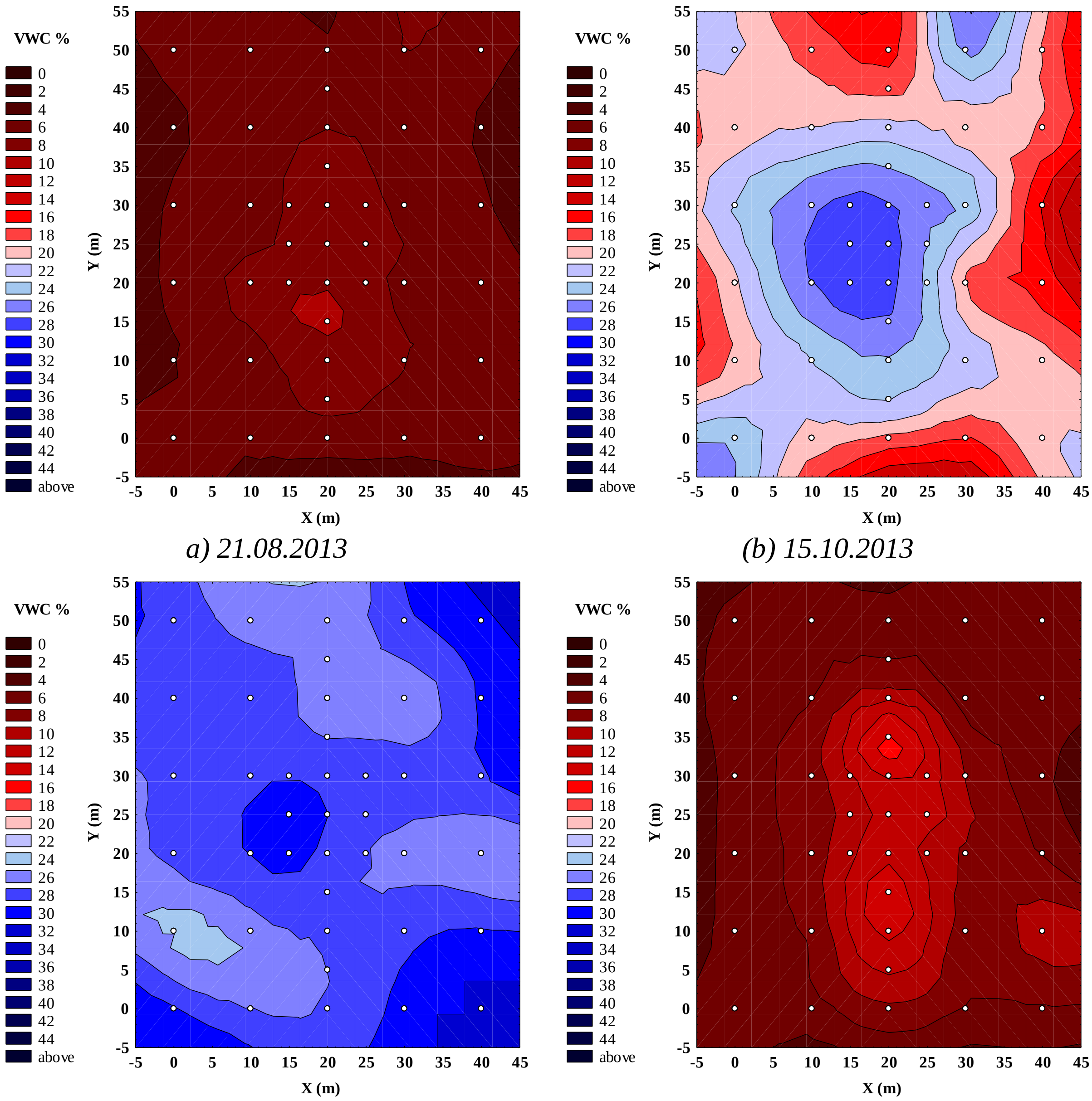


Figure 6. Average soil moisture (Volumetric Water Content) data of 2013 and 2014, different letters indicate significant differences (p<0.05) between means inside a parcel

There are differences in the absolute values of soil moisture between the two sites and also between various gaps (*Figure 6*), but the tendencies are the same. Manninger (2008) stated similar results in beech stands. The gaps have become watered. For all samples in the research period, the mean value of Volumetric Water Content (soil moisture) in the vegetation period in the sites is about 6 percentage points higher in the middle of a gap (29%) than at the sides of it (23%). The soil moisture is a further 2 percentage points lower under closed canopy (21%). It is also evident that standard deviations are decreasing as measurements move from the middle of a gap to under closed canopy. This shows the same results as Gálhidy (2006), who wrote that the soil moisture values are more diverse in a gap.

The differences in the absolute value of average soil moisture between the north-south and east-west oriented gaps cannot be explained yet, but tendencies are similar.



a) 21.08.2013 (b) 15.10.2013

(c) 22.04.2014 (d) 23.06.2014

Figure 7. Vép 32/D, north-south gap
21.08.2013: the driest soil phase (a), 15.10.2013: a medium moist soil phase (b), 22.04.2014: moist soil phase (c), 23.06.2014: the driest soil phase in 2014 (d).

The spatial changes of soil moisture can be exemplified in 3D contour plot diagrams. In *Figure 7 (a, b, d)* the moister phase of the middle of a gap has clearly been drawn; difference remains in the driest periods, too (a). Close to the saturation of the soil in spring and fall, these differences can decrease or almost disappear *(c)*. The water uptake of the still standing mother stand's rooting area has a greater impact on the spatial changes of soil moisture in a gap and its surroundings than the gap's light conditions, as it seemed in the case of total site factor. These moist phases cannot be compensated by greater amount of sunlight in the monitored gap size.

3.3 Regeneration measurements

There were no significant regenerations in the Bejcgyertyános site; only very few (0.88 n/m^2 in 2013, 0.44 n/m^2 in 2014) sessile oak (*Quercus petraea*) seedlings were found in the gaps. In the Vép 32 D site, a great number (5.38 n/m^2 in 2013, 5.31 n/m^2 in 2014) of Turkey oak (*Quercus cerris*) seedlings were found during the two-year period. *Figure 8* shows the average height of seedlings in 2014.

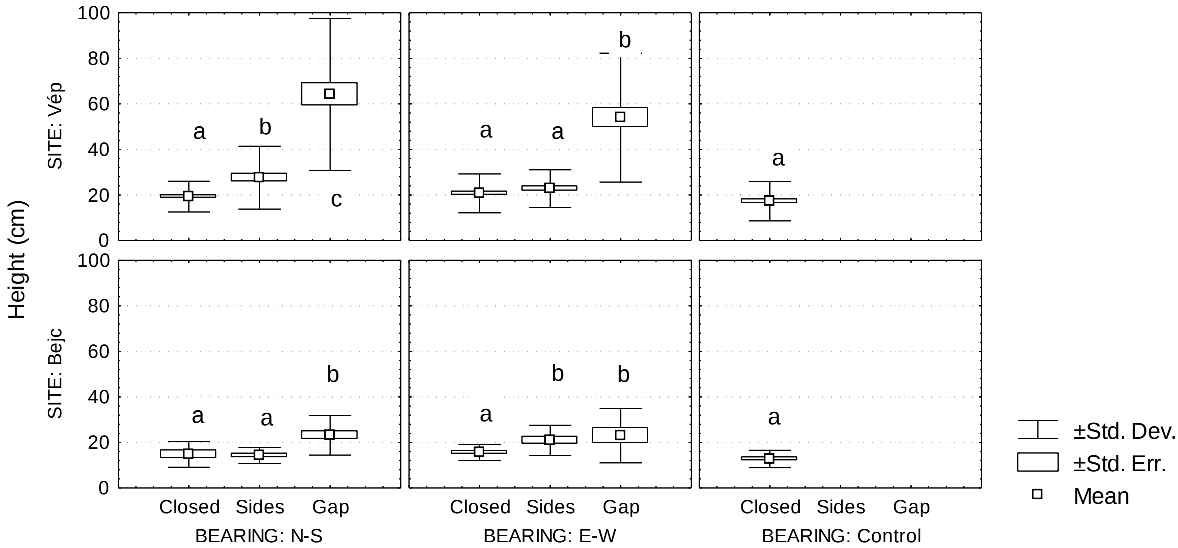


Figure 8. Height of seedlings in 2014
(Quercus cerris in Vép site, Quercus petraea in Bejcgyertyános site),
different letters indicate significant differences (p<0.05) between means inside a parcel

The number of seedlings was similar (not significantly more seedlings than in 2014) at the Vép site in 2013, but the height of the seedlings was significantly lower. In 2013, the height of Turkey oak (*Quercus cerris*) seedlings for all samples was 45 (±21) cm in the middle of gap, in 22 (±8) cm at the sides of gap and 18 (±8) cm under closed canopy. Comparing 2013 against 2014, the height growth was mostly in the middle of the gap, where the height yield was 14 cm. At the sides of the gap, height yield was 3 cm, while under closed canopy it was only 1 cm. While in 2013 there were significant differences between the heights of seedlings in the middle of the two gap, these differences were not significant in 2014; therefore, differences between gaps decreased in the two years of the research.

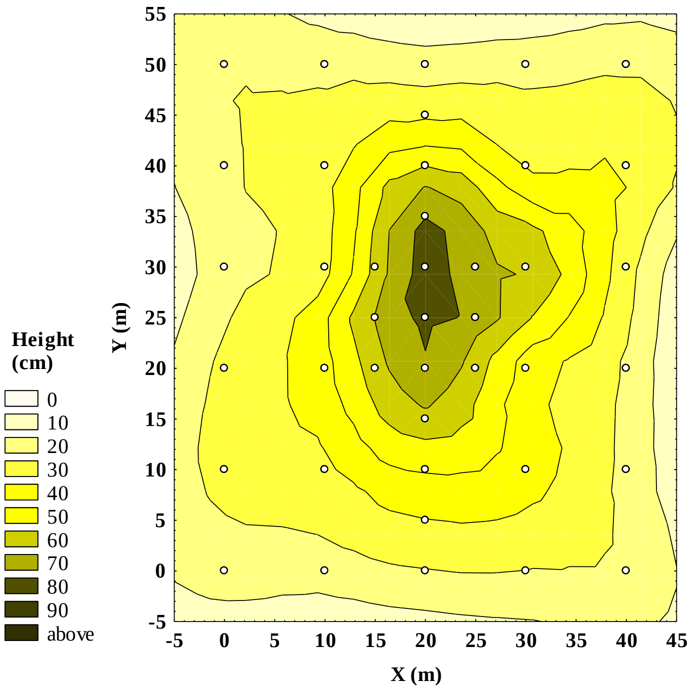


Figure 9. Vép 32/D, north-south gap, vertical distribution in 2014 of Turkey oak (Quercus cerris) seedlings

The vertical distribution (height) of seedlings in *Figure 9* shows similar centralised symmetry as openness or soil moisture.

3.4 Vegetation cover

The dominant species in the Bejcgyertyános site in order of coverage were pokeweed (*Phytolacca americana*), common nettle (*Urtica dioica*), blackberry (*Rubus fruticosus*), giant goldenrod (*Solidago gigantean*), and bush grass (*Calamagrostis epigeios*).

In the Vép site, blackberry (*Rubus fruticosus*), giant goldenrod (*Solidago gigantean*), and bush grass (*Calamagrostis epigeios*) were the dominant species.

In the case of these species, it is a constant pattern that the greatest cover is in the middle of the gap, while the cover of herbs decreases rapidly closer to the closed canopy forest stand. *Figure 10* shows the average total herb cover in 2014.

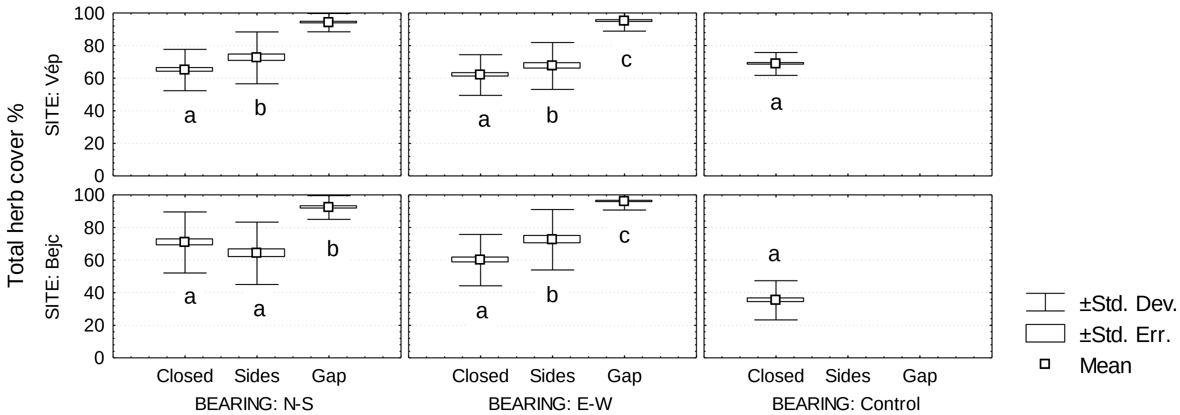


Figure 10. Average total herb cover in 2014, different letters indicate significant differences (p<0.05) between means inside a parcel

Vegetation cover shows a very disperse pattern in the sites, and because of unknown parameters (such as the long lasting history of the forest stand before gap opening), sometimes it is inexplicable why species appear somewhere or not, or how much cover percentage a given species has.

In the case of vegetation cover, the control parcel in Bejcgyertyános has significantly less total cover than the closed canopy gap regions; therefore, in that variable, parcels should also be greater, as in the case of light conditions.

3.5 Correlations

In correlation analyses, the two sites and different years were separately tested (*Table 2*).

Table 2. Correlation matrix; red marked correlations are significant at p < 0.05, VWC: Volumetric Water Content

		Bejcgyertyános 13 A				**Vép 32 D**			
	Variable	*Quercus petraea* height (cm)	Total herb Cover (%)	Openness (%)	Total Site Factor (%)	*Quercus cerris* height (cm)	Total herb Cover (%)	Openness (%)	Total Site Factor (%)
	Year: 2013	**N=141**	**N=392**			**N=384**	**N=392**		
VWC %	Beginning of vegetation season	0.30	0.59	0.59	0.31	0.44	0.59	0.65	0.32
VWC %	Drought period	0.20	0.61	0.59	*0.19*	0.53	0.58	0.64	0.33
VWC %	End of vegetation season	0.39	0.68	0.72	0.47	0.57	0.61	0.69	0.51
	Openness (%)	0.45	0.72		0.72	0.66	0.66		0.82
	Total Site Factor (%)	0.49	0.49	0.72		0.54	0.43	0.82	
	Year: 2014	**N=93**	**N=392**			**N=384**	**N=392**		
VWC %	Beginning of vegetation season	0.40	0.67	0.75	0.47	0.52	0.67	0.70	0.40
VWC %	Drought period	*0.11*	0.66	0.71	0.33	0.61	0.62	0.69	0.43
VWC %	End of vegetation season	0.35	0.60	0.69	0.41	0.53	0.64	0.67	0.45
	Openness (%)	0.50	0.70		0.75	0.64	0.69		0.75
	Total Site Factor (%)	0.51	0.51	0.75		0.52	0.50	0.75	

The correlations were significant at almost every analysed pair of variables; therefore, a gap had demonstrable effect on the variables, but at a different scale. Openness has greater correlation with VWC of any period or total herb cover than total site factor; therefore, the slight northward light effect has less importance than the actual gap opening in those variables. In the case of regeneration height, the correlation with soil moisture and light is high in Vép where greater regeneration numbers are at the site; the greatest correlations were with openness. These correlations are slightly fewer in Bejcgyertyános; openness has no greater correlation than Total Site Factor, probably because fewer data exist.

4 CONCLUSIONS

The paper summarizes the results of a two-year intensive mapping of various bearing artificial gaps at two sites in western Hungary: a sessile-oak-hornbeam, and a Turkey oak forest. The short observation period and small number of sites and parcels made it difficult to compare the results. However, there are significant differences in soil moisture, regeneration, and herb coverage between the middle of a gap and the closed canopy forest stands.

The results suggest that in the case of Turkey oak (*Quercus cerris*) forests, the openness of a gap show great importance as a determining factor. As an initial step of natural regeneration, the gap size used in the experiment should be enough to start a natural regeneration if there were sufficient seedlings or acorns during the time of gap opening. The orientation of the gap shows less importance in the research sites in the studied period.

If no seedlings were present at the time of the gap opening, as in case of sessile-oak-hornbeam forests, the scattering of acorns would be minimal into the middle of a half-tree wide gap and herbs would colonise the gap.

It is also an important fact that even in drier forest stands, like the Vép 32/D site, gaps became significantly watered. This promotes the colonization of soil moisture indicator herbs species and other competitors. For all samples in the research period, the mean value of Volumetric Water Content (soil moisture) during the vegetation period in the sites was about 6 percentage points higher in the middle of a gap (29%) than at the sides of it (23%). The soil moisture was a further 2 percentage points lower under closed canopy (21%).

Correlation analyses reveal that soil moisture, the height of regeneration, and the summarized cover of vegetation depended mostly on openness, and only slightly on the total site factor; therefore, the slight northward light effect of a gap under the closed canopy has less importance in a flat area than in the case of beech (*Fagus sylvatica*) forests in mountainous areas.

APPENDIX

Analysed depths were changed several times in 2013 with Field Scout TDR 300 Soil Moisture Meter with default calibration for standard soils. Comparison measurements were taken to standardise the data in 2014 from spring till summer in Bejcgyertyános 13/A forest sub-compartment control parcel, when in 8 constant control grid point measurements were taken with all used rod lengths (20 cm (n=194), 12 cm (n=224), 7.6 cm (n=224)) in all soil moisture conditions (moist to dry). The standard soil depth for analysis was defined as 7.6 cm because most of the measurements were in that depth; based upon this, the other rod length measurements were converted with converter equations. Volumetric Water Content data with depths of 20 cm and 12 cm were paired with 7.6 cm deep data, and these results were plotted in a diagram. Trend lines were fitted for these pairs to receive the best fitted function (R^2, and equations). The final converter equations (power function) are shown in *Figure 11*. In the upper level (7.6 cm), the soil is moister than the lower levels (12 cm and 20 cm), but there were no significant differences in the soil moisture in the lower levels.

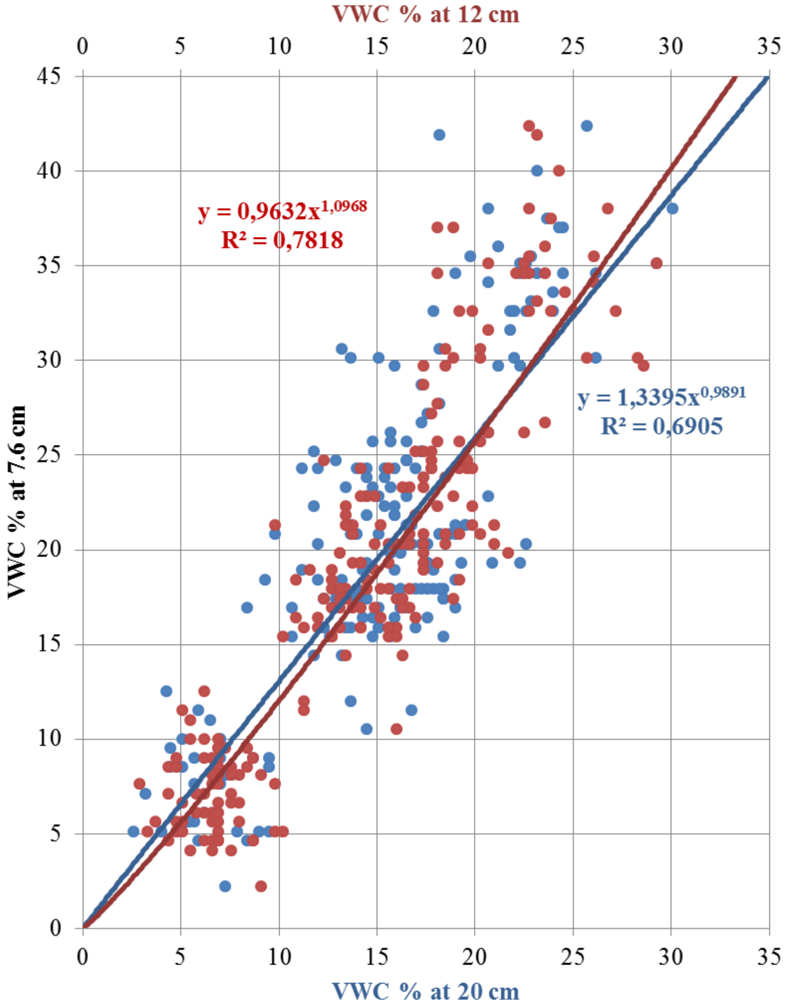


Figure 11. Converting equations of different Volumetric Water Content (VWC) data from 20 cm and 12 cm to 7.6 cm rod length used with Field Scout TDR 300 Soil Moisture Meter with default calibration for standard soils

Acknowledgements: First of all, I am grateful for the altruistic assistance of the publisher's reviewers without whom this article could not have been finished.

I also would like to thank Szombathely Forestry Corporation for providing the forest stands for my research. Finally, I would like to thank my colleagues for their help. This study was supported by the Silva naturalis - Investigation of continuous forest cover in ecological, conservational biological, public welfare and nature conservational aspects TAMOP-4.2.2.A–11/1/KONV-2012-0004 project sponsored by the EU and the European Social Foundation.

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10.1515/aslh-2017-0003 *Acta Silv. Lign. Hung., Vol. 13, Nr. 1 (2017) 41–54*

The Effect of Artificial Lights on Nocturnal Macrolepidoptera (Lepidoptera: Macroheterocera) Communities

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Abstract – We examined the light sources and illuminated environments in Sopron's public areas and studied the impact they had on the composition of macrolepidopteran moth communities. We employed light traps with three different light sources in three differently illuminated environments (seminatural, transitional, urban) on 60 occasions during the summer period of 2012-2013 and 20 times in the seminatural area in the spring and autumn of 2014. In the first two years, we evaluated the number of individuals; in year three, we evaluated the number of species. In the first two years, the high-pressure sodium light in the seminatural site trapped the largest number of nocturnal lepidopteran specimens (2,569), while the mixed HMLI light trapped the most individuals in the transitional (1,098) and urban (822) areas. Based on the average number of individuals the first two years, we compared the locations and light sources. In terms of average number of specimens collected, significant differences emerged between two light sources and two locations. When we completed the species diversity index, we determined the compact fluorescent tube in spring and the high-pressure sodium light in the autumn showed the greatest values.

light pollution / Lepidoptera / light trapping / Sopron / illumination

Kivonat – A mesterséges fényforrások hatása az éjszakai nagylepke közösségek (Lepidoptera Macroheterocera) összetételére. Sopron város közterületein előforduló fényforrások és az ebből eredő eltérő megvilágítottságú környezet hatását vizsgáltuk az éjszakai nagylepke közösségek összetételére. Három különböző típusú fényforrással ellátott fénycsapdát használtunk három eltérő megvilágítottságú környezetben (természetközeli, átmeneti, városi). 2012-2013 év nyarán 60, 2014 tavaszán és őszén a természetközeli helyszínen 20 alkalommal gyűjtöttünk mintákat. Az első két évben egyedszám, a harmadik évben fajszám szerint végeztük a kiértékelést. Az éjszakai nagylepkék egyedszáma az első két évben a természetközeli területen volt a legmagasabb; a nagynyomású nátrium lámpánál (2,569), az átmeneti (1,098) és a városi területen (822) a HMLI kevert lámpa esetén. A fényforrások összehasonlításánál két helyszínen, a területek összehasonlításánál két fényforrás típusnál volt szignifikáns eltérés az egyedszámok átlaga között. A diverzitás vizsgálatnál a diverzitási mutatók tavasszal a kompakt fénycsőnél, ősszel a nátrium lámpánál mutattak nagyobb diverzitási értéket.

fényszennyezés / Lepidoptera / fénycsapázás / Sopron / megvilágítottság

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1 INTRODUCTION

Artificial light sources (streetlights, houses, advertising lights, automobile lights) affect the natural brightness of the night sky and thus exert negative effects on the environment of nocturnal organisms. Illumination emitted from artificial light sources causes ecological light pollution (Horváth et al. 2009), which is spreading at an increasing rate over built environments and is expanding into other habitats. Aristotle was among the first in antiquity to make note of the attraction light sources had on insects at night (Kovács 1962). Nocturnal moths are especially prone to the lure of artificial light sources. Moths are the most significant nocturnal pollinators of flowers and plants (MacGregor et al. 2015), and face the same dangers as butterflies: habitat fragmentation, climate change, pesticides (Fox at al. 2014), and in recent decades, increasing light pollution (Hölker et al. 2010). Artificial lights inhibit the release of pheromones in female moths and effect ovipositioning (Nemec 1969, Sower et al. 1970). If a moth oviposits an unusually high density of eggs in a small space in an unsuitable location near light, the result is an ecological trap (Pfrimmer et al. 1955, Brown 1984) that increases competition for limited food sources among caterpillars (MacGregor et al. 2015). Moths clustering around artificial light sources like lamps also expose themselves to greater risk of predation by spiders, bats, reptiles, and amphibians (Howe 1959, Rydell 1992, Heiling 1999, Henderson – Powell 2001). Thus, increasing light pollution has resulted in significantly reduced moth populations in some European countries (MacGregor et al. 2015).

There are number of studies that deal with the decrease of individuals in pollinator populations around the world, but these focus mainly on diurnal insects (Williams 1982, Potts et al. 2010, Carvalheiro et al. 2013).

There are a number of studies focusing on the level of attraction to various lights within the orders of insect species. Frost (1954) experimented with black (100 W) and white (10 W) lights both together and separately. He experienced black light attracts most insects of the Diptera order, while white light attracted the greatest number of individuals from the Miridae and Chrysopidae orders. In India, monitoring investigations with mercury vapour lamps, black lamps and UV lamps have been carried out. After assessing these light traps, it was found that the mercury vapour lamp attracted the greatest number of individual specimens from the Lepidoptera, Hymenoptera, Hemiptera, Odonata and Diptera orders while the black lights attracted the greatest number of insects from the Coleoptera, Orthoptera, Isoptera and Dictyoptera orders. The UV lamp collected the greatest number of insects from the Orthoptera, Diptera and Dermaptera orders (Ramamurthy et al. 2010). Eisenbeis – Hassel (2000) light trapped in three differing areas including a residential village (with some garden ponds), a farmhouse site and a road site near a village. The lamps were high-pressure mercury vapour (80 W) or high-pressure sodium vapour (70 W or 50 W) and high-pressure sodium-xenon vapour (80 W). For special purposes, some of the high-pressure mercury vapour lamps were fitted with ultraviolet absorbing filters over the glass cover of the luminaires. The high-pressure mercury vapour light attracted the greatest number of insects and the high-pressure mercury vapour light with filter attracted the fewest. Walker – Galbreath (1979) experimented with four types of lights. The mixed mercury vapour lamp (160 W) attracted twice as many insects the black light (8 W). The black light (8W) collected double the insects than the white or kerosene lamps (8W) did.

Our study is important because it examines the relationship between artificial lights and nocturnal macrolepidopteran moths and draws attention to the dangers artificial lights pose to these populations.

The aim of this study is to investigate different types of illumination in the environment – especially those originating from artificial light sources – and the effect these have on the number of lepidopteran individuals collected by light-traps in the summer. Furthermore, the study compares the diversity of the lepidopteran community collected by different artificial lights in the spring and in the autumn. In addition to this, we compare the diversity of lepidopteran communities that we attracted to the various light in both spring and autumn. We assumed that of the three location we used, the greatest number of lepidopteran individuals would occur in the seminatural area. Moreover, we also assumed that the HMLI lamp would produce the highest diversity value of collected lepidopteran communities in the spring and in the autumn as well.

2 MATERIALS AND METHODS

2.1 Study area

We selected three areas of different illumination intensity in Sopron and its surrounding for light-trapping. We termed the sites as follows: seminatural, transitional and urban. The seminatural study area is devoid of artificial lights, has virtually no light pollution, and is located in the Sopron highlands (47°40'N, 16°27'E). The characteristic tree species of the area include beech, hornbeam, sessile oak, sporadically, common alder, birch, crack willow and aspen (Dövényi 2010). The transitional area had slight to moderate light pollution in the area caused by street lamps and illumination of local residences. The transitional site of our study is located in Bánfalva, which is a suburb of Sopron. The tree species present in this area are: cherry, linden, silver fir and white birch (47°68'N, 16°55'E). The urban area is located at the meteorological station, which is in the centre of Sopron; there is significant light pollution from artificial light in this area. The meteorological station was built in 1972 and the park around it was constructed on a limestone foundation with artificial fill. The park contains several shrub and tree species including cherry laurel, hornbeam, common spindle, oriental thuja, and Russian olive (47°40'N, 16°30'E).

2.2 Sampling design

Nocturnal moths specimens were collected in the summers (June, July and August) of 2012 and 2013 as well as in the spring (March, April) and autumn (October, November) of 2014 (*Table 1*). Nocturnal moth specimens were collected on 60 occasions in the years 2012 and 2013 and on 20 occasions in 2014 (*Table 1*). The sampling times were in three-day cycles adjusted to the new moon, the prime of the moon, the wane of the moon, and full moon. For our research, we used Jermy-type light-traps with three different light sources. The individuals collected by light-trapping were killed with ethyl acetate. In 2012 and in 2013, we employed one light trap in each area; we exchanged the lights in each area in three-day cycles (*Photo 1, 2, 3* in Appendix). We utilized all three kinds of light traps simultaneously only in the seminatural area where we separated the light traps from each other with plank dividers (*Photo 4* in Appendix). Light trapping went on for the entire duration of the night, from sunset to sunrise. Based on prior information and knowledge, we used the following three kinds of light sources: a high-pressure sodium lamp (150 W, 1950 K, 17500 lm), a HMLI mixed lamp (160 W, 4200 K, 3100 lm), and a compact fluorescent tube (36 W, 4000 K, 2900 lm). We selected these light sources because they were the most commonly occurring ones in residential settlements.

Table 1. Light- trapping dates in the first two years

Year	June	July	August
2012	10;11;12;18; 19;20;26;28	2;3;4;10;12; 17;18;19;27; 28	7;8;9;16;17;18; 23;24;25;30;31
2013	7;8;9;15;16; 17; 22;23;24;29;30	1;7;8;9;15; 16;17;28;29;30	5;6;7;13;14; 15;21;22;23

Year	March	April	October	November
2014	29;30;31	7; 8;	14;15;16;22;23;24;30;31	1;5;6;7;13;14;15

We counted the collected lepidopteran individuals in 2012 and in 2013, and on the species level in 2014. The following literature was used for identification: Reichholf-Riehm (1996), McGavin (2000a, b), Sterry-Mackay (2004), MacGavin (2005), Varga (2010).

2.3 Data analysis

We analysed the results in two ways. The first analysis was based on the number of collected Lepidoptera individuals in the three areas in the summer 2012 and 2013. We investigated the correlation between the different illumination areas and the number of lepidopteran individuals collected. For the analysis of the average number of individuals, we made a comparison of the locations and light sources used based on the average number of collected lepidopteran specimens. Using the nonparametric Kruskal-Wallis H test, we examined data lines to determine if they could stem from same distribution (the test in accordance ANOVA nonparametric); this examination had a 95 % level of trustworthiness. We used a Statistica 12 program for the assessment and with the help of the Lilliefors and Shapiro test we employed a normalization investigation. The results of this determined that the collected data was usually within the range of normal distribution (Kemény et al. 2011); the evidence for this were the „p" values, which were smaller than 0.05 (α=0.05) in many cases, but did not hold true for every pattern. In the second analysis, community ecological comparisons were completed on Lepidoptera assemblages collected by the various light traps using the Past program (Paleontological Statistics Software 2.17) (Hammer et al. 2012). We measured and compared the light attraction of lepidopteran communities to various light sources with the Jaccard similarity index (Raup – Crick 1979). To determine lepidopteran diversity, the Shannon index, Simpson index were calculated, and a Pielou-type equitability test (Krebs 1985). To compare diversity values, we used the Rényi diversity profiles (Tóthmérész 1997). To determine the species dominance of the lepidopteran communities, we utilized the Berger-Parker dominant index (Southwood 1984).

3 RESULTS

Summarised, 10,902 individuals of Lepidoptera were collected in 2012 and 2013. Of the three areas, the greatest number of individuals collected was in the seminatural area (6,568) using the HMLI mixed lamp (5,145) (*Table 2*). When we compare the catch results based on light source, the high-pressure sodium lamp in the seminatural area yielded the largest number of individuals (2,569) while in the transitional (1,989) and urban area (822) the HMLI mixed lamp yielded the most individuals specimens.

Table 2. Number of collected Lepidoptera individuals

2012			
Area/Lamp	seminatural	transitional	urban
High-pressure sodium lamp	938	194	200
HMLI mixed lamp	780	532	429
Compact fluorescent tube	750	183	224
2013			
High-pressure sodium lamp	1631	188	278
HMLI mixed lamp	1554	566	393
Compact fluorescent tube	915	124	78

There was no significant difference among light sources in the seminatural area (p>0.99). In the transitional area, we found a notable difference between the high-pressure sodium lamp and the HMLI mixed lamp (p<0.02), and between the compact fluorescent tube (p<0.001). In the urban area we found a notable difference between the HMLI mixed lamp and the compact fluorescent tube (p<0.04) (*Table 3*).

Table 3. Comparison of light sources based on catch number average in the transitional and in the urban area

Area		p value	
Transitional		Lamp	
		High-pressure sodium lamp	HMLI mixed lamp
Order	High-pressure sodium lamp		
Lepidoptera	HMLI mixed lamp	p < 0.02	
	Compact fluorescent tube	n.s.	p < 0.01
Urban			
		High-pressure sodium lamp	HMLI mixed lamp
Order	High-pressure sodium lamp		
Lepidoptera	HMLI mixed lamp	n.s.	
	Compact fluorescent tube	n.s.	p < 0.04

Based on location comparisons, we found notable dissimilarities in the average number of specimens trapped using the high-pressure sodium lamp and the compact fluorescent tube in the seminatural and transitional areas as well as between the seminatural (p<0.001) and the urban (p<0.001). We detected no considerable discrepancies in the averages in any of the locations with the HMLI mixed lamp; however, with the compact fluorescent tube, the difference between the seminatural and the transitional was (p<0.001), while the difference between the seminatural and urban locations was (p<0.001) (*Table 4*).

According to lamp source, we identified 134 macrolepidopteran individuals from 13 species in the seminatural area in the spring of 2014. In the same location in the autumn, we identified 851 individuals from 11 Lepidopteran species using Varga (2010) nomenclature (1. appendix, 2. appendix).

We analysed the number of collected lepidopteran individuals using the Berger-Parker dominance test. The dominant species in the spring collected by the high-pressure sodium lamp was *Colocasia coryli* (L.1758), while in the autumn *Operophtera brumata* (L.1758) was the dominant species. With the HMLI mixed lamp and the compact fluorescent tube, the dominant lepidopteran species in the spring was *Lycia hirtaria* (C.1759), and in the autumn, it was *Operophtera brumata* (L.1758) (*Table 5*).

Table 4. Comparison of areas based on catch number averages using high-pressure sodium lamp, HMLI mixed lamp and compact fluorescent tube

Lamp		p value	
High-pressure sodium lamp		Area	
		Seminatural	Transitional
Order	Seminatural		
Lepidoptera	Transitional	$p < 0.001$	
	Urban	$p < 0.001$	n.s.
HMLI mixed lamp			
		Seminatural	Transitional
Order	Seminatural		
Lepidoptera	Transitional	n.s.	
	Urban	n.s.	n.s.
Compact fluorescent tube			
		Seminatural	Transitional
Order	Seminatural		
Lepidoptera	Transitional	$p<0.001$	
	Urban	$p<0.001$	n.s.

Table 5. Berger-Parker dominance index of Lepidoptera species

Berger-Parker dominant index (D)			
Month	Lamp	Species	D value
March-April	High-pressure sodium lamp	*Colocasia coryli* (Linnaeus,1758)	0.5455
October-November	High-pressure sodium lamp	*Operophtera brumata* (Linnaeus, 1758)	0.2552
March-April	HMLI mixed lamp	*Lycia hirtaria* (Clerk,1759)	0.6857
October-November	HMLI mixed lamp	*Operophtera brumata* (Linnaeus, 1758)	0.4220
March-April	Compact fluorescent tube	*Lycia hirtaria* (Clerk,1759)	0.3889
October-November	Compact fluorescent tube	*Operophtera brumata* (Linnaeus, 1758)	0.6118

We compared the species similarity of nocturnal lepidopteran communities according to the three light sources and determined that the similarity comparison of the communities was highest with the HMLI mixed lamp and the compact fluorescent tube, while in the autumn the highest similarity was the high-pressure sodium lamp and the compact fluorescent tube (*Table 6*).

Table 6. Jaccard similarity coefficient in the spring and in the autumn

	Jaccard similarity coefficient			
	March-April		October-November	
Lamp	High-pressure sodium lamp	HMLI mixed lamp	High-pressure sodium lamp	HMLI mixed lamp
Compact fluorescent tube	0.22	0.42	0.9	0.82
HMLI mixed lamp	0.2		0.73	

We found the greatest similarity when investigating density in the spring between the high-pressure sodium lamp and the compact fluorescent tube, while in the autumn the closest similarity in terms of density was between the HMLI mixed lamp and the compact fluorescent tube (*Table 7*).

Table 7. Bray-Curtis similarity index in the spring and in the autumn

	Bray – Curtis similarity index			
	March-April		October-November	
Lamp	High-pressure sodium lamp	HMLI mixed lamp	High-pressure sodium lamp	HMLI mixed lamp
Compact fluorescent tube	0.55	0.24	0.59	0.6
HMLI mixed lamp	0.17		0.54	

The diversity indices for macrolepidopteran communities showed the greatest values in the spring with the compact fluorescent tube, while in the autumn the greatest values occurred with the high-pressure sodium lamp (Simpson, Shannon, Pielou equitability) (*Table 8, 9*).

Table 8. Diversity indices in the spring

Month	March-April		
	Lamp		
Species richness	High-pressure sodium lamp	HMLI mixed lamp	Compact fluorescent tube
Simpson index	0.562	0.511	0.772
Shannon index	0.917	1.199	1.749
Pielou equitability	0.834	0.546	0.841

Table 9. Diversity indices in the autumn

Month	October-November		
	Lamp		
Species richness	High-pressure sodium lamp	HMLI mixed lamp	Compact fluorescent tube
Simpson index	0.804	0.748	0.585
Shannon index	1.782	1.703	1.290
Pielou equitability	0.811	0.739	0.560

By comparing the lepidopteran community diversity profile to the three types of lamp sources, we determined that the community trapped in the spring using the compact fluorescent tube was more diverse than the community trapped using the high-pressure sodium lamp. In addition to this, from the perspective of lepidopteran diversity, the communities trapped with the HMLI mixed lamp and the high-pressure sodium lamp cannot be ranked (*Figure 1*).

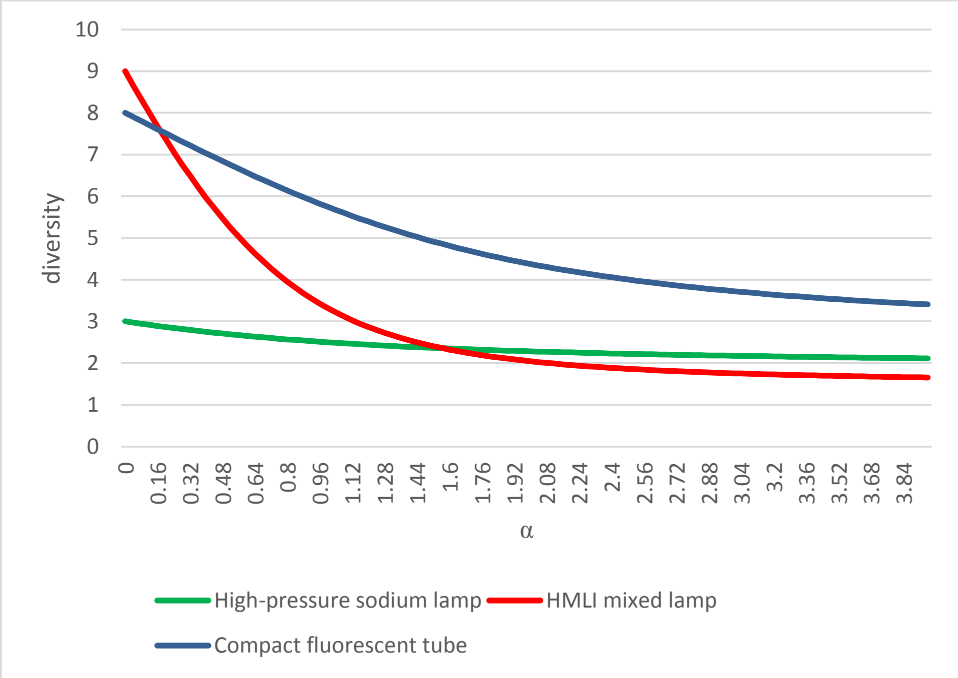

Figure 1. Rényi diversity graph in the spring according to the three lamp sources

The lepidopteran community collected with the HMLI mixed lamp in the autumn is more diverse than the community collected with the compact fluorescent tube. The graph lines of the high-pressure sodium lamp, the HMLI mixed lamp, and the compact fluorescent tube all intersect on the graphs; therefore, the diversity of the light-trapped macrolepidopteran communities cannot be ranked by lamp source (*Figure 2*).

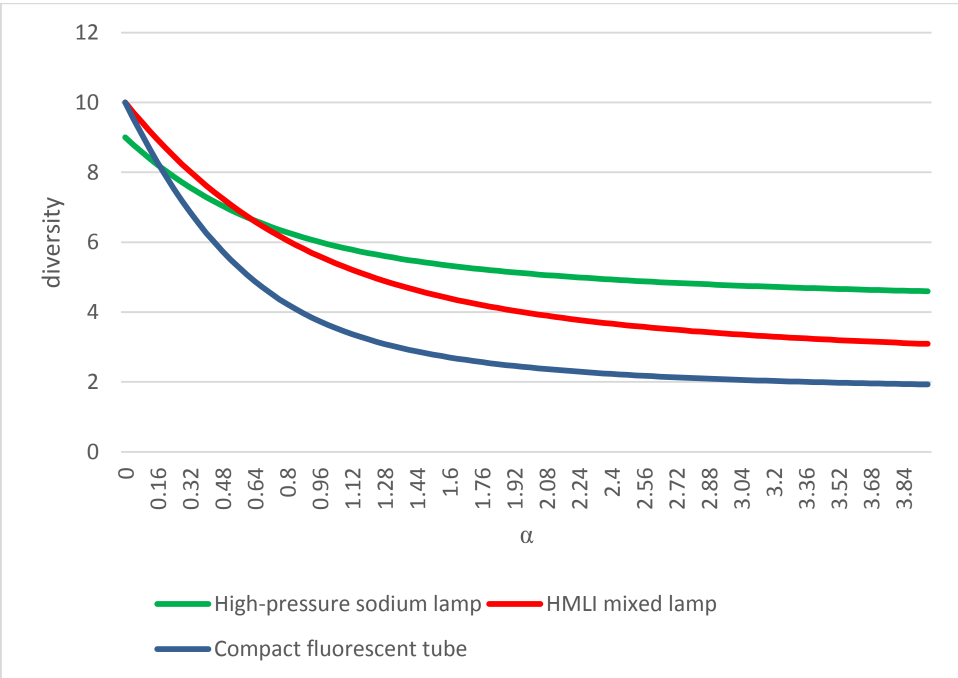

Figure 2. Rényi diversity graph in the autumn according to the three lamp sources

4 DISCUSSION

A study employing methods similar to ours was completed in rural Germany (Eisenbeis – Hassel 2000). As in our research, the German study used various locations to complete their light-trapping: the residential area of the town of Sulzheim, a more rural agricultural location with farmhouses, and a road near the edge of the Sulzheim settlement; although the study did not specify, we assumed that this area had different environmental illumination. The types of light used were high-pressures mercury vapour (80 W), high-pressure sodium vapour (70 or 50 W), high-pressure sodium-xenon vapour lamps (80 W), and for special purposes, some of the high-pressure mercury vapour lamps were fitted with ultraviolet absorbing filters. The number of collected insects was the greatest with the high-pressure mercury vapour lamp. The light sources used in the abovementioned study are different from the ones we used in our study; thus, the results of the two studies are incomparable. One new and innovative method in our study is the selection of light-trapping areas based on the light pollution in each given area. There were no significant differences in the average number of individuals trapped in the seminatural site; notable dissimilarities occurred only in the transitional and urban sites. From this, we can conclude that background illumination has a meaningful effect on trapping distance or, put another way the attraction distance, of the light sources. We come to the similar conclusion if we compare the sites by lights because in two cases there were significant differences: between the seminatural and the urban, and between the seminatural and the transitional sites.

In our study, we used light traps with three different light sources in the area of Sopron and the Sopron highlands. Many faunistic investigations concerning nocturnal macrolepidopteran communities have been completed in this location (Leskó – Ambrus 1998, Sáfián – Szegedi 2008, Sáfián et al. 2009, Horváth et al. 2013, Horváth – Lakatos 2014), but none employed methods that were similar to ours. The results gathered and compiled for the seminatural area cannot be considered complete due to the small number of specimens collected by light-trapping; nevertheless, the research studies still point to which nocturnal lepidopteran species are attracted to artificial lights in the spring and in the autumn. Therefore, our study draws attention to the potential danger artificial lights pose to certain nocturnal lepidopteran species. The basis of our results prove that in the spring individuals of the *Lycia hirtaria* (Clerk, 1759) species were drawn by the highest number to the HMLI mixed lamp, while individuals of *Colocasia coryli* (Linnaeus, 1758) species were attracted by the highest number to the high-pressure sodium lamp. In the autumn, individuals of *Operophtera brumata* (Linnaeus, 1758) species were attracted high-pressure sodium lamp in the highest number.

The type of light sources is not the only factor that influences the light attraction of individuals from the microlepidopteran and macrolepidopteran species (Frost 1954, Mészáros 1966, Nowinszky – Ekk 1996, Ábrahám et al. 2009, Puskás – Nowinszky 2011) the height positioning of the light also plays a role. This can be an especially important factor in the case of street lamps (Bürgés 1997). In our study, we positioned our light traps at a 2 m height from the ground. Before we embarked on the research, we assumed that the high-pressure sodium lamp would produce the greatest diversity index values in every season, because it was the light source with the highest luminosity value. In contrast, the results show that according to the Shannon, Simpson, and Pielou equitability indices, values are the highest in the spring with the compact fluorescent tube, whereas the high-pressure sodium lamp showed the highest values in autumn.

The similarity between macrolepidopteran communities in the spring and autumn with the HMLI mixed lamp (3100 lm) and the compact fluorescent tube (2900 lm) could be attributed to the similar luminosity of the two light sources. This condition is apparent in the diversity profile as well.

The results confirm our supposition that the greatest number of collected lepidopteran individuals occurred in the seminatural area. Therefore, artificial light sources may decrease the number of lepidopteran individuals. The results also partly support another of our supposition – the diversity of Lepidoptera communities was the greatest by compact fluorescent tube in the spring and by high-pressure sodium lamp in the autumn. Our results illustrate the diverse sensitivity of lepidopteran species to different lamps.
The results demonstrate that from a nature protection point of view, artificial lights can negatively affect the environment of lepidopteran communities.

For further investigation and for a better understanding of the effect artificial lights have on Lepidoptera communities, we would require more areas, sites, dates, and lights.

Acknowledgements: We would like to thank Institute of Geomatics, Forest Exploration, and Water Management Institute at the Faculty of Forestry of the University of West Hungary and the Meteorological Station in Sopron for ensuring and providing the research sites used for this study.

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APPENDIX

Appendix 1: The number of lepidopteran individuals collected by light source in the spring

Date March-April	Lamp		
Species	High-pressure sodium lamp	HMLI mixed lamp	Compact fluorescent tube
Lycia hirtaria	4	72	7
Colocasia coryli	6	11	4
Ectropis crepuscularia	1	0	0
Conistra vaccinii	0	4	1
Orthosia cruda	0	6	0
Orthosia incerta	0	3	0
Endromis versicolora	0	4	2
Orthosia gothica	0	3	0
Lampropteryx suffumata	0	1	1
Polyploca ridens	0	1	0
Panolis flammea	0	0	1
Euphia biangulata	0	0	1
Selenia dentaria	0	0	1

Appendix 2: The number of lepidopteran individuals collected by light source in the autumn

Date October-November	Lamp		
Species	High-pressure sodium lamp	HMLI mixed lamp	Compact fluorescent tube
Colotois pennaria	10	22	2
Erannis defoliaria	36	50	23
Asteroscopus sphinx	5	8	4
Conistra vaccinii	3	0	1
Epirrita dilutata	71	5	1
Ptilophora plumigera	24	85	24
Operophtera brumata	74	165	104
Operophtera fagata	63	25	3
Agriopis aurantiaria	4	13	6
Eriogaster rimicola	0	2	0
Poecilocampa populi	0	16	2

Photo 1: Seminatural, light pollution free site

Photo 2: Transitional, site with slight pollution

Photo 3: Urban site with considerable light pollution

Photo 4: Simultaneously operating light traps in the seminatural site

10.1515/aslh-2017-0004 *Acta Silv. Lign. Hung., Vol. 13, Nr. 1 (2017) 55–67*

Application of Environmental Information Systems in Environmental Impact Assessment (in Hungary)

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Abstract – The primary research aim was to explore the possibilities of transferring relevant data from information systems and databases required for practical environmental impact assessment. The necessary and adequate data content of environmental impact studies were defined according to legal regulations, expert recommendations as well as available impact studies. Furthermore, the data content of information systems pertinent to environmental impact analysis were investigated in view of data transmission. Disposing of the primary data required for impact studies, the classification of environmental objects (object class, object group, object type) was performed. Based on the latter, a pattern system design was completed; in the course of developing this, we defined the individual system overlays in the theoretical model, then assigned properties of the individual object types in the database model.

environmental impact assessment / environmental database / information system / system design / data model

Kivonat – Környezeti információs rendszerek alkalmazása a környezeti hatásvizsgálatok során. A kutatás elsődleges faladata a környezeti hatásvizsgálat gyakorlati kivitelezéséhez szükséges adatok információs rendszerekből, adatbázisokból való átvételi lehetőségének vizsgálata volt. Jogszabályi előírások, szakirodalmi ajánlások valamint már elkészült hatástanulmányok vizsgálata alapján meghatározásra került a környezeti hatásvizsgálatok szükséges és elégséges adattartalma. Vizsgáltuk továbbá a környezeti hatásvizsgálatok szempontjából relevánsnak tekinthető információs rendszerek adattartalmát illetve az adatátvétel lehetőségét. A hatástanulmányokhoz szükséges primer adatok ismeretében elvégeztük a szükséges környezeti objektumok osztályozását (objektumosztály-, csoport, típus). Ennek ismeretében egy minta rendszertervet dolgoztunk ki, amely során az elméleti modellben meghatároztuk a rendszer egyes fedvényeit, majd ezt követően a logikai adatmodellben megadtuk az egyes objektumtípusok tulajdonságait.

környezeti hatásvizsgálat / környezeti adatbázis / információs rendszer / rendszerterv / adatmodell

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1 INTRODUCTION

Prior to implementing, abandoning, or significantly extending establishments and operations that fall within the scope of certain conditions, conducting environmental impact assessments (EIA) are often required by law; even if there is no legal obligation for an EIAs, it is highly recommended as a precautionary measure (Elekné Fodor 2012). Since its introduction in the early 1970s, the role and scope of EIAs are continuously expanding, although its application, practice, and procedures vary from country to country (Lee 1995). Between 1994 and 1997, the number of environmental impact assessments submitted to the authorities in Hungary increased by an average 10% annually. There were more than 500 impact studies in 1997 (Pájer 2001); by 2005, this number exceeded 750 (Cseh at al. 2007).

The objective of an environmental impact assessment is to explore environmental impacts and to assess and demonstrate the resulting changes that can ensue from given human activities and their products (Pájer 1999, Chen 2014). By this method, environmental requirements have a better chance of prevailing in the course of decision-making (Glasson 1995, Rédey – Utasi 2004, Cserny et al. 2009). Generally, an impact study is an information collection and analysis process; thus, up-to-date, available, and relevant data are needed to attain useful results (Bulla et al. 2004). The importance and necessity of data is emphasized in the basic principles of an environmental impact assessment; the realisation of an EIA is only possible if the appropriate quantity and quality of data is available. Fortunately, when it comes to environmental impact studies, a rise in the quantity of studies conducted has also led to a rise in quality (Barker – Wood 1999).

One of our research objectives was to explore the primary environmental descriptive data that is both necessary and appropriate for the demonstration of the state of elements in the environment and for the probable effects assessment in the course of environmental impact studies. The data list we compiled contained the data needed in most environmental impact analyses. We set a further objective for investigating the data content, availability, and possibility of data transmission of information systems relevant to our research.

Science and engineering research will produce increasingly more scientific data. Databases and information systems are also increasing. They are used to describe the state of the environment and to track the impact individual companies have on the environment and to ensure these companies adhere to environmental protection goals (Dedrick 2010). Using this data successfully depends on the ability to access, integrate, and analyse these large databases (Tarboton et al. 2009). Environmental decision support systems as well as participatory environmental decision making also require a database that incorporates and allows dynamical incorporation of interdisciplinary expert knowledge (Bianconi et al. 2004). These have motivated more global initiatives to build spatial data infrastructures (Masser 1999, Kok – Van Loenen 2004) to facilitate the collection, maintenance, dissemination, and use of spatial information (Lagacherie et al. 2007, Bulla 2012). National and international initiatives aimed at building accurate data infrastructures increasingly call for standardized, harmonized, and up-to-date information. For example, INSPIRE (Infrastructure for Spatial Information in the European Community) encourages local and national contributors to apply standards of data format and quality to combine their information with information from other sources (Jensen et al. 2004). Comprehensive environmental information can be propagated to the public via the internet rapidly, simply, and in real-time (Schimak 2003).

In the light of the above, our task was to lay down the foundations of an information system that can support the data acquisition process of environmental impact analysis in view of the general list of data and the contents of relevant information systems.

2 MATERIALS AND METHODS

2.1 Exploration of the general data requirement of environmental impact assessment

The first step of our research was to study the specifications relative to data contained in EU and domestic laws pertinent to environmental impact analysis. We explored the relevant literature; moreover, we followed the method used by Hemann et al. (2007) and analysed the documentations of completed impact studies. In the course of our investigations, we examined 62 environmental impact assessments, of which 40 were preliminary examination documentations and 22 were completed environmental impact studies. Most of the impact assessments for investigation were randomly selected through electronic search (89%) as well as the studies conducted by the Institute of Environment and Earth Sciences of the University of West Hungary.

The data analysis is based on data collection, performance indicators, and data quantification (Wang et al 2014). In the course of investigation, we determined general primary environmental data that the law prescribes or recommends, or that were actually used by the authors of the examined environmental impact studies. On this basis, a data list was compiled containing only those data fields that occurred with at least 75% frequency in the examined impact studies as a result of statistical evaluation.

Besides the general list of data, the data requirement of a concrete type of establishment (roads) was explored in order to examine the deviations due to special data requirements, or, in other words, the usability of the general list of data. The investigations by Forman (2000) call the attention to the impact roads have on the environment. Since a notable part (40%) of the documents related to roads (*Table 1*), and we ourselves were concerned with environmental impact studies of this type in our professional work, the data requirement of these type of establishments was defined in our establishment-specific examinations.

Table 1. Distribution of the examined Environmental Impact Assessments according to their subject

Subject of EIA	Number of examined EIA (pc)
livestock farms	2
mine	6
power plants (thermal, nuclear)	2
wind farm	2
landfill	4
industrial factory	3
recreation facility	4
flood protection structure, reservoir	3
public utility (water, gas, electricity, sewerage)	8
thermal bath	1
railway	2
minor road	**14**
forestry road	**4**
express highway	**7**
Total	62

2.2 Examination of environmental information systems

From the point of view of environmental impact analysis, relevant environmental descriptive databases and information systems were those that can provide environmental data concerning the individual elements of the environment. Through internet searches and the examination of printed documents (handbooks, manuals, reports), 34 databases (9 international and 25 domestic) were identified which, based on their titles, can probably be used as a potential source of data for environmental impact analysis (*Table 2*).

Table 2. Examined international and national information systems and databases

International Information Systems and Databases
European Soil Database (ESD)
The Water Information System for Europe (WISE)
Air Quality in Europe
Natura 2000
Coordination of Information on the Environment (CORINE)
Global Environment Monitoring System (GEMS)
Copernicus
Shared Environmental Information System (SEIS)
European Pollutant Release and Transfer Register (E-PERT)
National Information Systems and Databases
Digital Kreybig Soil Information System (DKTR)
Forest Protection Measuring and Monitoring System (EMMRE)
Database of Office of Cultural Heritage (KÖH)
Database of the Hungarian Central Statistical Office (KSH)
Database of Geological and Geophysical Institute of Hungary (MÁFI)
Database of hydrophysical properties of Hungarian soils (MARTHA)
Database of the Hungarian Office for Mining and Geology (MBFH)
Land Parcel Identification System (MEPAR)
Landscape Ecological Vegetation Database & Map of Hungary (MÉTA)
Database of BirdLife Hungary (MME)
Database of Institute for Soil Sciences and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences (MTA TAKI)
Hungarian Biodiversity Monitoring System (NBmR)
National Remote Sensing Field Plant Monitoring (NÖVMON)
National Forest Database (OEA)
Database of National Institute of Environmental Health (OKI)
Database of Hungarian Air Quality Monitoring Network (OLM)
Database of Hungarian Meteorological Service (OMSZ)
National Game Management Database (OVA)
Soil Degradation Information System (TDR)
Land Information System (TEIR)
Landscape Value Cadastre (TÉKA)
Soil Conservation Information and Monitoring System (TIM)
Nature Conservation Information System (TIR)
Water Information System (VIZIR)
Monument database

As a selection criterion for further examinations, the scope and coordination of the databases by governmental bodies (managing offices, national institutes, and ministries) were applied. From this range of databases, 16 environmental databases that were deemed the most important and most useful for our research were selected; their actual importance was defined with expert assistance. Using questionnaires (102) and personal interviews (36), professionals who, according to the database of the Environmental Professional Information System (XIR), have been conducting environmental impact studies or have been practicing expert activities of this kind were invited to participate in our research project. To attain a realistic examination of the knowledge and use of the systems, we worked towards a well-balanced representation of the different professional fields in the sample when selecting professionals to be involved. The individual professional fields were defined according to the elements and environment systems. In the analyses of the databases, the general data content, and the spatial (number and distribution of measurement points) and temporal validity and reliability of data were examined, as well as the practical application of the systems according to different points of view, such as availability, operability, software demand, download possibilities and formats, and user fees.

The list of data required by environmental impact studies was compared against the data contents of the information systems; the extent of the overlay was also examined. The achievability of data required was examined through queries of databases. This way it is possible to identify what data can be taken from which information system.

2.3 Object classification and the elaboration of the pattern system design

Based on the compiled list of data, an object classification of the environmental data needed for the impact studies was performed. A possible hierarchic classification is class – group – type. One class can contain several groups and one group can contain several types. Based on the system worked out by the National Forestry Service (1999), the identifier of the objects was defined. The first letter in the identifier (from A to Z) stands for the object class, the second letter (from A to Z) designates the group, the third and fourth character (from 01 to 99) gives the object type.

During model building, a system design was worked out. Tsichritzis and Lochovsky (1977) define a data model as "a set of guidelines for the representation of the logical organization of the data in a data base (consisting) of named logical units of data and the relationships between them”. According to the concise definition by Detrekői and Szabó (1995), modelling amounts to describing the real world with a reduced set of information, in a three-step process of abstraction. In the first step, a theoretical model substitutes the real world; in this model, the entities, persons, objects, incidents and events to be used in the final model are defined. In our case, these entities are the individual system overlays of the system. In the following step, the parameters needed for the description of the theoretical model entities (geometrical and attribute data of the object types) are defined, as well as their interrelationships, that is the logical model of objects is set up. In the system design, the examination of relationships has not been touched upon, so the physical data model (third step) has not been created, which would mean the mapping and uploading the logical model in a digital environment (Czimber 2002).

3 RESULTS AND DISCUSSION

3.1 Definition of the general data requirement of environmental impact analysis

In examining the phases and work stages of impact analysis, it was established that the surveying phase is primarily the basic state in which databases or information systems can serve as potential data sources. Consequently, in our research the analysis of data needed for the examination of the basic state of the environment was emphasized; hence, they are taken into consideration for impact assessment and evaluation.

Environmental data needed for the execution of impact studies are defined by neither foreign nor domestic laws; however, they refer to the need of certain environmental information. Pertinent literature (Tombácz – Radnai 1989, Bisset – Tomlinson 1992, Rédey et al. 2002), however, pays attention to the examination of data that can serve as the basis for characterising the environment's basic state, assessing the range of impacts, and evaluating them. Our investigations verified that in environmental impact studies characterising the basic state of the environment, general data content can be defined, which the executors of impact studies can utilize in the case of any type of establishments. Those environmental data were incorporated into our master data list, which occurred in at least three-quarters (75%) of the studies that were investigated. *Table 3 shows* primary data grouped as elements of the environment.

Table 3. General data of Environmental Impact Assessments

Soil	topography, geomorphology, geological structure and bedrock, parent material, direction of slope, genetic and physical soil type, water balance, location and sensitivity of the soil layers, soil texture, pH, soil water management categories, depth of the column, soil compaction depth of the groundwater, protected geological values
Air	average hours of sunshine, prevailing wind direction, wind speed, precipitation conditions, spatial and temporal distribution of rainfall, average temperature data, air quality, background contamination, protected and sensitivity categories
Water	size and location of surface and groundwater, water flow conditions, standard flow, protected hydrological values, water facilities
Flora and fauna	types of habitat, habitat patches, species composition, rare plant communities, protected plants, animal species and population of the examined area, protected animals
Settlement, artificial environment	size and distance of built environment, built-up, cultural values, historical monuments, function of the examined area
Population	the size of the affected population
Land	landscape, land use, nature-function areas, protected areas, landscape values

The data requirement of a concrete type of establishment was revealed in order to check the usefulness of the general list of data. In the case of the master data of environmental impact analysis for roads, the difference with respect to the data in the general list was low (12% altogether); thereby, we considered our verified data list generally useful.

3.2 Comparison of the data requirement against the data content of environmental information systems

The number of information systems has shown an important increase in the last few years. However, data collection has become difficult because data cannot be found in a unique database, but rather are stored in several thematic databases.

In the case of soils, one of the biggest international systems is the European Soil Database. This is part of the European Soil Information System (EUSIS), a collaborative project involving all European Union and neighbouring countries and is a simplified representation of the diversity and spatial variability of the soil coverage. The database consists of both a geometrical dataset and a semantic dataset that links attribute values to the polygons of the geometrical dataset.

Thanks to the soil mapping and soil testing activities carried out for several decades, Hungary possesses soil science information that is unequalled within European countries (Várallyay et al. 2009). During the last two decades, an important part of the map-based pedological information has been digitalised and built into different special soil information systems (Szabó – Pásztor 1994). A detailed examination of three information systems related to soil has been carried out in our research. The Soil Conservation Information and Monitoring System (TIM), covering the whole area of the country, provides parameters of soil physics, soil chemistry, and soil biology from 1,236 measurement points. High-scale soil maps form the basis for the Database of Agro Topography. The map-based soil information system contains the main pedological parameters defining the site aptitude, including genetic soil type, soil-forming rock, physical soil type, clay composition, water balance properties, chemical reaction, lime state, organic stock, tilth thickness, and soil evaluation. The Hungarian Institute of Soil Sciences Database gives information about the geological structure, base rock and ground water for the whole area of the country in a map-based form.

Most of the systems involved with air are global; in these, atmospheric phenomena and climate change are stressed. Databases containing local data in relation with the air quality are rare. One such information system is Air Quality in Europe, the aim of which is to provide publically available data on the air quality in European big cities for information and comparison. In Hungary, the National Measuring Network of Air Pollution (OLM) database contains automatically and manually generated air quality data.

The last several years a significant improvement in hydrologic and environmental data availability has occurred (Beran – Piasecki 2009). The Water Information System for Europe (WISE) is a joint initiative from the European Commission (DG Environment, Eurostat, Joint Research Institute) and the European Environment Agency that aims to modernise and streamline the collection and dissemination of European water policy-related information (D'Eugenio 2007).

The development of hydrographic information in Hungary could be characterised as progress in small steps. In recent decades, work on the unified information system of the branch has been ongoing. In the directories of water management, several databases currently exist; some have been centrally developed, others are self-developed. The Water Information System (VIZIR) is a registration and processing system of water management data; its basic (descriptive) database system is the Data Store of Water Management created in 2004. The base data register of the Data Store of Water Management covers the whole Danube Basin. Currently, the national system of VIZIR comprises more than 20 databases.

Databases relevant to fauna and flora, and landscape are scarce both on the international and national levels. Among the international systems, the Coordination of Information on the Environment (CORINE) and the Natura 2000 network provide data of surface coverage and nature protection-related descriptive data for Hungary.

The Nature Conservation Information System (TIR), working as a sub-system of the National Information System of Environmental Protection, can be considered as the principle database of domestic nature conservation. The primary objective of the system is to register nature conservation databases belonging to local and governmental authorities (landscape values: objects of geology, hydrography, botany, zoology, scenery, cultural history, eco-tourism, protected natural areas) and organising these into a unified geographic information system compatible with the systems in the European Union. Because landscape value versatility, there was no unified domestic database that could collect and handle these data in a common registration system. Landscape Value Cadastre (TÉKA) is an integrated database covering the entire country. Uniting the databases of different professional organisations with the active participation of nearly a thousand civilians, it is the most detailed and most complete landscape values database.

In acquiring data regarding the built environment and humans, it was possible to rely primarily on domestic databases. Besides the Settlement Statistical Database System of the Hungarian Central Statistical Office (KSH T-STAR) and the Database of the Office of Cultural Heritage (KÖH), mention should be made of the National Regional Development and Country Planning Database. The aim of this GIS-based system is to provide objective, precise, and up-to-date information for regional development and planning activities. This system contains more than thirty-five thousand data by settlements. It is also interesting to mention the E-PRTR (European Pollutant Release and Transfer Register), which includes environmental use data for nearly 28,000 industrial establishments (Yoshida et al. 2014).

Based on their data content, the investigated domestic and international systems are applicable in the support of environmental impact studies. However, large portions of these systems consider local conditions; hence, the international databases are often insufficient to meet domestic data demand. In the case of international databases, commonly the number of measuring points has been limited; with respect to Hungary, there are considerably fewer measuring points than needed. Furthermore, several international systems call in data from the member states themselves and upload the same in its central database. Subsequently, regarding these facts in examining the possibilities of data transmission, the focus was on domestic information systems and databases.

Having compared the information systems' data content against the data requirement of EIA, it could be established that the environmental information systems include the majority (88%) of data needed for the characterisation of the basic state of the environment, so they are indeed appropriate for the support of environmental impact studies. Following this comparison, a preliminary guide was compiled for the use of practical environmental impact analysts. This guide contains data from the impact-analysis master data that are recommendable for transfer from the information systems and databases. Source of transfer, data model, transferrable data, geometry of objects are indicated for each data point along with additional notes regarding the systems. *Table 4* shows details of this guide.

Table 4. Detail of the guide to the transfer of data

Environmental data	Data source	Data model, geometry, visualization	
		SOIL	
Topography	MÁFI	GIS map with activated topographic layer and GIS groundwater map with contour lines	area-based representation (search with coordinate)
	TAKI	GIS map with activated topographic layer	area-based representation
Direction of slope	MÁFI	GIS groundwater map with contour lines	area-based representation
	TÉKA	map of FÖMI (Hungarian Institute of Geodesy, Cartography and Remote Sensing)	contour representation
Geological structure and bedrock, parent material	TAKI	GIS map representation: parent material	area-based representation
	MÁFI	GIS map representation: geological structure, parent material	area-based representation (search with coordinate)
	TIM	parent material	concerning measuring point (assigned to coordinate)
Susceptibility to erosion, deflation	TAKI	GIS map of National Soil Degradation Database: susceptibility to erosion, deflation	area-based representation (grayscale) erosion scale: 0-3 deflation scale: 0-4

3.3 Object classification and definition of data models of the system design

Due to the increasing demand for data in recent years, a number of different information systems have been created, our investigation confirms the importance of this. Most specialists involved in environmental impact analyses would require a correctly operating, user-friendly information system that includes appropriate data to facilitate their work in a meaningful way.

The provision of the required data can, however, be realised by the joint use of several systems (Barthel et al. 2008, Argent et al. 2009). Therefore, we found it necessary to define the basis of a unified information system that takes into consideration the existing ones. Knowing the environmental data necessary for describing the basic state of the environment, according to the object hierarchy, the object classes of the data model (*Table 5*) then the groups (*Table 6*), and finally the object types (*Table 7*) are defined. In the case of object types, the geometry of the object as well as the potential domestic sources of data supply are indicated.

Table 5. Classes of objects

Sign of classes	Classes of object	Number of types
A	Meteorological data	10
B	Geological and soil data	12
C	Hydrological data	8
D	Data of flora and fauna	8
E	Data of settlement and artificial environment	8
F	Data of landscape	4
		50

Table 6. Groups of geological and soil data

Sign of groups	Groups of object	Number of types
	B – Geological and soil data	
BA	Geological data	3
BB	Soil data	6
BC	Topography	3

Table 7. Types of Geological and soil data

Sign	Types of object	Point	Line	Area	Surface	Source
	B – Geological and soil data					
	BA – Geological data					
BA01	Geological structure		+	+		MÁFI
BA02	Parent material			+		MÁFI
BA03	Protected geological value	+	+	+		TIR
	BB – Soil data					
BB01	Genetic soil type			+		TAKI
BB02	Physical soil type			+		TAKI
BB03	Soil water management categories			+		TIM
BB04	Soil organic matter content	+				TIM
BB05	Depth of the column	+				TAKI
BB06	pH	+				TIM
	BC – Topography					
BC01	Topography			+	+	TAKI
BC02	Contour lines			+		MÁFI
BC03	Direction of slope			+		MÁFI

The theoretical and logical data models of the pattern system design were set up according to our object grouping. The objects of the data model were defined in the theoretical model, while in the logical model the geometrical and attribute data of the objects were given. Beside the names of the individual overlays, the code given in the course of object classification is indicated. As an example, *Table 8* illustrates the overlays of an object type of the geological and the pedologic group of object respectively.

Table 8. Layers of logical data model (details)

PARENT MATERIAL (BA02)		
Geometry:	vector, area	
Primary data table:	Parent material	
Source:	TAKI Agrotopo	
Projection:	Hungarian national grid (EOV)	
	Primary data fields	
Name	Description	Type
PARENT MATERIAL	type of parent material of the examined area	text code
Comment: –		

pH (BB06)		
Geometry:	vector, point	
Primary data table:	pH	
Source:	TIM	
Projection:	Hungarian national grid (EOV)	
	Primary data fields	
Name	**Description**	**Type**
NUMBER	number of measurement point	numerical
TYPE	type of measurement point	enumeration
EOVX	x coordinate of measurement point	numerical
EOVY	y coordinate of measurement point	numerical
PH	value of pH	numerical (1 decimal place)
DATE	date of measurement (year, month, day)	date
Comment: –		

The object classification illustrated in the foregoing can form a basis for later legal modifications concerning the completion of environmental impact analyses. It may also help revise the existing information systems on environmental protection and help plan their integration. When set up, the data model includes those overlays that are necessary in the course of environmental impact analysis. The creation of the system design ensures its applicability in any geological information systems serving related goals.

4 CONCLUSIONS

Research results support the completion of the basic state survey phase of environmental impact analysis. Completing this will make the execution and verification of environmental impact studies more efficient and less time consuming. We consider this a high priority. The set up data list and guide can both assist implementing this into practice. The current investigation focused on Hungarian information systems and impact analyses; at the same time, the pattern system design set up is feasible in any country with any geoinformatics systems.

Acknowledgements: We want to thank Levente Csóka for many helpful comments and suggestions on the manuscript and Zsolt Kovács for providing language help.

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10.1515/aslh-2017-0005 *Acta Silv. Lign. Hung., Vol. 13, Nr. 1 (2017) 69–79*

Energy Grass as Raw Material for MDF Production

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Abstract – Medium density fiberboards are widely produced and used in Europe. The main raw materials used in Hungary are beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*), poplar (*Populus spp.*) and pine (*Pinus spp.*). Governmental subsidizing of biomass for power plants has created economic pressure and a shortage of wood prompting a major producer of energy grass to initialize a project to examine the possibility for the production of MDF from energy grass "Szarvasi-1" (*Elymus elongatus (Agropyron elongatum) cv. Szarvasi-1*). Prior to this, no research results on the experimental production of MDF from energy grass had been published. In our research study, energy grass was defibrated and MDF boards were produced with the use of different adhesives. Standard tests were completed to evaluate the suitability of this alternate raw material in MDF production. The best result was achieved with phenol formaldehyde (PF) adhesive.

energy grass / MDF / dry process / annual plant

Kivonat – Energiafű alkalmazhatósága MDF gyártásában. A közepes sűrűségű farostlemezeket széles körben gyártják és használják Európában. A legfontosabb magyarországi nyersanyagok a bükk (*Fagus sylvatica*), a gyertyán (*Carpinus betulus*), a nyárak (*Populus spp.*) és a fenyőfélék (*Pinus spp.*). A biomassza energetikai célú felhasználásának kormányzati támogatása gazdasági nyomást és faanyaghiányt eredményezett, amely az energiafű fő termelőjét arra késztette, hogy egy projektet kezdeményezzen a "Szarvasi-1" (*Elymus elongatus (Agropyron elongatum) cv. Szarvasi-1*) energiafű MDF gyártásában való alkalmazhatóságának bevizsgálására. Ezt megelőzően nem publikálták kutatási eredményeket az energiafű MDF célú kísérleti gyártásáról. Kutatásunk során az energiafüvet defibráltuk és MDF lemezeket készítettünk belőle különböző ragasztóanyagok felhasználásával. Szabványos vizsgálatokat végeztünk ezen alternatív nyersanyagok MDF gyártására való alkalmasságának értékelésére. A legjobb eredményt fenol-formaldehid (PF) ragasztóanyaggal értük el.

energiafű / MDF / száraz eljárás / egynyári növény

1 INTRODUCTION

Medium density fiberboard (MDF) is one of the most commonly used wood-based panels composed of wood fibers, bonded with adhesive, and cured under heat and pressure (Koch 1972; Maloney 1993; Saligna et al. 2001). In the decade before the 2008 economic crisis, the

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production of MDF had quadrupled in Europe and had a major market share in the wood composites industry. The total production capacity of MDF for the year 2005 was 1.350.000 m^3 (EPF 2006). Currently, 5% of round wood of softwood and hardwood species, 75% recycled wood, and 20% mill residues are used as raw material to manufacture MDF (EPF 2006). MDF is used to manufacture molding, laminated flooring, packaging materials, containers, and overlaid panels for the furniture and cabinet industry. Compared to wood, fiberboard has a looser texture and lower internal strength; therefore, it does not require strong adhesives (Zhong et. al. 2002). Following the upturn in 2010, MDF production continued to grow slightly (up by 3.7%) in 2011, reaching 14.1 million m^3 in Europe (Eastin et al. 2012). From 2014 to 2015, MDF production showed a 2.7% growth in Europe as EPF (2016) reports.

Low quality lignocellulosic materials from wood, sawdust, used furniture, agricultural wastes, different grass species, and other biomass products can be raw material for MDF production. The overall cost and environmental load can be reduced by the utilization of these waste raw materials. Several publications report research on different annual plants as possible raw materials for industrial utilization, e.g. rapeseed stalks, straw, and switch grass. This research focused on annual plant residues from agricultural production, especially from industrial plantations. This raw material became known under the term energy grass.

Pahkalaa et al. (2008) examined the possibilities of the energetic use of energy grass (reed canary grass) in Finnish power plants. In 2006, 2,300 ha of energy grass was grown for power plants in the Ostrobothnia region, Finland. Xu et al. (2011) reported on another use of energy grass through their results on the delignification of three types of switch grasses (*Panicum virgatum*) for bioethanol production in the USA. They described an effective prediction on the lignin reduction and sugar production of switchgrass. Kaur et al. (2010) examined two other grass types that they used as raw material for oil extraction. The researchers have done pulping experiments of the production residues on vegetable oil distillation. Both types of grasses yielded 41-43% pulp, which could be used for production of printing paper. Tofanica et al. (2011) examined rapeseed (*Brassica napus*) stalks, which is used as biofuel raw material in different forms. Stalks have higher extractives and soluble contents, which may cause lower pulping yields. Another fast growing species, Johnson grass, (*Sorghum halepense*) was tested by Albert et al. (2011), and examined for its suitability for paper production. They have concluded that *Sorghum halepense* fibers can be used for paper production only after being mixed with other longer fibers.

MDF is widely produced and used in Europe. In Hungary, the main raw materials are beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*), poplar (*Populus spp.*) and pine (*Pinus spp.*). In the past decade, governmental subsidizing of biomass electric power generation caused a shortage of wood raw material for the wood panel industry. In addition, farms started to produce annual plants for energetic use, but this was never introduced in power plants due to the ease of procuring and burning of wood. In these circumstances, a major producer of energy grass (Bóly Co.) started a project to examine the possibility of production of MDF from energy grass Szarvasi-1 (*Elymus elongatus (Agropyron elongatum) cv. Szarvasi-1*). The giant grass or so-called energy grass Szarvasi-1 was cross-fertilized for 10 years in Szarvas, Hungary as reported by Jankowsky et al. in 2004. Cross-fertilization of plant materials collected in the sodic soil areas of the Great Plain and in the arid areas of Central Asia was completed. Energy grass grows to a height of 2 meters. It has small spear-like seeds, and looks like huge couch grass (Jankowsky 2003). It was planted in larger agricultural areas after 2000. Possible uses as biomass fuel for power plants and as raw material for cellulose end paper production were examined with positive results. On one hectare, 10-15 t/a dry matter can be grown, which can produce 15 (GJ/ha) of energy. (Janowszky et al. 2012) Research by Lele et al. (2004) was conducted on Szarvasi-1 as a raw material for paper production. Since production costs are considerably lower than for existing pulp production processes, this presents a very attractive and economically viable commercial proposition, which can result in the establishment of a large scale pulp mill in Hungary. Szántó et al. (2003) successfully produced hard fiberboard with a wet process (HB) from the Szarvasi-1 energy grass on an industrial scale. This research produced boards with strengths similar to those produced by wood fibers, yet with lower density values and high thickness swelling.

No reports of grass used in this manner was found, especially none concerning energy grass for fiberboard production by dry process (MDF). Klie (2005) made 4 mm MDF boards by mixing energy grass fibers with wood fibers (from 0% to 100% giant grass content by 20% steps) and urea formaldehyde (UF) resin, but without the addition of paraffin. The results showed high thickness swelling (average 50%), low internal bond (average 0.22 MPa) values, and low MOR (average 10 MPa) values. Klie's results showed that the preparation of energy grass for MDF production requires special technology. Giant grass alone, without being mixed with wood fibers, is not suitable for the production of MDF. The aim of the present study was to evaluate the mechanical properties of MDF boards produced from energy grass mixed with wood fibers when using alternate adhesives like phenol formaldehyde (PF) and melamine urea formaldehyde (MUF). Urea formaldehyde (UF) served as a control, to provide wood composite panel manufacturers with a comparison basis.

Markessini et al. (1997) produced experimental MDF boards (6 mm thickness, 700 kg/m^3 density) from wheat straw where a chemi-thermomechanical treatment was applied to produce fibers. They used pMDI (polimeric 4.4'-Methylene diphenyl isocyanate) and UF resins (15% resin content) (*Table 1*).

Table 1. Board properties of MDF from wheat straw fibers with a thickness of 6 mm (Markessini et al. 1997)

Property	PMDI	UF
Internal bond [MPa]	0.83	0.5
Bending strength [MPa]	18.7	13.1
Modulus of elasticity [MPa]	2,676	1,974

2 MATERIALS AND METHODS

2.1 Raw materials

Two kinds of fibers were used as raw material during the experiments: wood fibers produced by the Hungarian fiberboard company, MOFA Co., (recently Kronospan-MOFA Hungary Ltd.), and hammermilled energy grass obtained from the BOLY Agricultural Company. The wood fibers were used as received, and the energy grass was defibrated in our laboratory.

The industrial wood fibers were 25% saw mill cut offs from low-density hardwood species (mostly *Populus spp*.), 25% pine fiber logs (*Pinus spp*.) and 50% low-density hardwood species logs (mostly *Populus spp*.).

The pretreatment parameters to produce wood fibers on an industrial scale were 8.4 bar steam pressure, 177°C temperature, and 3 minutes defibration time in an Asplund Defibrator. The pretreatment parameters for energy grass in the laboratory were boiling in water at 100°C in a Lorentzen type rotating autoclave for 30 min. The dry content of the suspension was 250g/L. The pre-softened energy grass was then defibrated in a disc defibrator in a wet condition. The distance of the disks was set to 0.1 mm. The disintegrated energy grass fibers were then milled in a Hollander type mill for 20 minutes. The treated, wet energy grass fibers were stored in a well-ventilated room for 10 days. The initial and final dry matter contents were 120% and 10.1% respectively. The dried, agglomerated fibers were then broken up in a Retsch type laboratory mill with an 8 mm sieve hole. At the same time, the longer fractions were shortened. The final moisture content, obtained by drying in a laboratory drier at 60 °C, was around 4%.

The type and dry content of adhesives used in laboratory board production are given in *Table 2*.

Table 2. Adhesives used during laboratory board production

Adhesive type	Dry matter content [%]	Catalyst
Urea formaldehyde (UF)	65	$(NH_4)_2SO_4$
Phenol formaldehyde (PF)	44.93	–
Melamine urea formaldehyde (MUF)	65.6	$(NH_4)_2SO_4$

A 1.5% paraffin dispersion (calculated on dry matter content of fibers) was added to the fiber furnish in order to decrease water absorption. As a catalyst for the aminoplast adhesive (calculated on dry matter content of UF and MUF adhesives), 2% ammonium sulfate, which cures in an acidic condition, was used. The concentration solution of ammonium sulfate was 35%.

Fiber size distribution was determined by a Fritsch Analysette vibrating separator. The sieve hole diameters were in millimeters as follows for both raw materials: 0.08, 0.18, 0.315, 1.0, and 4.0 respectively.

The testing parameters were 5 min. for duration of separation, 1.7 mm vibrating amplitude, 2.5 mm vibration amplitude, and a 5 second interval between two vibration impulses.

The degree of beating was tested by a Schopper-Riegler freeness tester and was measured in both raw materials: wood and energy grass fibers.

2.2 Moisture content of fibers

The moisture content of the mat plays an important role during hot pressing, so the moisture content of the mixture of fibers, adhesive and other additives has to be set carefully. The moisture in the mat helps to transport the heat from the hot plates into the core layer. If the mat is too dry, the time for total warm up will be too long causing the surface layers to dry out or be burned; in addition, the adhesive in the core layer will not get cured. If the moisture content of the mat is too high, the evaporating water cannot escape from the board under high pressure; this may cause the board to explode or delaminate when the press is opened. (Heller 1995).

The final moisture content of giant grass was 1.1% and that of the wood fibers was 1.0%. The moisture content was determined based on standard EN 322.

2.3 Experimental board production

The following fiber mixtures were applied to produce boards in laboratory conditions: 0%, 20%, 40%, 60%, 80%, 100% of energy grass fiber and the complementary amounts were wood fibers. Dry process fiberboards with dimensions of 500 mm square x 4 mm for UF and 300 mm square x 4 mm for PF and MUF were made from the wood and energy grass fibers. The samples with the specific gravities of 700 and 800 kg/m^3 were weighed and placed into a drum blend. While being tumbled in the rotating drum blend, the chemicals were sprayed with the appropriate amount of adhesives (*Table 3*). The paraffin emulsion was spread separately.

A pre-calculated amount of blended raw materials was then hand-felted into a forming box and pre-pressed into a mat by 784 N (80 kg). The mat was then hot-pressed with a SIEMPELKAMP laboratory heat press at different press conditions into 4 mm thickness guided by two rectangular steel stops. Press temperatures were 180°C and the pressure varied according to three pressing stages: 2.5 MPa, 1.9 MPa, and 0.95 MPa. The hot-pressing time for each pressure stage was 64 seconds. After hot pressing, the pressure was gradually released; the boards were stored at room temperature and finally trimmed to remove the rough edges.

Table 3. Detailes of the three experimental runs

Board parameters	UF-MDF	PF-MDF	MUF-MDF
Length of the board [mm]	500.0	300.0	300.0
Width of the board [mm]	500.0	300.0	300.0
Thickness of the board [mm]	4.0	4.0	4.0
Desired oven dry density [kg/m^3]	650.0	700.0	700.0
Fiber : adhesive ratio	0.88 : 0.12	0.92 : 0.08	0.90 : 0.10
Catalyst [%]	2.0	–	2.0
Paraffin dispersion [%]	1.5	1.5	1.5
Moisture content of mat [%]	8	8	8

The ratio of adhesive was different according to Deppe – Ernst (1996) who recommend different ratios for different adhesive types to achieve similar board properties.

After 24 hours of conditioning, the boards were cut and tested according to the MSZ EN 310, 317, 319 and 323 standards. Modulus of elasticity (MOE), modulus of rupture (MOR), specific gravity (SG), and thickness swelling (TS) of the boards were determined. Static bending tests were done on an Instron 5566 universal testing machine to calculate MOE and MOR. The standard specimens were soaked in tap water for 24 hours to test thickness swelling. Requirements of EN 622-5 standard for MDF with thickness of 4 mm are listed in *Table 4*.

Table 4. Requirements for MDF with a thickness of 4 mm

Property	Requirement (EN 622-5)
Thickness swelling - 24 h [%]	max. 35
Internal bond [MPa]	min. 0.65
Bending strength [MPa]	min. 23
Modulus of elasticity [MPa]	–

3 RESULTS AND DISCUSSION

3.1 Fiber size

Figure 1 represents the mean values of fiber distribution. There are differences between the wood fibers and energy grass fibers; hence, the former was made on an industrial scale and the latter in laboratory conditions with different equipment. Important characteristics of fibers are the ratio of length and diameter (aka slenderness) and the surface structure, because they have a great influence on mat forming and on joining (felting) of fibers (Winkler 1999):

- for a wet production process, the long, slender, wavy fibers are the most suitable – l/d : 89 – 115,
- for a dry process, shorter, smoother, thin fibers are best – l/d : 30 – 50.

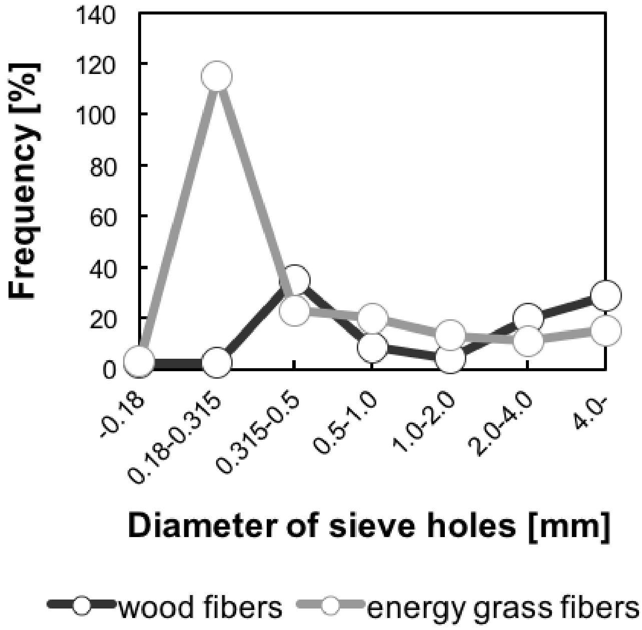

Figure 1. Size distribution of the fibers

The ratio of fine parts, (dust) is much higher in energy grass fibers from laboratory production. The reasons for this are: firstly, the annual plants contain more silica (2-4%) and ash (4-8%) than wood (close to 0%) (Halvarsson et al. 2004), and secondly, the applied laboratory technique regarding the refining of the fibers in a Hollandi mill caused much shortening. For board production, the dust was eliminated from energy grass fiber raw material.

3.2 Degree of beating of fibers

The degree of beating of the two fibers were:

- wood: 10.3 SR°
- energy grass: 8.7 SR°

This means that wood component contains more fine fibers, and energy grass contains less fibrous particles, but energy grass has coarser elements and dust, as shown in *Figure 1*. This is caused by the laboratory techniques that were used.

3.3 Experimental board properties

Table 5. shows results of our recent research on boards made of 100% energy grass fiber.

Table 5. Board properties of MDF from 100% energy grass

Property		UF	PF	MUF
Internal bond [MPa]	Mean	0.26	0.10	0.42
	Std. dev.	0.0321	0.0219	0.0469
Bending strength [MPa]	Mean	11.0	17.7	16.1
	Std. dev.	3.261	5.3597	2.4287
Modulus of elasticity [MPa]	Mean	1015	2022	1812
	Std. dev.	124.0325	567.2913	218.0057
Thickness swelling (24h) [%]	Mean	63.08	45.37	38.32
	Std. dev.	4.5261	4.1724	4.6135

Similar to Markessini et al.'s (1997) results (see above and Table 1), the strength values of boards with UF adhesive are the weakest, but strength of boards made with PF and MUF are close to the similar values of boards made with PMDI. In our case, no chemical treatment was applied, so the wax content of the fibers decreased the strength of the boards, especially regarding internal bond. Also in our case, only 12% of UF was used instead of 15%, because dry blending was applied.

During this research grass fibers were mixed with wood fibers, where the ratio of energy grass was 0%, 20%, 40%, 60%, 80% and 100%.

Mean values of results are shown in *Figures 2-5*.

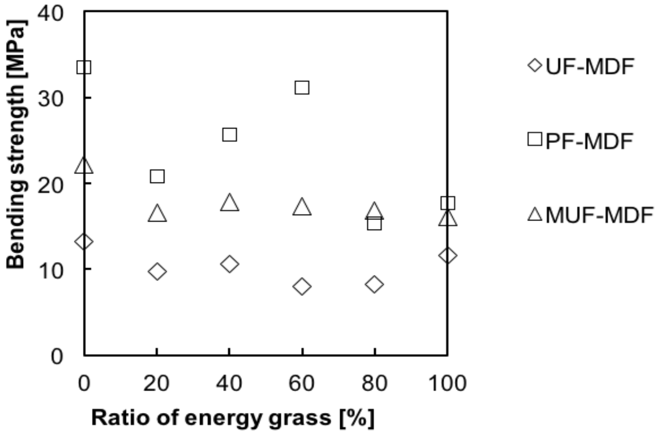

Figure 2. Comparison of bending strength mean values

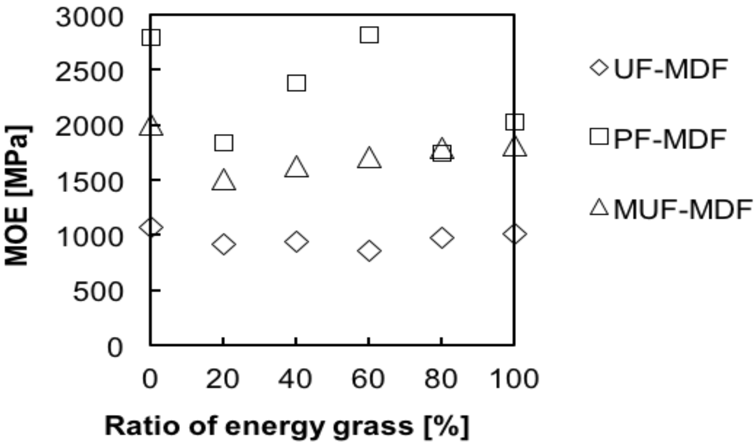

Figure 3. Comparison of modulus of elasticity mean values

By comparing bending strength values (*Figure 2)* of the three experimental runs (UF, PF, MUF) it is clearly shown that UF type boards have the lowest values. Although the highest values come from using a PF adhesive, the MUF adhesive produced the most balanced results, so MUF is the least sensitive to the properties of giant grass fibers. Some abnormal values (those outside of the trend) are caused by uneven laboratory blending and manual mat forming. Halvarsson et al. (2004) reported successful laboratory experiments on wheat straw produced MDF with the addition of 15% and 19% melamine urea formaldehyde resin. Their results with urea formaldehyde resin were also unsatisfactory.

The trends of modulus of elasticity values (*Figure 3*) are very similar to the trends of bending strength values. Since these have no standard requirements, they are only for comparison among themselves. The values are the lowest in UF type boards, highest in PF type boards and most balanced in MUF type boards.

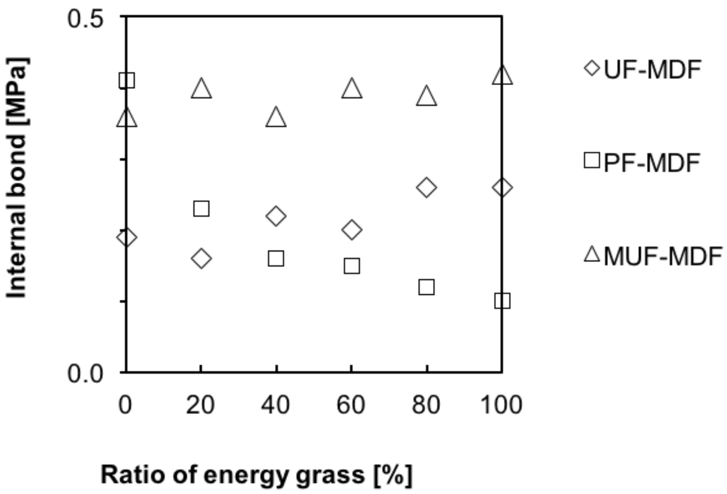

Figure 4. Comparison of internal bond mean values

Internal bond values (*Figure 4*) are below expectations. Hence, these were below standard requirements in every case, including the UF board produced by Markessini et al. (1997). The best results were found using MUF adhesive where the values were very balanced independent from the wood-grass ratio. The values of PF were very low, which shows that there is some incompatibility between the adhesive and grass. This is caused by the high wax content of the grass.

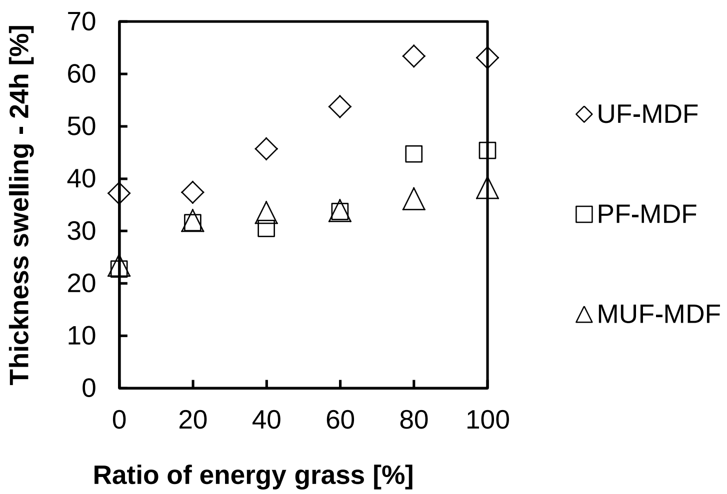

Figure 5. Comparison of thickness swelling mean values

Thickness swelling (*Figure 5*) tests are usually not reported in publications because the standard requirements (max. 35%) are difficult to fulfill. There were very clear trends in this research. None of the experimental boards using UF adhesive fulfilled the requirement. Using PF and MUF with up to 60% grass content, the thickness swelling values remained under 35%. Again, the most balanced values were found with MUF. An increasing trend was found with every adhesive type when the ratio of energy grass was increased.

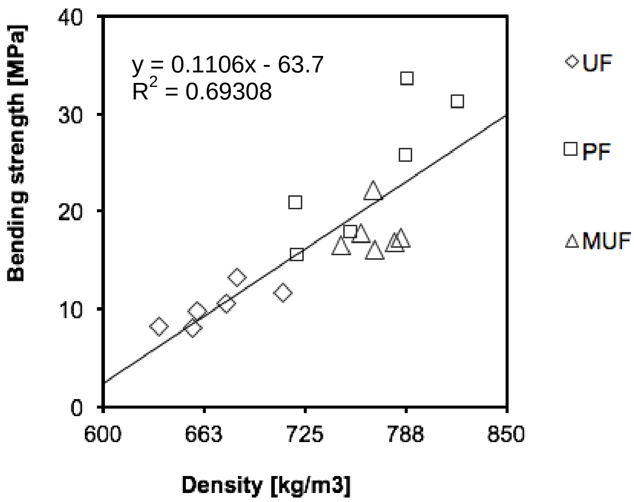

Figure 6. Bending strength as a function of density for all experimental boards

The bending strengths of the boards as a function of density are shown in *Figure 6*. Globally, a linear trend can be observed on the graph with increasing density, as is usually observable in the case of wood-based panels. This trend verifies that the measurements were correct. This increase in bending strength was found in all three types. Results are more balanced only in MUF type boards. In Fig.6, the bending strength depends only on density of the MDF. It does not depend on the ratio of the energy grass to wood fiber or on the type of adhesives. From these results it could be concluded that there is no difference between wood fiber and energy grass on the contributions for MDF properties except thickness swelling. In other words, energy grass can be used for MDF raw materials almost as effectively as wood fiber. However, the thickness swelling increased with the ratio of energy grass on any type of adhesives, so water absorption of energy grass may be a little bit higher than wood fiber.

On this graph, the disadvantage of manual mat forming is proven, as there is a large deviation in density across the surface of the board. The bending strength values show much lower values in the case of low-density test pieces.

The density of UF board types is lower than that of the others and this is partly the reason for their low strength values.

4 CONCLUSIONS

In this research, the possibility of producing MDF from energy grass using different adhesives was examined. The following can be concluded about the results of bending strength as a function of density:

- MDF boards made with UF adhesive are the weakest and had the lowest density values.
- Boards made with an MUF adhesive the most balanced strength values (MOR, MOE and IB).

- The highest strength values (MOR, MOE and IB) were found in boards made with PF adhesive, but the deviations are also the largest here. It should also be noted that the lower strength values occurred with lower density, and it is well known that with such panel boards there is a linear correlation between density and bending strength as measured by Alpar (2007) and Deppe – Ernst (1996). These irregular values might be caused by manual mat forming.

Based on these results, the advantages of both MUF and PF adhesives are demonstrated. A co-condensed MUPF type adhesive could combine the good effect of both adhesives on the board properties. Our previous research results proved that mixing different types of adhesives like MUF and PF does not combine the advantages of these two adhesives. It should be a directly synthesized, co-condensed adhesive to gain the best strength (Winkler et al. 2007).

Energy grass can be grown at high yield; based on our results, it can be a potential raw material for MDF production.

Acknowledgments: Research was supported by Bóly Zrt and in frame of the „EFOP-3.6.1-16-2016-00018 – Improving the role of research+development+innovation in higher education through institutional developments assisting intelligent specialization in Sopron and Szombathely.”

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Testing the Photostability of Acetylated and Boiled Linseed Oil-coated Common Hornbeam (*Carpinus betulus* L.) Wood

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Abstract – In this study, the effect of acetylation and coating with boiled linseed oil was evaluated concerning the photodegradation of common hornbeam wood (*Carpinus betulus* L.). To measure colour stability, a 10-month-long outdoor weather resistance test without soil contact was performed as well as artificial aging using a 200 hour mercury-vapour lamp irradiation test. The measurements were done on hornbeam, acetylated hornbeam, boiled linseed oil-treated hornbeam, and acetylated and boiled linseed oil-treated hornbeam samples. The control and treated samples' colour change was determined by comparing them to the original colour in all cases. The photodegradation process was examined with Fourier Transform Infrared (FTIR) spectra. Acetylated hornbeam was less prone to crack, but the modification did not hinder the fading and greying caused by UV irradiation. Coating the samples with boiled linseed oil decreased the rate of colour change and cracking. The photodegradation of lignin was confirmed by the FTIR spectra.

hornbeam / acetylation / photodegradation / colour / boiled linseed oil / FTIR

Kivonat – Acetilezett és lenolajkencével kezelt gyertyán (*Carpinus betulus* L.) fotostabilitásának vizsgálata. A tanulmányban az acetilezés és lenolajkencés kezelés hatását vizsgáltuk a közönséges gyertyán (*Carpinus betulus* L.) faanyag fotodegradációs folyamataira vonatkozóan. A fotostabilitás vizsgálatához időjárásállósági tesztet végeztünk 10 hónapos kültéri kitettség során (talajjal való érintkezés nélkül), illetve mesterséges öregítést végeztünk 200 órás higanygőzlámpás besugárzással. A méréseket gyertyán, acetilezett gyertyán, lenolajkencével kezelt gyertyán és acetilezett és lenolajkencével kezelt gyertyán próbatesteken végeztük. A kezeletlen és kezelt próbatestek színváltozását minden esetben az eredeti színhez képest határoztuk meg. A fotodegradációs folyamatokat Fourier Transzformációs Infravörös Spektroszkópiával (FTIR) vizsgáltuk. Az acetilezett gyertyán kevésbé repedékeny, de a kezelés nem csökkentette az UV sugárzás okozta fakulás illetve szürkülés mértékét. A lenolajkencés kezelés mérsékelte a színváltozás és repedés mértékét. A lignin fotodegradációját az FTIR színképek alapján igazoltuk.

gyertyán / acetilezés / fotodegradáció / szín / lenolajkence / FTIR

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1 INTRODUCTION

The aesthetic appearance of wooden products is greatly influenced by their colour. This is why consumers expect colour stability in wood products whether it be indoor furniture or outdoor decking. The colour of wood changes if it is exposed to ultraviolet (UV) light or thermal impact. The colour can be objectively determined by various methods. In this work, CIELAB colour system was used where L* defines lightness (0 is black and 100 is white), a* denotes red/green hue (positive values for red and negative values for green), and b* denotes yellow/blue hue (positive values for yellow and negative for blue). The colour change of wooden products can be determined by calculating the change in colour components (ΔL, Δa, Δb) and then the total colour difference (ΔE*). According to Terziev – Boutelje (1998) and Mononen et al. (2002), the difference can be seen with the naked eye if ΔE* is 2 or more. Jirouš – Ljuljka (1999) determined the levels of colour differences for paper, but these can be used for wood as well (Straže – Gorišek 2008). It should be noted that the difference between wooden surfaces cannot be noticed simply due to colour change, but also due to the inhomogeneity of wood itself (vessels, tyloses, ray flecks, grain structure, early and late wood transition).

If wood is exposed to natural weather, colour change is affected by the temperature, sunny hours, precipitation, rate of UV-A and UV-B radiation, the effect of insects collecting the loose cellulose fibres, etc. Lightness can have some initial increment, but it will decrease in the end. The surface starts to yellow at first, then it will grey after months due to the leaching of lignin and extractives, thus a* and b* decrease significantly (Tolvaj – Papp 1999, Tolvaj – Mitsui 2005).

UV degradation on uncoated and coated wood surfaces is due to the degradation of lignin in the cell wall. Lignin absorbs more UV energy than holocelluloses, and this energy is absorbed by double bonds, phenolic and carbonyl groups, quinones, quinone methids and biphenyls. The energy absorbance is affected by the density and the chemical composition of wood. During UV exposure, the photo-oxidation mechanism in lignin leads to demethylation and the formation of quinones (Rowell – Bongers 2015, Jawaid et al. 2017). As the lignin is degraded by UV light and washed away by rainwater, the surface cracks and the grey cellulose fibres become visible.

The advantage of artificial ageing is the reproducibility of the measurements, the constant settings and the short testing time. In these tests, artificial light sources like a xenon lamp, a mercury-vapour lamp, etc., are used. Unlike weather exposure, only photodegradation occurs during artificial ageing.

The colour of objects is determined by the conjugated double bonds in their chemical structure. These bonds are present in lignin and extractives. The colour of wood is mainly defined by the quantity and quality of extractives. The changes in the chemical structure can be examined by Fourier Transform Infrared (FTIR) spectroscopy. In recent decades, many researchers reported on the topic of photodegradation using a mercury-vapour lamp (Ohkoshi 2002, Colom et al. 2003, Tolvaj et al. 2011, Tolvaj 2013). The degradation of lignin is presented by the reduction in absorption of guaiacyl lignin (1510 cm^{-1}) and syringyl lignin (1600 cm^{-1}). This phenomenon is always accompanied by the formation of quinones and the increase of carbonyl groups absorption (Popescu et al. 2011).

Acetylation is a chemical wood modification method that improves the durability, dimensional stability and strength of wood without being toxic to the environment (Hill 2006). During the process, the wood is impregnated with a liquid reagent using vacuum and pressure so that it becomes integrated in the wood, modifying its chemical structure and properties. At the industrial level, acetic anhydride is used (Accsys Technologies, the Netherlands). When acetic anhydride reacts with the hydroxyl (OH) groups in the cell wall, acetyl groups form. These are bigger molecules than OH groups, which results in a denser, heavier wood material. The properties of acetylated wood are generally given according to its WPG (Weight Percentage Gain) as the physical and mechanical properties usually improve by increasing the WPG (Hill et al. 2004, Hill 2006).

The colour of wood does not necessarily change significantly after acetylation unlike in the case of thermal modification, which is done at lower temperatures. Broadleaved species usually darken at a higher rate than coniferous species, and dark-coloured species usually become brighter while light-coloured species usually darken (Mitsui 2010, Rowell 2013, Fodor 2015, Dong et al. 2016).

After acetylation, the absorption of carbonyl groups (1740 cm^{-1}) and methine (CH), methylene (CH_2), methyl (CH_3) groups (2970 cm^{-1}) increase while the absorption of the functional groups of lignin decrease (Mohebby – Radjihassani 2008, Fodor et al. in press).

It is reported that acetylation increases the weather (light and moisture) resistance of wood (Leary 1968, Feist et al. 1991, Plackett et al. 1992, Dawson et al. 1992, Owen et al. 1993, Ota et al. 1996, 1997, Ohkoshi 2002, Rowell 2006), noting that the photostability increases at higher WPG levels (Dawson et al. 1992). However, acetylated wood only shows initial stability against UV radiation; later, it begins to fade and grey (Kalnins 1984, Dunningham et al. 1992, Hon 1995, Torr et al. 1996, Ota et al. 1996, 1997, Ohkoshi 2002, Mitsui – Tolvaj 2004, 2005). This is also true for Accoya® Radiata pine (Meyer 2006, Lahtela – Kärki 2015). The colour change caused by photodegradation is influenced by the structural change of extractives too. According to Guo – Guan (2010), the degradation of lignin is hindered due to acetylation and the increased moisture resistance and dimensional stability also restrains the photodegradation mechanism of wood. On the other hand, acetylating the phenolic OH groups, which retard the formation of quinones, reduce this protective mechanism (Pu – Ragauskas 2005, Rowell 2005). This makes acetylated wood vulnerable to colour change and greying even at high WPG levels (Placket et al. 1992). Feist et al. (1991) found that acetylation only protects lignin to a small extent while protecting hemicellulose (xylan) to a greater extent during UV radiation. Acetylated wood exposed to weather or irradiation needs to be treated with dark, pigmented wood finish in order to stabilize its colour (Rowell – Bongers 2015).

In this work, a mercury-vapour lamp was used for the irradiation of wood. This creates a stronger colour change in a shorter time compared to a xenon lamp or natural sunlight. This is because the mercury-vapour lamp has a different wavelength emission. Unlike a xenon lamp, it emits light in all UV regions. UV light amounts to 80% of its emission, from which 31% is in the UV-A (380-315 nm) region, 24% is in the UV-B (315-280 nm) region, and 25% is in the UV-C (> 280 nm) region.

Boiled linseed oil is a mixture of linseed oil, stand oil, and metallic dryer to accelerate drying. These solvents cause linseed oil to dry more quickly, acting as if it were "boiled". Regular linseed oil can take weeks or sometimes months to cure depending on the weather conditions. According to Treu et al. (2004), boiled linseed oil significantly reduces the degradation and staining of wood when exposed to brown rot and blue stain. It deepens the colour of wood and protects it from UV and moisture. It is easy to handle, but its flammability needs to be considered during usage. It penetrates deeply into the wood, which is why it is mainly used as a sealant before the application of other coatings. In this work, it was chosen as a preliminary test for the coatability and colour change of acetylated hornbeam.

The aim was to examine the effect acetylation and boiled linseed oil coating have on the photostability of hornbeam wood. The samples were exposed to natural sunlight and weather, and also to artificial irradiation (mercury-vapour lamp). The rate of photodegradation was evaluated according to the change of colour components and FTIR differential spectra.

2 MATERIALS AND METHODS

Edged and air-dry hornbeam boards were ordered from a Hungarian sawmill (BOPAÁR Ltd.). The dimensions were 27 × 160 × 2500 mm (thickness × width × length). Half of the boards were left untreated and the other half was sent to Accsys Technologies to be acetylated under industrial conditions. The average WPG was 15%.

For the tests, half of the samples were coated with boiled linseed oil (from Kőházy - Tradíció Ltd.). The oil coating was applied two times (as it was recommended by the manufacturer) with one day drying time to ensure better penetration.

2.1 Weather exposure

The samples were put to exposure without soil contact in the Outdoor Exposure Testing Field of the Department of Wood Science in 2016 July. The tests were carried out according to Csizmadia (2015): the samples were of 20 mm × 45 mm × 200 mm (thickness × width × length) with planed, smooth, tangential surface. There were five circles marked on each sample for colour measurement. Small spacers provided air gap between the samples.

There were 10 hornbeam (marked H), 10 acetylated hornbeam (A), 10 boiled linseed oil-treated hornbeam (H + BLO), and 10 boiled linseed oil-treated and acetylated hornbeam (A + BLO) samples. They were placed on metal stands tilted at 45°. The colour measurement and visual inspection of the samples were done every month, in their current state, without conditioning.

The colour was expressed in CIE L*a*b* colour space with X-Rite SP60 Portable Colorimeter and Colour iControl program. The colorimeter's sensor head was 8 mm. The colour was measured and calculated based on the D65 illuminant and 10° standard observer.

2.2 Mercury-vapour lamp irradiation

The UV irradiation was carried out in an ageing machine at the Department of Physics and Electronics at the University of Sopron. There were two mercury-vapour lamps used (800 Watt), which were 64 cm above the samples. The temperature of the equipment was set to 50°C.

The samples were of 20 mm × 45 mm × 140 mm (thickness × width × length) with planed, smooth, tangential surface. There were five circles marked on each sample for colour measurement done as described above.

The samples for FTIR spectroscopy were of 5 mm × 10 mm × 30 mm (thickness × width × length) with planed, smooth, radial surface. For the measurements JASCO FT/IR-6300 spectrometer and Spectra Manager program was used. The final spectra of each sample was the average of 45 measurements.

The colour and FTIR measurement was determined after 0-5-10-20-30-60-120-200 hours of irradiation.

3 RESULTS AND DISCUSSION

As a result of acetylation, the colour of hornbeam became darker, greyish brown. The ray flecks became darker; the wavy grain has become more prominent to the naked eye. The modification process affected the whole cross section. The outer layer of wood (2-3 mm) was darker, but it was removed after further processing.

3.1 Weather exposure

The samples were already exposed to strong sunlight in the first month (July), which resulted great colour change.

The change of colour coordinates and colour change is shown in *Figure 1* according to exposure time. *Figure 2* indicates the shifting of red and yellow hue as an effect of photodegradation.

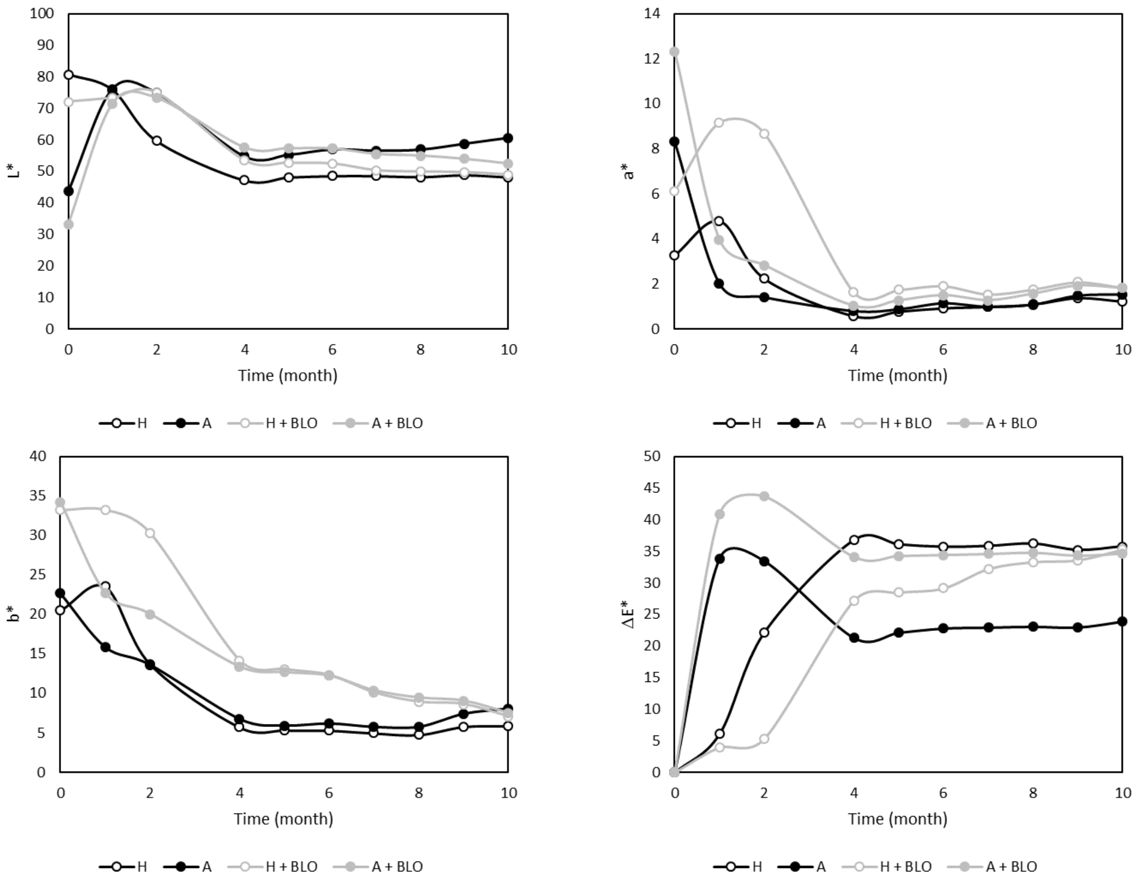

Figure 1. Change of colour coordinates during weather exposure. The measurements started in July 2016 (L: lightness, a*: red hue, b*: yellow hue, ΔE*: colour difference of the actual and the original colour, H: hornbeam, A: acetylated hornbeam, untreated or BLO: coated with boiled linseed oil)*

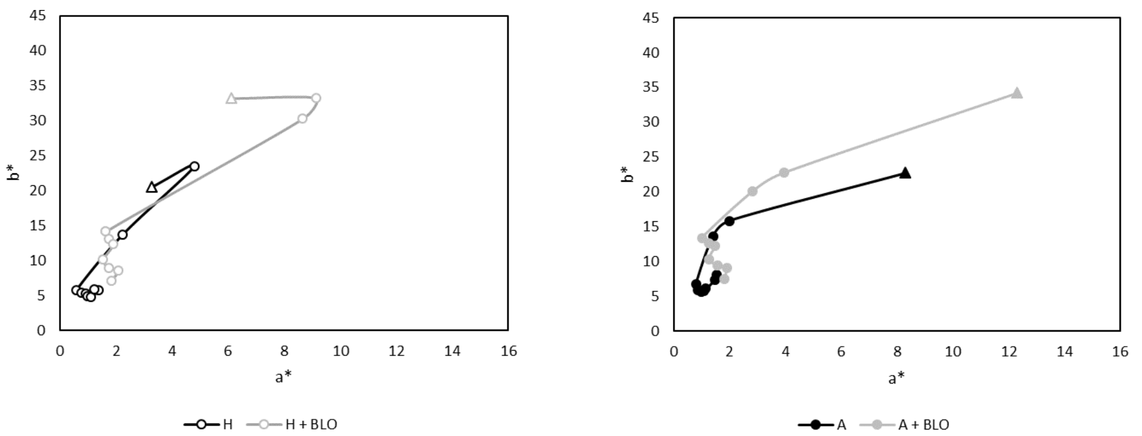

Figure 2. Change of red (a) and yellow (b*) colour points during weather exposure. The points marked with triangles represent the colour points of the original sample, then it is followed by the colours measured in the 1st, 2nd, 3rd, etc. month. (H: hornbeam, A: acetylated hornbeam, untreated or BLO: coated with boiled linseed oil)*

The hornbeam samples were cracked, moulded and faded after the first month exposure. The linseed oil-covered samples had a deeper yellow colour than untreated hornbeam. The red and yellow hue initially increased then decreased in the cases of both samples (*Figure 1 and Figure 2*). The surfaces gradually greyed and moulded in the months following. In the final months, long and deep cracks appeared on the end grain and sides as well. The shape and dimensions of the samples changed. Small wasp damages are visible in some cases.

Despite the improvement of strength and durability properties, acetylation did not increase the photostability of hornbeam wood. Prominent fading was already experienced in the case of acetylated and also acetylated and coated samples in the first month (July). Coating acetylated wood with boiled linseed oil eased the rate of photodegradation (*Figure 1*). In the months following, the samples greyed gradually. The change of temperature and humidity did not affect the shape and size of the acetylated samples. Some small hairline cracks appeared in the final months.

By coating the wood with boiled linseed oil, no cracks formed on the surface and the samples had better resistance to moisture *(Figure 3)*. The red and yellow hue gradually decreased and the grey colour stabilized after the fourth month *(Figure 2)*. The coating did not stop the rate of degradation, it just hindered it. The coated surfaces which were not exposed directly to weather – but contacted the metal stand – preserved their original colour, unlike the uncoated samples.

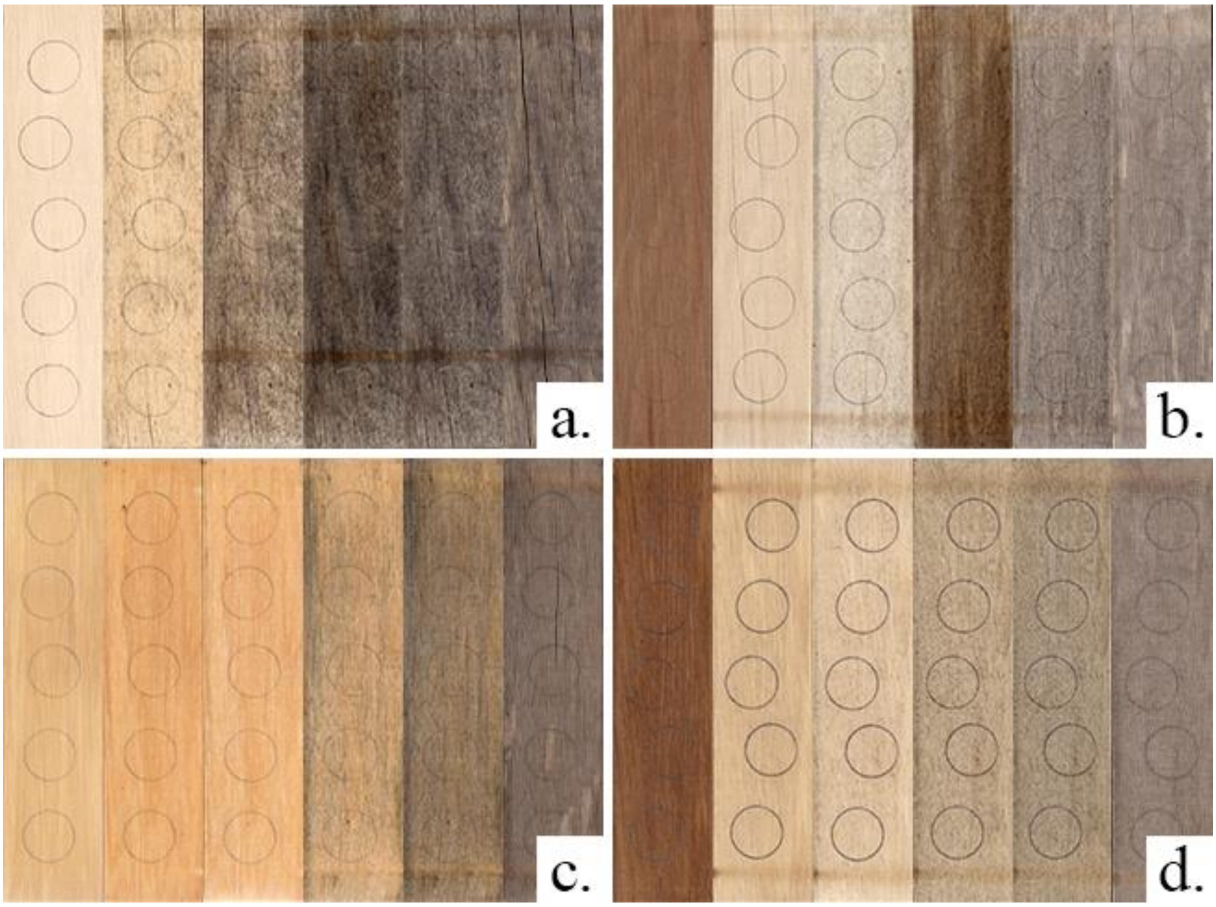

Figure 3. Series of photos of hornbeam samples exposed to weather. It shows the scans of the samples before exposure, and 1, 2, 3, 4 and 10 months after the exposure (a.: untreated hornbeam, b.: acetylated hornbeam, c.: hornbeam coated with boiled linseed oil, d.: acetylated hornbeam coated with boiled linseed oil)

In the third month (October), heavy rain occurred, which affected the colour change of the samples *(Figure 3)*. Here the measured data has big variation because of the moist surface so it was excluded from the results. According to various studies (Hon – Minemura 2001, McCurdy et al. 2006, Teischinger et al. 2012, Németh et al. 2013, Tolvaj 2013) the increase of moisture content and the wetting of the surface makes the wood more vivid, as it reduces the lightness and increases the red and yellow hue. The rain leaches out the water-soluble extractives, which define the colour of wood, and also the photodegradation products.

3.2 Mercury-vapour lamp irradiation

After 5 hours of mercury-vapour lamp irradiation, the colour changed remarkably, especially in the case of acetylated hornbeam coated with boiled linseed oil. The rate of colour change decreased over time (*Figure 4*).

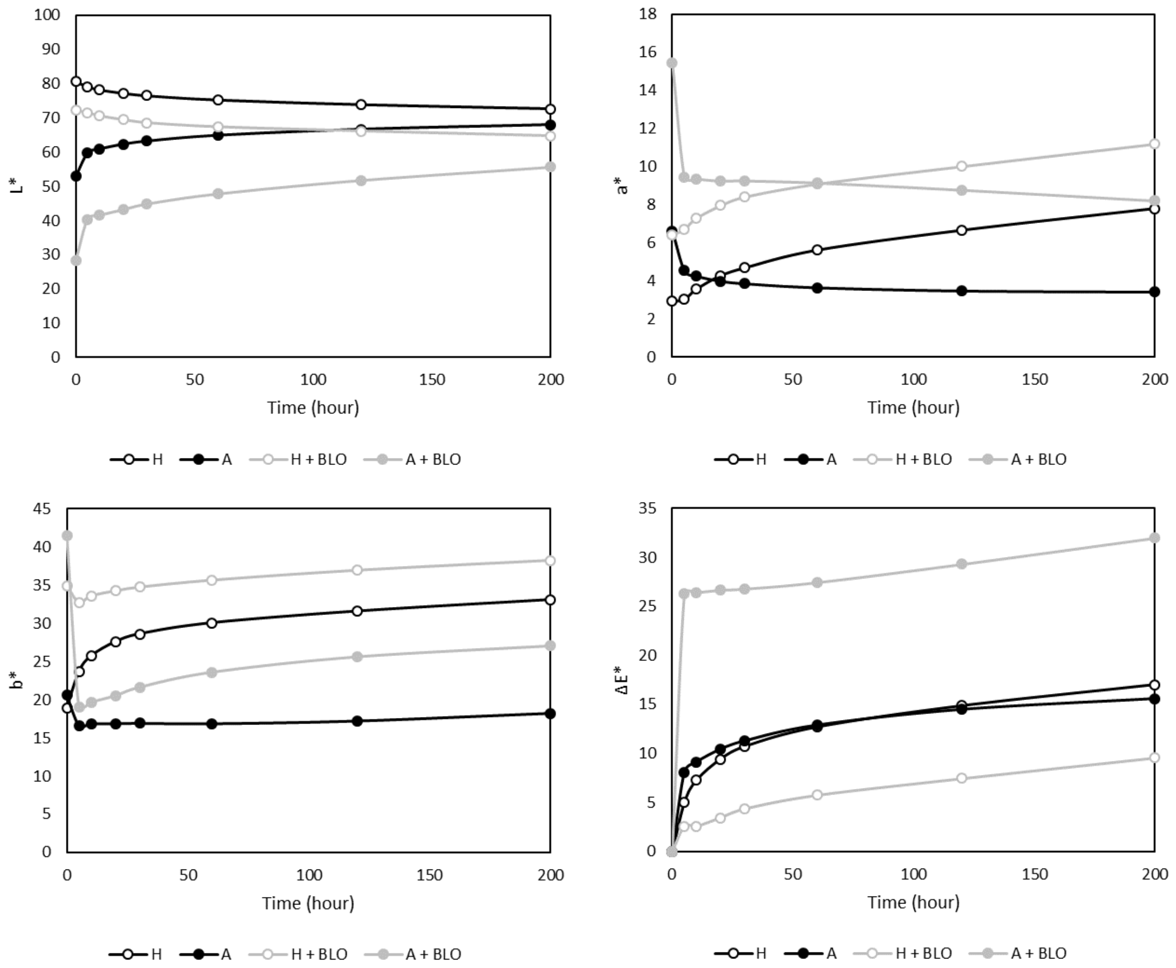

Figure 4. Change of colour coordinates during mercury-vapour lamp irradiation (L: lightness, a*: red hue, b*: yellow hue, ΔE*: colour difference of the actual and the original colour, H: hornbeam, A: acetylated hornbeam, untreated or BLO: coated with boiled linseed oil)*

During irradiation, hornbeam's light colour became a darker yellow. The lightness decreased while the red and yellow hue increased *(Figure 4)*. *Figure 5* shows the shifting of the yellow and red hue during irradiation. The colour of hornbeam coated with boiled linseed oil changed similarly, the brightness decreased, the red hue increased, while the yellow hue initially (in the first 5 hours) decreased and then increased. Coating hornbeam wood with boiled linseed oil improved its colour stability *(Figure 6)*.

Acetylated hornbeam's dark greyish brown colour brightened greatly as a result of mercury-lamp irradiation. The biggest colour change was measured in the first 5 hours. The lightness increased, the red hue decreased, the yellow hue initially decreased then increased *(Figure 4)*. The biggest total colour change was in case of coated and acetylated hornbeam *(Figure 4)*. The change of its colour components were similar to acetylated hornbeam, but the shifting of red and yellow hue was more prominent *(Figure 5)*.

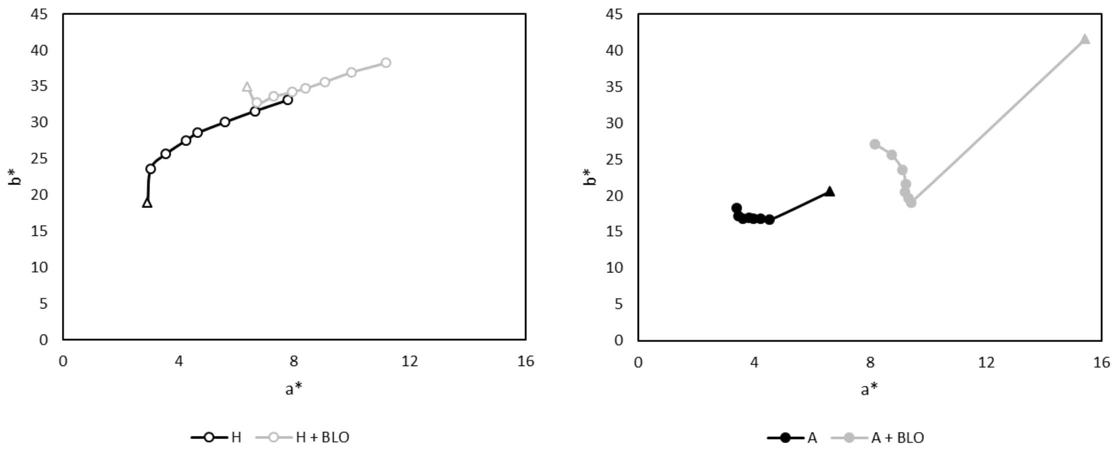

Figure 5. Change of red (a) and yellow (b*) colour points during mercury-vapour lamp irradiation. The samples are of untreated or acetylated hornbeam, with or without boiled linseed oil coating. The points marked with triangles represent the colour points of the original sample, which is then it is followed by the colours measured in the 5th, 10th, etc. hours (H: hornbeam, A: acetylated hornbeam, untreated or BLO: coated with boiled linseed oil)*

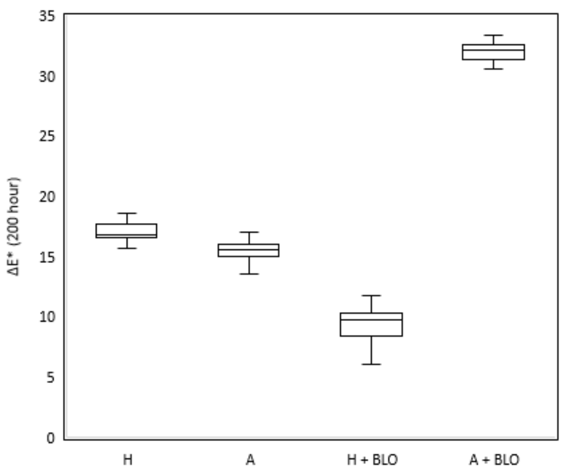

Figure 6. Box diagram of the colour changes (ΔE) caused by 200 hours mercury-vapour lamp irradiation compared to the original colour (H: hornbeam, A: acetylated hornbeam, untreated or BLO: coated with boiled linseed oil, the boxes are bounded on the top by the third quartile, and on the bottom by the first quartile, the box is divided by the median, the whiskers represent the maximum and minimum)*

Figure 7. shows the scans of one sample from each type before and after 200 hours of irradiation. The yellowing of hornbeam and brightening of acetylated hornbeam is visible to the naked eye.

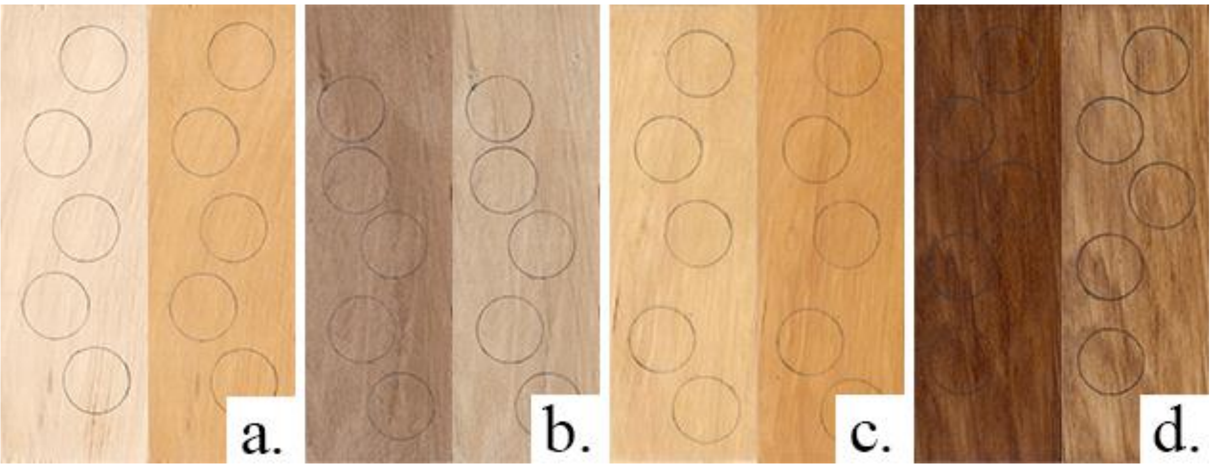

Figure 7. Photos of hornbeam samples before and after being exposed to 200 hours of mercury-vapour lamp irradiation (a.: untreated hornbeam, b.: acetylated hornbeam, c.: hornbeam coated with boiled linseed oil, d.: acetylated hornbeam coated with boiled linseed oil)

The colour change induced by natural weathering and artificial ageing (mercury-vapour lamp) has similar results or tendency, but in the case of weather exposure, the colour is influenced by many other factors besides UV radiation. The exposure to real conditions is more useful for industry rather than for laboratory tests, which lack these factors. On the other hand, the weathering tests are non-repeatable and uncontrollable, which makes it difficult to compare results. The sunlight (UV radiation) causes the greatest change in the colour and the surface. The mercury-vapour lamp can help study the photodegradation mechanism in wood, but it cannot simulate natural sunlight (Tolvaj – Persze 2011, Tolvaj – Varga 2012). During irradiation, the leaching of lignin and extractives does not take place, which greys the surface. The colour obtained after 200 hours of irradiation is obtained in less than 1 month of weather exposure.

The FTIR spectra was measured before irradiation and after each phase (5-10-20-30-60-120-200 hours). The changes were determined according to differential spectra, which was calculated by subtracting the initial (non-irradiated) spectra from the irradiated spectra (*Figure 8.*). In each spectrum, the peaks and absorption bands were determined (*Table 1*) and marked with numbers on each diagram and in the text.

According to previous studies (Fodor 2015), the moisture content of hornbeam is greatly reduced due to the bulking of the cell wall during acetylation. As the cell wall's OH groups were replaced by acetyl groups, the weight increased by 15% (WPG). During UV irradiation, the hydrogen bonds were broken and the OH groups changed and rearranged in the system, which is indicated by the positive and negative peaks in the spectra (1). There are bigger peaks (differences) in the differential spectrum of acetylated hornbeam than in untreated hornbeam.

The absorption of methine (CH), methylene (CH_2) and methane (CH_3) groups (2) increased after UV-B and UV-C irradiation. This band is usually not affected by photodegradation. The reason for this absorption change may be due to the fact that this band cannot be separated from the band of OH stretching (Tolvaj – Faix 1995).

A previous research study proved that there was no significant degradation in the cellulose of hornbeam after acetylation (Fodor 2015). The spectra show a reduction in symmetrical C-H deformation (8), asymmetric C-O-C stretching (12), and symmetric C-O-C stretching (13), but an increase in C-H deformation (9) and C-O stretching (14). Cellulose is more resistant to photodegradation; thus, the reduction of these absorption bands are associated with the change in hemicellulose.

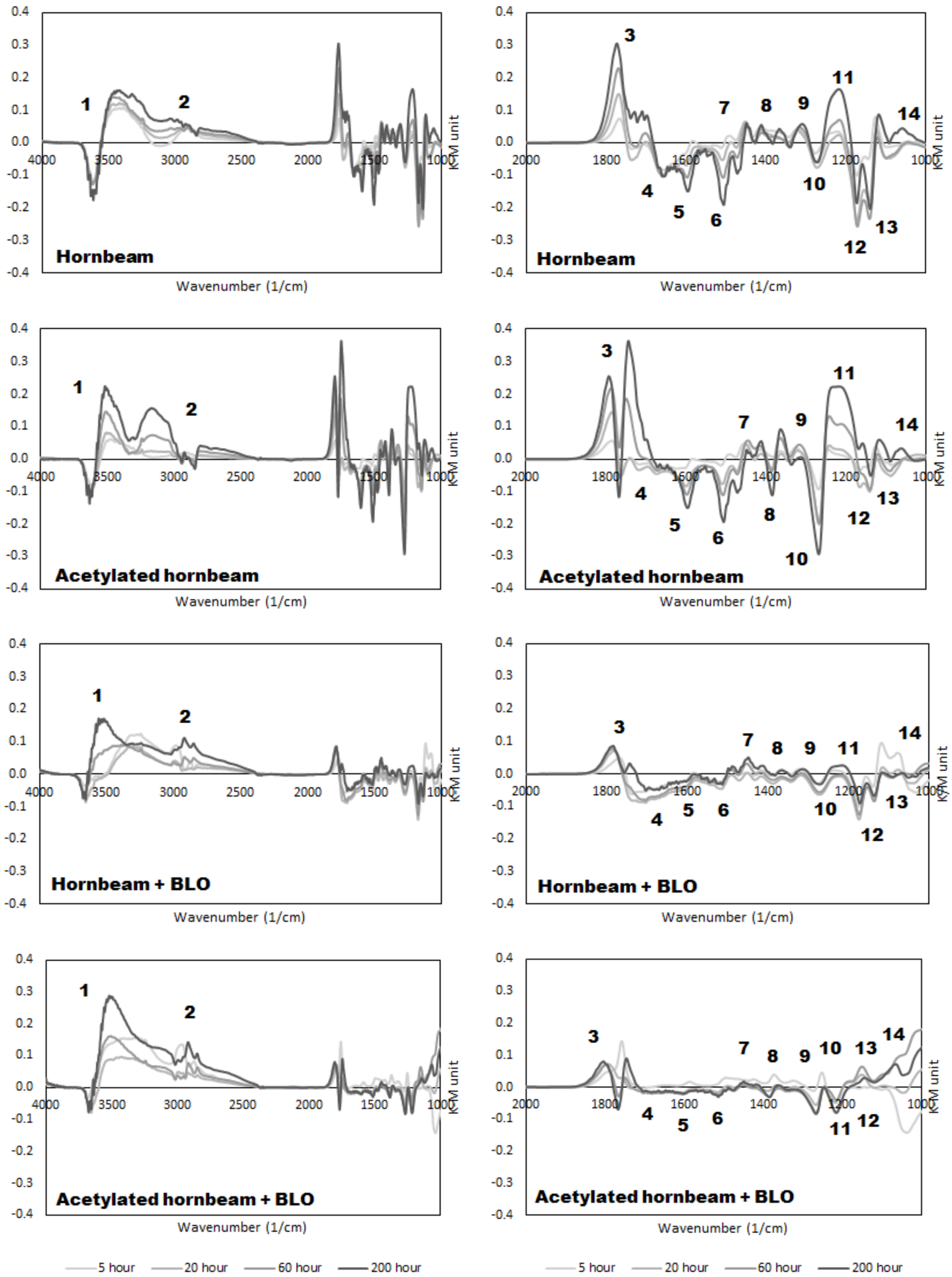

Figure 8. Change of hornbeam samples' FTIR difference spectra during 200 hours of mercury-vapour lamp irradiation (BLO: coated with boiled linseed-oil)

Table 1. Wavenumber characterization of the infrared spectra of hornbeam samples according to Tolvaj (2013).

Band number	Wavenumber (1/cm)	Functional group	Assignment
1	3677-3152	Hydroxyl group (OH) stretching	Cellulose, hemicellulose, lignin
2	2983-2844	CH stretching	Methine (CH), methylene (CH_2), methyl (CH_3) groups
3	1804-1773 1745-1698	Unconjugated C=O (carbonyl group) stretching	Xylan
4	1675-1658	Conjugated C=O (carbonyl group) stretching	Xylan
5	1604-1596	Aromatic skeletal vibration	Syringyl lignin
6	1514-1495	Aromatic skeletal vibration	Guaiacyl lignin
7	1476-1411	Asymmetric C-H deformation	Lignin, carbohydrates
8	1397-1383	Symmetric C-H deformation	Cellulose and hemicellulose
9	1372-1309	C-H deformation	Cellulose
		C-OH vibration	Syringyl derivatives
10	1279-1266	Ring vibration	Guaiacyl lignin
11	1219-1215	C-O stretch	Xylan
12	1176-1159	Asymmetric C-O-C stretching	Cellulose and hemicellulose
13	1146-1117	Symmetric C-O-C stretching	Cellulose and hemicellulose
		Aromatic C-H skeletal vibration	Lignin
14	1102-1067	C-O vibration	Cellulose and hemicellulose

According to Fodor et al. (in press), the absorption of conjugated carbonyl groups decreases slightly in wood after acetylation, probably due to minor degradation of xylans in acidic medium. As a result of UV irradiation, the aromatic rings of lignin rupture, carboxyl groups and/or lactones form; thus, the absorption of carbonyl groups increases (Tolvaj – Faix 1995). The unconjugated carbonyl region has two distinct wavenumber ranges at 1800-1760 cm^{-1} and 1740-1700 cm^{-1} (3). In the case of acetylated hornbeam, the absorption at 1743 cm^{-1} is higher than at 1793 cm-1. The absorption of hornbeam is smaller at 1698 cm-1 than at 1773 cm^{-1}. In every case, the absorption of conjugated carbonyl groups decreased (4). These peaks are less prominent in the case of samples coated with boiled linseed oil. After acetylation the amount of carbonyl groups increased, thus the rate of photodegradation was higher. In the case of non-acetylated samples, the thermally unstable acetyl groups degraded, which indicates the reduction of carbonyl groups. There are positive and negative peaks as well in C-H deformation (8), C-O stretching (11), asymmetric C-O-C stretching (12), and symmetric C-O-C stretching (13) in hemicellulose; this can be due to the rupture of etheric bonds and reformation in the system.

During acetylation, some parts of lignin can dissolve in the acidic medium (Rowell 2005). The structural change and degradation of lignin was indicated by low absorption of aromatic functional groups in the study of Fodor et al. (in press). As a result of mercury lamp irradiation, the aromatic rings of lignin ruptured, which is indicated by lower absorptions in syringyl (5) and guaiacyl (6) lignin, asymmetric C-H deformation in lignin at 1476-1470 cm^{-1} (7), ring vibration in guaiacyl lignin (10) and aromatic C-H skeletal vibration (13). The absorption reduction in samples coated with boiled linseed oil is less notable.

Alterations of the lignin structure can also account for the slightly darker, walnut-like colour of acetylated hornbeam. These changes can include the oxidation of the phenolic skeletal system as an effect of heat and acidic medium, as well as the reaction of lignin with evolving furfural in strong acidic medium (Dongre et al. 2015, Fodor et al. in press), which results in not only structural changes of lignin, but also alterations in the colour of wood. However, the strength and stiffness properties of acetylated hornbeam increased (Fodor 2015), which indicates the degradation of lignin was not significant. The brightening of acetylated hornbeam during weather exposure and mercury lamp irradiation is probably associated with the extractive content. After acetylation, the extractive content of hornbeam increased (Fodor et al. in press), which transformed during UV irradiation, thus influencing the colour. This effect was somewhat eased by coating it with boiled linseed oil.

The weather exposure tests are continuously carried out until no significant difference is measured between the samples (starting from July 2016). In the future, other sealants and varnishes are to be tested on acetylated hornbeam that are natural, non-toxic and pigmented.

4 CONCLUSIONS

The aim of this work was to examine the effect of acetylation and boiled linseed oil treatment on the photodegradation of hornbeam wood. A 10-month-long outdoor weather exposure test and a 200 hour mercury-vapour lamp irradiation test were carried out. The measurements were done on hornbeam and acetylated hornbeam, with or without boiled linseed oil coating.

According to our results, during UV irradiation hornbeam yellowed, the red hue (a*) and yellow hue (b*) increased. During weather exposure, where the fluctuation of temperature and moisture is frequent, hornbeam wood cracked, discoloured, and greyed in the end. The greying of wood is due to the bleaching of lignin leaving the grey cellulose chains on the surface.

Acetylated hornbeam did not crack during the exposure to frequently changing weather, but it had worse colour stability than native hornbeam. The dark, greyish brown colour of acetylated hornbeam brightened during UV irradiation because of the transformation of extractives and degradation of lignin. Unlike hornbeam, its brightness increased while the red and yellow hue decreased.

Coating the samples with boiled linseed oil decreased the rate of colour change and cracking. It is best to use it as a sealant and combine it with other outdoor finishes.

According to the FTIR spectra, lignin did degrade during mercury-vapour lamp irradiation. The absorption of functional groups in lignin decreased while that of methane, methylene, methyl and carbonyl groups increased. The rate of degradation and structural changes were highest in case of acetylated samples, but the strengthening polymers did not degrade notably.

Acknowledgements: This work was supported by the ÚNKP-16-3-1 New National Excellence Program of the Ministry of Human Capacities.

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