



UNIVERSITY
of SOPRON

11th Hardwood Conference

30-31 May 2024
Sopron

11TH HARDWOOD CONFERENCE PROCEEDINGS

Róbert Németh, Christian Hansmann, Holger Militz, Miklós Bak, Mátyás Báder



11TH HARDWOOD CONFERENCE PROCEEDINGS

Sopron, Hungary, 30-31 May 2024

**Editors: Róbert Németh, Christian Hansmann, Holger Militz,
Miklós Bak, Mátyás Báder**



UNIVERSITY OF SOPRON PRESS

SOPRON, 2024

11TH HARDWOOD CONFERENCE PROCEEDINGS

Sopron, Hungary, 30-31 May 2024

Editorial board

Prof. Dr. Róbert Németh

Dr. Christian Hansmann

Prof. Dr. Holger Militz

Dr. Miklós Bak

Dr. Mátyás Báder

[University of Sopron](#) – Hungary

[FATE - Scientific Association for Wood Industry](#) – Hungary

[Wood K Plus](#) – Austria

[Georg-August University of Göttingen](#) – Germany

[University of Sopron](#) – Hungary

[University of Sopron](#) – Hungary

[FATE - Scientific Association for Wood Industry](#) – Hungary

Scientific committee

Prof. Dr. Dr. h.c. Peter Niemz

Prof. Dr. Dr. h.c. Alfred Teischinger

Prof. Dr. George I. Mantanis

Prof. Dr. Bartłomiej Mazela

Prof. Dr. Julia Mihailova

Prof. Dr. Joris Van Acker

Prof. Dr. Ali Temiz

Prof. Dr. Henrik Heräjärvi

Prof. Dr. Andreja Kutnar

Prof. Dr. Goran Milić

Dr. Vjekoslav Živković

Dr. Rastislav Lagana

Dr. Milan Gaff

Dr. Lê Xuân Phương

Dr. Peter Rademacher

Dr. Emilia-Adela Salca

Dr. Galina Gorbacheva

[ETH Zürich](#) – Switzerland / [Luleå University of Technology](#) – Sweden

[BOKU University Vienna](#) – Austria

[University of Thessaly](#) – Greece

[Poznań University of Life Sciences](#) – Poland

[University of Forestry](#) – Bulgaria

[Ghent University](#) – Belgium

[Karadeniz Technical University](#) – Turkey

[Natural Resources Institute Finland \(LUKE\)](#) – Finland

[InnoRenew CoE](#) – Slovenia

[University of Belgrade](#) – Serbia

[University of Zagreb](#) – Croatia

[TU Zvolen](#) – Slovak Republic

[Mendel University Brno](#) – Czech Republic

[Vietnam National University of Forestry](#) – Vietnam

[Eberswalde University for Sustainable Development](#) – Germany

[“Transilvania” University of Brasov](#) – Romania

[Bauman Moscow State Technical University](#) – Russian Federation

Cover design

Ágnes Vörös

[University of Sopron](#) – Hungary

Webservices

Dr. Miklós Bak

[11th Hardwood Conference official website](#)

[University of Sopron](#) – Hungary

ISBN 978-963-334-518-4 (pdf)

DOI <https://doi.org/10.35511/978-963-334-518-4>

ISSN 2631-004X (Hardwood Conference Proceedings)

Constant Serial Editors: Prof. Dr. Róbert Németh, Dr. Miklós Bak

Cover image based on the photograph of Dr. Miklós Bak, 2024

The manuscripts have been peer-reviewed by the editors and have not been subjected to linguistic revision.

In the articles, corresponding authors are marked with an asterisk (*) sign.

[University of Sopron Press](#), 2024 (Bajcsy-Zsilinszky 4, 9400 Sopron, Hungary)

Responsible for publication: Prof. Dr. Attila Fábián, rector of the [University of Sopron](#)

Creative Commons license: CC BY-NC-SA 4.0 DEED



Nevezd meg! - Ne add el! - Így add tovább! 4.0 Nemzetközi
Attribution-NonCommercial-ShareAlike 4.0 International

Sponsors: [University of Sopron](#), Hungary; [Wood K Plus](#), Austria; [Georg-August University of Göttingen](#), Germany; [Scientific Association for Wood Industry](#), Hungary



UNIVERSITY
of SOPRON

WOOD
KPLUS



FATE

Content

Preface to the 11TH HARDWOOD CONFERENCE

Róbert Németh..... 9

Plenary Session - Keynotes of the 11TH HARDWOOD CONFERENCE

- The role of black locust (*Robinia pseudoacacia*) in Czechia
Ivan Kuneš, Martin Baláš, Přemysl Šedivka, Vilém Podrázský 11
- Engineered wood products for construction based on beech and poplar resources in Europe
Joris Van Acker, Liselotte De Ligne, Tobi Hallez, Jan Van den Bulcke 23
- The situation in the hardwood sector in Europe
Maria Kiefer-Polz, Rainer Handl 60

Session I - Silvicultural aspects and forest management of hardwoods

- Monitoring xylogenesis as a tool to assess the impact of different management treatments on wood formation: A study case on *Vitis vinifera*
Angela Balzano, Maks Merela, Meta Pivk, Luka Krže, Veronica De Micco 62
- The History of Forests - Climate Periods of the Middle Ages and Forestry
Emese Berzsenyi, Dóra Hegyesi, Rita Kattein-Pornói, Dávid Kazai..... 63
- Climate change mitigation aspects of increasing industrial wood assortments of hardwood species in Hungary
Éva Király, Zoltán Börzsök, Attila Borovics..... 71
- Uncovering genetic structures of natural Turkey oak populations to help develop effective climate change strategies for forestry
Botond B. Lados, László Nagy, Attila Benke, Csilla É. Molnár, Zoltán A. Köbölkuti, Attila Borovics, Klára Cseke..... 78
- Ash dieback: infection biology and management
Nina E. Nagy, Volkmar Timmermann, Isabella Børja, Halvor Solheim, Ari M. Hietala..... 86
- The Role of Industrial Hardwood Production Plantations and Long-Term Carbon Sequestration in a Circular Economy via the New *Robinia pseudoacacia* ‘Turbo Obelisk’ Varieties
Márton Németh, Kálmán Pogrányi, Rezső Solymos..... 95
- Initial growth of native and introduced hardwoods at the afforested agricultural lands – preliminary results
Vilém Podrázský, Josef Gallo, Martin Baláš, Ivan Kuneš, Tama Abubakar Yahaya, Miroslav Šulitka
 102

Poster Session

- Light response curve analysis of juvenile Püspökladányi and Üllői black locust
Tamás Ábri, Zsolt Keserű, József Csajbók..... 111
- Revealing the optimum configuration of heat-treated wood dowel joints by means of Artificial Neural Networks and Response Surface Methodology
Bogdan Bedeleian, Cosmin Spîrchez..... 115
- Artificial neural networks as a predictive tool for thrust force and torque during drilling of wood-based composites
Bogdan Bedeleian, Mihai Ispas, Sergiu Răcășan 121

Research on the value retention of hardwood products in the spirit of sustainability <i>Daniel Bodorkós, József Zalavári, Péter György Horváth</i>	126
Abrasive Water Jet Cutting vs. Laser Jet Cutting of Oak Wood Panels <i>Camelia Cosereanu, Gheorghe Cosmin Spirchez, Antonela Lungu, Sergiu-Valeriu Georgescu, Alexandru Catalin Filip, Sergiu Racasan</i>	131
Polyphenol content of underutilized wood species from Hungary <i>Tamás Hofmann, Haruna Seidu, Kibet Tito Kipkoror</i>	136
Wood quality evaluation of 32 grafted clone linages of Keyaki (<i>Zelkova serrata</i>) plus trees 12 years after planting <i>Kiyohiko Ikeda, Shigehiro Yamamoto</i>	141
Influence of the number of belts over vibrations of the cutting mechanism in woodworking shaper <i>Georgi Kovatchev, Valentin Atanasov</i>	146
The impact of litter forest fires on the internal structure of wood from stem of beech trees <i>Elena-Camelia Musat, Costin-Ovidiu Vantoiu, Emilia-Adela Salca</i>	153
Analysing innovative wood joints crafted by laser cut spline curves <i>László Németh, József Garab, Péter György Horváth</i>	158
Dynamic fatigue tests of hardwoods <i>Gábor Orbán, Antal Kánnár</i>	163
Restoration of an old painted oak boardsign - A case study <i>Gabriel Calin Canalas, Emilia-Adela Salca, Elena-Camelia Musat</i>	168
Some physical properties of native and thermo-treated <i>Fraxinus excelsior</i> timber <i>Cosmin Spirchez, Aurel Lunguleasa, Alin Olărescu, Camelia Coşereanu, Bogdan Bedelea</i>	173
The surface morphology of sanded curly maple in comparison with straight grain maple selected for musical instruments <i>Mariana Domnica Stanciu, Lidia Gurau, Florin Dinulica, Catalin Constantin Roibu, Cristian Hiciu, Andrei Mursa, Marian Stirbu</i>	178
Analysis of changes in the composition of beech as an important industrial raw material in Hungary <i>Katalin Szakálosné Mátyás, Attila László Horváth</i>	183
Investigation of old hardwood structure element <i>Fanni Szőke, Antal Kánnár</i>	187
An investigation of the influence of coating film thickness on the light induced colour changes of clear coated maple (<i>Acer pseudoplatanus</i>) wood surfaces with natural aspect <i>Mihai-Junior Torcătoru, Maria Cristina Timar</i>	192
Composite Material Manufacturing from Plantation Paulownia Wood with Using Microwave Technology: Technical and Cost Analyses <i>Grigory Torgovnikov, Peter Vinden, Alexandra Leshchinskaia</i>	198
Thermal modification of wood as a tool for changing the colour of hardwoods <i>Vidholdová Zuzana</i>	203
High termite resistance of kempas (<i>Koompassia malaccensis</i>) hardwood protected with a novel vegetal extracts-cypermethrin wood preservative under outdoor aboveground tropical environment <i>Messaoudi Daouia, Wong Andrew H.H.</i>	209
Comparison of wood properties of pedunculate oak and non-native northern red oak from an anthropogenic site <i>Aleš Zeidler, Vlastimil Borůvka</i>	214
Acoustic Parameters of Pioneer Wood Species <i>Petr Horák, Vlastimil Borůvka</i>	219
Determination of Elastic Parameters of Birch and Oak Wood Using Optical Method <i>David Novák, Vlastimil Borůvka, Petr Horák, Tomáš Kytka</i>	224

Preliminary study on climate change impacts on annual wood growth development in Hungary <i>Péter Farkas, Zsolt György Tóth, Huba Komán</i>	230
Combustion characteristics of Russian olive (<i>Elaeagnus angustifolia</i> L.) <i>Szabolcs Komán, Krisztián Töröcsi</i>	236
Withdrawal capacity of Green ash (<i>Fraxinus pennsylvanica</i> Marsh.) and Box elder (<i>Acer negundo</i> L.) <i>Szabolcs Komán, Boldizsár Déri</i>	241
Formaldehyde emission from wood and wood-based products <i>Szabolcs Komán, Csilla Czók, Tamás Hofmann</i>	246
Finite element analysis of heat transfer of Turkey oak (<i>Quercus cerris</i>) <i>Sándor Borza, Gergely Csiszár, József Garab, Szabolcs Komán</i>	250
Possible alternative to creosote treated railway sleepers, Fürstenberg-System Sleeper (FSS) <i>Szabolcs Komán, Balogh Mátyás Zalán, Sándor Fehér</i> ,.....	255
Investigation of bendability characteristics of wood-based polymer composites <i>S. Behnam Hosseini, Milan Gaff</i>	260
Comparing the blossoming and wood producing properties of selected black locust clones <i>Alexandra Porcsin, Katalin Szakálosné Mátyás, Zsolt Keserű</i>	266
The influence of two different adhesives on structural reinforcement of oak-wood elements by carbon and glass fibres <i>Andrija Novosel, Vjekoslav Živković</i>	271
Investigating Kerf Topology and Morphology Variation in Native Species After CO ₂ Laser Cutting <i>Lukáš Štefančin, Rastislav Igaz, Ivan Kubovský, Richard Kminiak</i>	272
Comparison of fluted-growth and cylindrical hornbeam logs from Hungarian forests <i>Mátyás Báder, Maximilián Cziczzer</i>	279
Thermal modification affects the dynamic vapor sorption of tree of heaven wood (<i>Ailanthus altissima</i> , Mill.) <i>Fanni Fodor, Lukas Emmerich, Norbert Horváth, Róbert Németh</i>	285
How conditions after application affect the depth of penetration of gel wood preservative in oak <i>Jan Baar, Štěpán Bartoš, Anna Oberle, Zuzana Paschová</i>	290
The weathering of the beech wood impregnated by pigmented linseed oil <i>Jakub Dömény, Jan Baar</i>	294
Examination of the durability of beeswax-impregnated wood <i>Miklós Bak, Ádám Bedők, Róbert Németh</i>	299
Preparation of pleated oak samples and their bending tests at different moisture contents <i>Pál Péter Gecseg, Mátyás Báder</i>	304
Bending test results of small-sized glued laminated oak timber consisting of 2, 3 and 5 layers <i>Dénes Horváth, Sándor Fehér</i>	308
Homogenized dynamic Modulus of Elasticity of structural strip-like laminations made from low-grade sawn hardwood <i>Simon Lux, Johannes Konnerth, Andreas Neumüller</i>	314
Impact of varnishing on the acoustic properties of sycamore maple (<i>Acer pseudoplatanus</i>) panels <i>Aleš Straže, Jure Žigon, Matjaž Pavlič</i>	319
The effect of wood and solution temperatures on the preservative uptake of Pannonia poplar and common spruce – preliminary research <i>Luca Buga-Kovács, Norbert Horváth</i>	325

Session II - Hardwood resources, product approaches, and timber trade

Birch tar – historic material, innovative approach <i>Jakub Brózdowski, Monika Bartkowiak, Grzegorz Cofa, Grażyna Dąbrowska, Ahmet Erdem Yazici, Zbigniew Katolik, Szymon Rosołowski, Magdalena Zborowska</i>	330
Beech Wood Steaming – Chemical Profile of Condensate for Sustainable Applications <i>Goran Milić, Nebojša Todorović, Dejan Orčić, Nemanja Živanović, Nataša Simin</i>	336
Towards a complete technological profile of hardwood branches for structural use: Case study on Poisson's ratio <i>Tobias Nennung, Michael Grabner, Christian Hansmann, Wolfgang Gindl-Altmutter, Johannes Konnerth, Maximilian Pramreiter</i>	342
Low-value wood from non-native tree species as a potential source of bioactive extractives for bio-based preservation <i>Viljem Vek, Ida Poljanšek, Urša Osolnik, Angela Balzano, Miha Humar, Primož Oven</i>	349
Hardwood Processing - do we apply appropriate technologies? <i>Alfred Teischinger</i>	357

Session III - Surface coating and bonding characteristics of hardwoods

Influence of pretreatments with essential oils on the colour and light resistance of maple (<i>Acer pseudoplatanus</i>) wood surfaces coated with shellac and beeswax <i>Emanuela Carmen Beldean, Maria Cristina Timar, Dana Mihaela Pop</i>	365
Oak timber cross-cutting based on fiber orientation scanning and mechanical modelling to ensure finger-joints strength <i>Soh Mbou Delin, Besseau Benoit, Pot Guillaume, Viguiet Joffrey, Marcon Bertrand, Milhe Louis, Lanvin Jean-Denis, Reuling Didier</i>	376
From Phenol-Lignin Blends towards birch plywood board production <i>Wilfried Sailer-Kronlachner, Peter Bliem, Hendrikus van Herwijnen</i>	386
Flatwise bending strength and stiffness of finger jointed beech lamellas (<i>Fagus sylvatica</i> , L.) using different adhesive systems and effect of finger joint gap size <i>Hannes Stolze, Adefemi Adebisi Alade, Holger Militz</i>	395
Mode I fracture behaviour of bonded beech wood analysed with acoustic emission <i>Martin Capuder, Aleš Straže, Boris Azinović, Ana Brunčič</i>	402

Session IV - Hardwood structure and properties

Compression strength perpendicular to grain in hardwoods depending on test method <i>Marlene Cramer</i>	410
Compensatory Anatomical Studies on <i>Robinia</i> , <i>Sclerocarya</i> and <i>Ulmus</i> <i>Fath Alrhman A. A. Younis, Róbert Németh, Mátyás Báder</i>	420
The influence of the type of varnish on the viscous-elastic properties of maple wood used for musical instruments <i>Roxana Gall, Adriana Savin, Mariana Domnica Stanciu, Mihaela Campean, Vasile Ghiorghe Gliga</i>	426
XRF investigation of subfossil oak (<i>Quercus</i> spp) wood revealing colour - iron content correlation <i>Nedelcu Ruxandra, Timar Maria Cristina, Beldean Emanuela Carmen</i>	435
Investigating the Development of Heartwood in <i>Quercus robur</i> in Denmark <i>Andrea Ponzeccchi, Albin Lobo, Jill Katarina Olofsson, Jon Kehlet Hansen, Erik Dahl Kjær, Lisbeth Garbrecht Thygesen</i>	445

Modelling tensile mechanical properties of oak timber from fibre orientation scanning for strength grading purpose <i>Guillaume Pot, Joffrey Viguier, Benoit Besseau, Jean-Denis Lanvin, Didier Reuling</i>	452
Green oak building – small diameter logs for construction <i>Martin Huber, Franka Brüchert, Nicolas Hofmann, Kay-Uwe Schober, Beate Hörnel-Metzger, Maximilian Müller, Udo H. Sauter</i>	461
An evaluative examination of oak wood defect detection employing deep learning (DL) software systems. <i>Branimir Jambreković, Filip Veselčić, Iva Ištok, Tomislav Sinković, Vjekoslav Živković, Tomislav Sedlar</i>	466
Comparison of surface roughness of milled surface of false heartwood, mature wood, and sapwood within beech wood <i>Lukáš Adamčík, Richard Kminiak, Adrián Banski</i>	467

Session V - Hardwoods in composites and engineered materials

Developing Laminated Strand Lumber (LSL) based on underutilized Hungarian wood species <i>László Bejő, Tibor Alpár, Ahmed Altaher Omer Ahmed</i>	475
Feasibility study on manufacturing finger-jointed structural timber using <i>Eucalyptus grandis</i> wood <i>Adefemi Adebisi Alade, Hannes Stolze, Coenraad Brand Wessels, Holger Militz</i>	481
A novel approach for the design of flame-retardant plywood <i>Christian Hansmann, Georg Baumgartner, Christoph Preimesberger</i>	486
The use of beech particles in the production of particleboards based on recycled wood <i>Ján Iždinský, Emilia Adela Salca, Pavlo Bekhta</i>	493
Thermal properties of highly porous wood-based insulation material <i>Kryštof Kubista, Přemysl Šedivka</i>	501

Session VI - Modification & functionalization

Quantitative and qualitative aspects of industrial drying of Turkey oak lumber <i>Iulia Deaconu, Bogdan Bedeleian, Sergiu Georgescu, Octavia Zeleniuc, Mihaela Campean</i>	508
Changes in properties of maple by hygrothermally treatment for accelerated ageing at 135-142°C <i>Tobias Dietrich, Herwig Hackenberg, Mario Zauer, Holger Schiema, André Wagenführ</i>	518
Change of chemical composition and FTIR spectra of Turkey oak and Pannonia poplar wood after acetylation <i>Fanni Fodor, Tamás Hofmann</i>	525
Change of cellulose crystal structure in beech wood (<i>Fagus sylvatica</i> L.) due to gaseous ammonia treatment <i>Herwig Hackenberg, Tobias Dietrich, Mario Zauer, Martina Bremer, Steffen Fischer, André Wagenführ</i>	535
Evaluation of weathering performance of acetylated hardwood species <i>Rene Herrera Diaz, Jakub Sandak, Oihana Gordobil, Faksawat Poohphajai, Anna Sandak</i>	539
Unlocking a Potential Deacetylation of Acetylated Beech (<i>Fagus sylvatica</i> L.) LVL <i>Maik Slabohm, Holger Militz</i>	544
Fork and flying wood tests to improve prediction of board stress development during drying <i>Antoine Stéphane, Patrick Perré, Clément L'Hostis, Romain Rémond</i>	549
Modification of different European hardwood species with a bio-based thermosetting resin on a semi-industrial scale <i>Christoph Hötte, Holger Militz</i>	557

Preliminary study on climate change impacts on annual wood growth development in Hungary

Péter Farkas^{1*}, Zsolt György Tóth¹, Huba Komán²

¹ Bajcsy-Zs. u. 4, 9400 Sopron, Hungary, University of Sopron

² Fővám tér 8, 1093 Budapest, Hungary, Corvinus University of Budapest

E-mail: farkaspeter@phd.uni-sopron.hu

Keywords: climate change in Hungary, aridity index, FAI, dendroclimatology, annual growth, latewood

ABSTRACT

The density of wood is closely related to its mechanical properties such as hardness, strength and elasticity of wood. To estimate some of these properties, one only needs to analyse the growth rings and related density data of wood. The density and growth rings have a close connection with climatic data. Based on climate change scenarios, it could be possible to prepare estimates for wood properties during the climate change period. For forestry climate simulation, the Forestry Aridity Index (FAI) was developed which can be specially applied to Hungary for estimating changes in wood species habitats under climate change scenarios. Several methods use statistical procedures to model past climatic data using the genetic properties of the tree species and annual ring data. It is also possible to simulate annual growth development based on climate data, but we do not know which wood properties will be affected by climate change in Hungary. Furthermore, research is being conducted to find the answer to this question.

INTRODUCTION

Wood anatomy overview

The xylem primarily consists of prosenchymatous, elongated and parenchymatous, brick-shaped cells. Important prosenchymatous cell types in hardwoods include tracheas (also called vessels), libriform fibers, separate fibers, fiber-tracheids, vasicentric tracheids, and vascular tracheids; in conifers, these include fiber-tracheids, vertical tracheids, strand tracheids, and ray tracheid cells. Important parenchymatous cell types in hardwoods are strand parenchyma, fusiform parenchyma, crystalliferous cells, epithelial cells, and ray cells; in conifers, they are vertical parenchyma, epithelial cells, and ray parenchyma cells (Schweingruber 1996, p. 67). The annual ring structure results from the intermittent activity of the vascular cambium in trees within the temperate zone (Molnár et al. 2007, pp. 68–69). In the spring, when the cambium activates, it produces parenchymatic cells and vessels (only in hardwoods) as well as tracheids with large lumens and thin-walled fiber cells — this forms the earlywood. Later, as summer and autumn progress, the cambium continues to produce parenchymatic cells, and the vascular area decreases with narrower-lumen vessels (only in hardwoods), along with thick-walled fiber and tracheid cells — this is the latewood. During the winter, the cambium enters dormancy. (Schweingruber 1996, p. 67; Molnár et al. 2007, pp. 68–69). The annual ring boundary is formed between the latewood and earlywood. Outside the temperate zone, in subtropical and tropical areas, the growth ring often does not correspond to the annual ring because the cambium's activity is cyclical, influenced by wet and dry periods (Molnár et al. 2007, pp. 68–69). Schultz (2005) identifies nine climatic ecozones on Earth that exhibit seasonal cambial rhythms (Schmitt et al. 2023, pp. 58–59). Prosenchymatous cells are primarily responsible for water conduction and structural strength. In earlywood, these cells live for a few weeks, while in latewood, they can survive for a few months. This type of cell has the ability to adapt to the climate over its lifespan, reflecting the impact of environmental events. Parenchymatous cells, on the other hand, can live for several years and typically have thickened cell walls regardless of age; thus, they do not retain climatic information (Schweingruber 1996, p. 67). In the temperate zone, the earlywood and latewood can be visually distinguished in ring-porous species and some conifers. They can be separated under a microscope in semi-ring-porous or semi-diffuse-porous species and are hard to differentiate with any equipment in diffuse-porous species. Table 1 summarizes the main identification markers for earlywood and latewood in trees from the temperate zone. Earlywood

has a lower density than latewood, making the percentage of latewood within an annual ring important both technically and from the perspective of timber utilization (Molnár et al. 2007, p. 69).

Table 1: Earlywood and latewood identification marks in temperate zone trees

Tree	Earlywood identification marks	Latewood identification marks
<i>Softwoods (conifers)</i>	- thin-walled tracheids with shorter lengths - visibly lighter colour (in multiple species)	- thick-walled tracheids with greater lengths - Mork's criterion: in the latewood, the double tracheid cell wall thickness \geq lumen ¹ - visibly darker colour (in multiple species)
<i>Ring-porous hardwoods</i>	- the diameters of the vessels are clearly larger and arranged in a circle along the annual ring ² - fiber cells are thin-walled	- the diameters of the vessels are clearly small and not follow the line of the annual ring ² - fiber cells are thick-walled
<i>Semi-ring and semi-diffuse porous hardwoods</i>	- the transition between earlywood and latewood is continuous - the diameter of vessels decreases continuously from earlywood to latewood - the frequency of vessels decreases continuously from earlywood to latewood - there is a visible colour transition from lighter to darker between earlywood and latewood - fiber cell diameter decreases and cell wall thickness increases in a continuous transition from earlywood to latewood	
<i>Diffuse-porous hardwoods</i>	- the transition between earlywood and latewood is continuous - in some species, the diameter of vessels decreases slightly from earlywood to latewood (e.g., beech) - in some species, the frequency of vessels decreases from earlywood to latewood (e.g., common alder) - a visible colour transition from lighter to darker between earlywood and latewood is rare - in a continuous transition from earlywood to latewood, the diameter of fiber cells slightly decreases and cell wall thickness increases	

Own adapted table, based on sources: ¹(Denne 1989), ²(Molnár et al. 2007, p. 54-55), (Schmitt et al. 2023, pp. 58–59).

Figure 1 schematically represents the relationship between tracheid cell wall thickness, radial diameters, and wood density in the annual rings of conifers (Cuny et al. 2014, p. 1232). In Figure 1, the schematic cells could also be interpreted representing the lumen area in the case of hardwood cells. For conifers, changes in annual ring width are primarily determined by the earlywood, with less variability in the latewood. In contrast, for ring-porous hardwood trees, the variability in annual ring width is determined by the latewood, because the width of the earlywood is almost constant (approximately 0.4 to 0.6 mm in Hungary). For example, the outstanding strength characteristics of black locust (*Robinia pseudoacacia*) are primarily related to the high percentage of latewood, which can reach up to 85%. The typical density_(MC12%) is 770 kg/m³, porosity is 52%, fiber cell wall volume is 68%. For similar densities, the high fiber cell wall volume is responsible: 86% in the case of sessile oak (*Quercus petraea*) and Turkey oak (*Q. cerris*) which have a 60–80% latewood percentage, and also in European beech (*Fagus sylvatica*) which has an 89% fiber cell wall volume, 55% porosity, and typical density_(MC12%) value is 720 kg/m³. In the case of native and hybrid poplars (*Populus spp.*) the fiber cell wall is thin, with a volume of 50–60%, and the porosity can reach a high rate of 75%, resulting in a low density_(MC12%) that ranges from 360 to 490 kg/m³, with an typical value of 400 kg/m³ (Molnár et al. 2007).

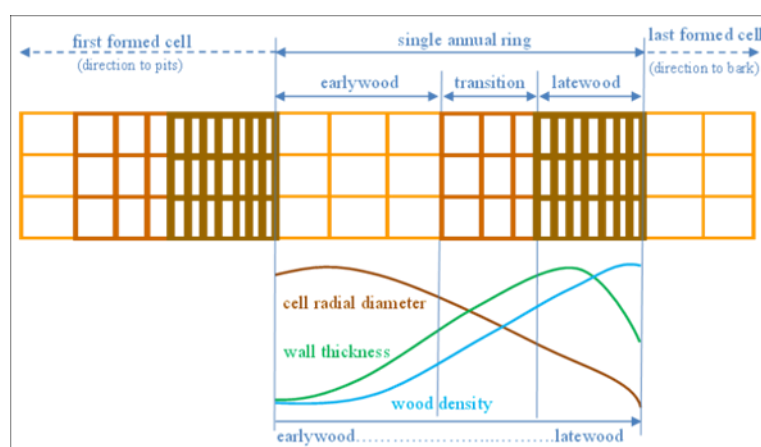


Figure 1: Relationship between tracheid cell wall thickness, radial diameters, and wood density in the annual rings of conifers. Adapted from Cuny et al. (2014).

“The density of wood is directly related to the ratio of cell wall thickness to cell diameter, meaning that the overall density depends on the proportion of thin-walled earlywood to thick-walled latewood.” (Sandberg et al. 2023, p. 1839) The density of wood is closely related to mechanical properties such as hardness, strength, and elasticity. Based on this, estimating some properties may only require analysing the growth rings and related density data of the wood (Molnár et al. 2007, p. 68). The density and growth rings have a close connection with climatic data, according to Schweingruber (1996). This means that, based on climate change scenarios, it could be possible to prepare estimations of wood properties for the period affected by climate change.

Climate change and important wood species of Hungary

The current forested area in Hungary comprises 21% of the country's total land area. As of 2022, the economically most important tree species and their respective percentages of forest area are as follows: oak (*mainly: Q. robur, Q. petraea*) at 21.0 %, Turkey oak (*Q. cerris*) at 11.6%, beech (*F. sylvatica*) at 6.1%, hornbeam (*C. betulus*) at 5.2%, black locust (*R. pseudoacacia*) at 24.4%, hybrid and native poplars (*Populus spp.*) at 10.5%, softwood (*mainly: P. sylvestris, P. nigra*) at 9.4%. In 2022, the total living tree resource was 408,091,878 m³. The total annual growth and total annual timber logging amounted to 12,937,847 m³ and 7,343,656 m³, respectively (National Land Centre 2024). The forested area in Hungary is increasing. The National Forest Strategy aims to achieve a 27% forested area by 2050 (Ministry of Agriculture 2016). This goal is important both economically and ecologically. Climate change affects the forest, and monitoring this process requires the application of improved forestry climate models.

From a forest hydrology and life cycle perspective in Hungary, the period from November to April is marked by water accumulation, dormancy, and early growth. The most critical period for water consumption, vitality, and organic matter production is between May and August, when the evapotranspiration rate is high, and the forest is very sensitive to extreme weather conditions. July and August are particularly crucial, as these are arid and hot months when growth diminishes. In the concluding period, from September to October, growth gradually ceases, and the focus shifts physiologically to seed production and nutrient storage (Führer 2010; Führer et al. 2011). Based on the relationship between the girth growth of trees and meteorological parameters, and recognizing the critical period from May to August, Führer (2010) introduced the newly developed Forestry Aridity Index (FAI) for Hungarian conditions (Eq. 1):

$$FAI = 100 \cdot \frac{\bar{T}_{July-Aug}}{P_{May-July} + P_{July-Aug}} \quad (1)$$

where $\bar{T}_{July-Aug}$ is the average temperature from July to August (°C) and $P_{May-July} + P_{July-Aug}$ is the precipitation sum (mm) in May, June, July, and again in July and August (Führer 2010), so the equation is weighted with the most critical July month.

Führer (2010), Führer et al. (2017), Gálós and Führer (2018), and Mátyás et al. (2018) identified five forestry climate categories based on the Forestry Aridity Index (FAI): beech (FAI < 4.75), hornbeam oak (FAI: 4.75–6.00), sessile oak turkey oak (FAI: 6.00–7.25), forest-steppe (FAI: 7.25–8.50), and grass steppe (FAI > 8.50). Applying the FAI, Führer et al. (2017) and Gálós and Führer (2018) projected the macroclimate classes onto the area of Hungary (Figure 2) and created simulations with climate scenario A1B for the period 2021–2050. These FAI-based aridity simulations suggest that climate change will shift Hungary's forest climate towards dry sessile oak-turkey oak and forest-steppe, and in some areas, to grass steppe. Mátyás et al. (2018) reported that the annual temperature has increased by 1.2–1.7°C over the last 30 years. Illés and Móricz (2022) conducted a climate envelope analysis for nine native wood species in Europe and Hungary under the RCP4.5 climate scenario. Their findings indicate that the applied climate model predicts an increase in the annual average temperature in Hungary (2011–2040: +1.7 °C; 2041–2070: +2.5 °C; 2071–2100: +3.1 °C). Meanwhile, the amount of annual (+5%) and summer precipitation (–10%) shows only minor changes by the end of the century compared to the period 1961–1990. Figure 3 represents the decrease in precipitation (3a) and increase in temperature (3b) over the past 120 years (World Bank Group 2024). When compared with the estimations by Illés and Móricz (2022), Figure 3 shows similar trends. Additionally, when compared with FAI-based aridity maps (Figure 2), a slight decrease in precipitation and a definite increase in temperature can be observed, which will result in a xeric shift in Hungary's forest climate. As described by Illés and Móricz (2022),

due to climate change, over the next 40-80 years, the habitats of beech (*F. sylvatica*), Scots pine (*P. sylvestris*), sessile oak (*Q. petraea*), and European oak (*Q. robur*) will significantly decrease in Hungary. Conversely, the habitats of Turkey oak (*Q. cerris*), pubescent oak (*Q. pubescent*), and Austrian pine (*P. nigra*) are expected to increase and expand into the hilly and mid-mountain areas. Porcsin et al. (2023) investigated cultivars of black locust (*R. pseudoacacia*). This species is frost-sensitive and tolerant of summer heat. The increasing temperatures associated with climate change in Hungary could be advantageous for this tree. It is expected that the area covered by black locust forests will increase in the forest-steppe regions. However, despite its economic importance, it is also an invasive species, necessitating well-regulated planting with high-quality cultivars. (Komán and Varga 2021; Komán and Lehoczki 2022; Komán et al. 2022). Bartha et al. (2018) estimated a significant expansion of the invasive hackberry (*Celtis occidentalis*) during the simulated period from 2021 to 2070.

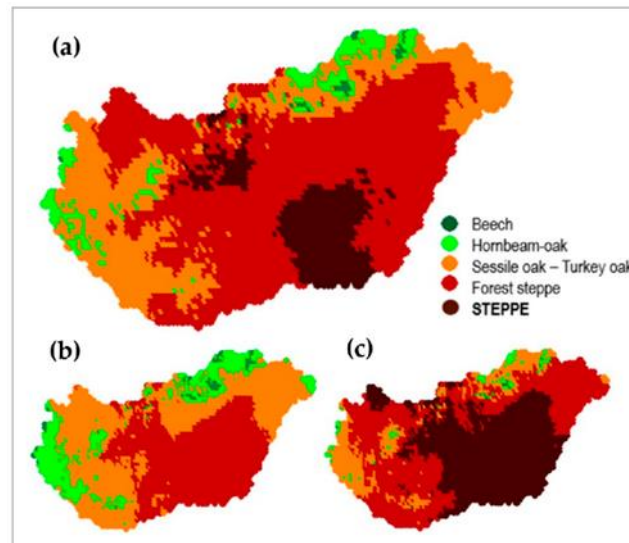


Figure 2: Simulated shift in macroclimate classes in Hungary, 2021–2050. Defined by the Forestry Aridity Index. (a) Mean of the simulation; (b) optimistic result; (c) pessimistic result of simulation (b, c: 66% range of the simulation results, emission scenario: A1B). Adapted from B. Gálos in Mátyás et al. (2018), licence CC-BY 4.0.

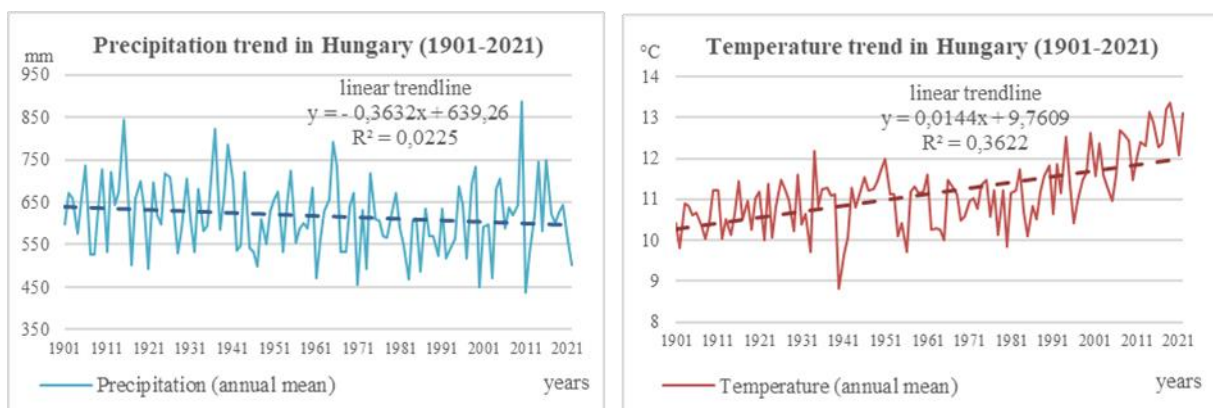


Figure 3: Precipitation (3a) and temperature (3b) change trends between 1901 and 2021 in Hungary. Own edited figure based on dataset of World Bank Group, CCKP (2024), license: (CC BY 4.0)

DISCUSSION

The international research on dendroclimatology and dendrochronology primarily focuses on softwoods or, in some cases, ring-porous analyses (Cook and Kairiukstis 1990; Schweingruber 1996; Cuny et al. 2014; Gärtner et al. 2015). In Hungary, Majer (1972) examined the relationship between annual growth and climate in beech trees. Dávid and Kern (2007) and Kern (2007) analyzed oak trees using dendroecological and dendrochronological methods. Misi (2017) conducted a comprehensive dendroclimatology analysis of Scots pine. Grynaeus (2002), Morgós (2007), and Árvai (2019) focused

their main research on dendrochronology from an archaeological perspective. Various methods employ mathematical and statistical procedures to model past climatic data using the genetic properties of tree species and annual ring data (Biondi and Waikul 2004; Jevšenak 2020). Shishov et al. (2016, 2021) developed a band model for cambium development, which simulates the seasonal cell production of cambium based on specific wood species and estimated temperature and precipitation trends. This model was tested in the semi-arid Southern-Siberian area by the authors.

Summarizing, we understand the types of climatic changes possible in Hungary and which wood species will survive in future Hungarian forests. However, we currently do not know what quality properties these woods will possess. Further research will attempt to answer this question by applying mathematical models and the aforementioned software calculation methods adapted to Hungarian climate scenarios.

ACKNOWLEDGEMENTS

The publication was supported by the project no. TKP2021-NKTA-43, which has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme. The authors are very grateful to Foundation for University Research in Wood Industry (Faipari Egyetemi Kutatásért Alapítvány – FAEKA) for the supports the research.

REFERENCES

- Árvai M (2019) Holtfaanyag évgyűrűvizsgálatával nyert információk környezettörténeti szempontú értelmezése egy hegyvidéki és egy alluviális lelőhely példáján. ELTE
- Bartha D, Berki I, Lengyel A, et al (2018) Erdőtársulások és fafajaik átrendeződési lehetőségei a változó klímában. Erdészettudományi Közlemények 8:163–195
- Biondi F, Waikul K (2004) DENDROCLIM2002: A C++ program for statistical calibration of climate signals in tree-ring chronologies. Comput Geosci 30:303–311. <https://doi.org/10.1016/j.cageo.2003.11.004>
- Cook ER, Kairiukstis LA (eds) (1990) Methods of Dendrochronology. Springer Netherlands, Dordrecht
- Cuny HE, Rathgeber CBK, Frank D, et al (2014) Kinetics of tracheid development explain conifer tree-ring structure. New Phytol 203:1231–1241. <https://doi.org/10.1111/nph.12871>
- Dávid S, Kern Z (2007) Keleti-bakonyi és geressei tölgyek dendrokronológiai és dendroökológiai vizsgálata. In: Gömöri J (ed) AZ ERDŐ ÉS A FA RÉGÉSZETE ÉS NÉPRAJZA (Kézművesipar-történeti megközelítésben). MTA VEAB Soproni Tudós Társasága, Sopron, pp 104–122
- Denne MP (1989) Definition of Latewood According to Mork (1928). IAWA J 10:59–62. <https://doi.org/10.1163/22941932-90001112>
- Führer E (2010) A fák növekedése és a klíma. KLÍMA-21 Füzetek 61:98–107
- Führer E, Gálos B, Rasztoivits E, et al (2017) Erdészeti klímaosztályok területének várható változása. Erdészeti Lapok 174–177
- Führer E, Horváth L, Jagodics A, et al (2011) Application of a new aridity index in Hungarian forestry practice. Idojaras (Budapest, 1905) 115:205–116
- Gálos B, Führer E (2018) A klíma erdészeti célú előrejelítése. Erdészettudományi Közlemények 8:43–55
- Gärtner H, Cherubini P, Fonti P, et al (2015) A Technical Perspective in Modern Tree-ring Research - How to Overcome Dendroecological and Wood Anatomical Challenges. JoVE J Vis Exp e52337. <https://doi.org/10.3791/52337>
- Grynaeus A (2002) Dendrokronológiai kutatások és eredményei Magyarországon. Földt Közlöny 265–272
- Jevšenak J (2020) New features in the *dendroTools* R package: Bootstrapped and partial correlation coefficients for monthly and daily climate data. Dendrochronologia 63:125753. <https://doi.org/10.1016/j.dendro.2020.125753>
- Kern Z (2007) Évgyűrűvizsgálatok a Déli-Bakonyban és a Balaton-felvidéken. In: Gömöri J (ed) AZ ERDŐ ÉS A FA RÉGÉSZETE ÉS NÉPRAJZA (Kézművesipar-történeti megközelítésben). MTA VEAB Soproni Tudós Társasága, Sopron, pp 89–103
- Komán S, Lehoczki M (2022) Combustion characteristics of green ash and box elder. In: Németh R, Christian Hansmann, Rademacher P, et al. (eds) 10TH HARDWOOD CONFERENCE PROCEEDINGS. University of Sopron, Sopron, p 128

- Komán S, Szmorad G, Bak M (2022) Thermal modification of green ash and box elder. In: Németh R, Christian Hansmann, Rademacher P, et al. (eds) 10TH HARDWOOD CONFERENCE PROCEEDINGS. University of Sopron, Sopron, p 129
- Komán S, Varga D (2021) Physical and mechanical properties of wood from invasive tree species. *Maderas Cienc Tecnol* 23:1–8. <https://doi.org/10.4067/s0718-221x2021000100411>
- Majer A (1972) Évgyűrű-kronológia. *Az Erdő* 164–171
- Mátyás C, Berki I, Bidló A, et al (2018) Sustainability of Forest Cover under Climate Change on the Temperate-Continental Xeric Limits. *Forests* 9:489. <https://doi.org/10.3390/f9080489>
- Misi D (2017) Magyarországi erdeifenyő állományok komplex dendroklimatológiai elemzése az elmúlt 100 év klímaváltozásának tükrében. PhD, Szegedi Tudományegyetem
- Molnár S, Peszlen I, Paukó A (2007) Faanatómia. Szaktudás Kiadó Ház, Budapest
- Morgós A (2007) Faanyagok kormeghatározása – a dendrokronológia és a magyarországi helyzet. In: Gömöri J (ed) AZ ERDŐ ÉS A FA RÉGÉSZETE ÉS NÉPRAJZA (Kézművesipar-történeti megközelítésben). MTA VEAB Soproni Tudós Társasága, Sopron, pp 32–89
- National Land Centre (Nemzeti Földügyi Központ - NFK) (2024) Magyarország erdeivel kapcsolatos adatok (Data related to Hungary's forests). https://nfk.gov.hu/Magyarorszag_erdeivel_kapcsolatos_adatok_news_513. Accessed 11 Apr 2024
- Sandberg D, Gorbacheva G, Lichtenegger H, et al (2023) Advanced Engineered Wood-Material Concepts. In: Niemz P, Teischinger A, Sandberg D (eds) Springer Handbook of Wood Science and Technology. Springer International Publishing, Cham, pp 1835–1888
- Schmitt U, Koch G, Hietz P, Tholen D (2023) Wood Biology. In: Niemz P, Teischinger A, Sandberg D (eds) Springer Handbook of Wood Science and Technology. Springer International Publishing, Cham, pp 41–138
- Schultz J (2005) The ecozones of the world. The ecological division of the geosphere
- Schweingruber FH (1996) Tree rings and environment dendroecology. P. Haupt, Berne
- Shishov VV, Tychkov II, Anchukaitis KJ, et al (2021) A Band Model of Cambium Development: Opportunities and Prospects. *Forests* 12:1361. <https://doi.org/10.3390/f12101361>
- Shishov VV, Tychkov II, Popkova MI, et al (2016) VS-oscilloscope: A new tool to parameterize tree radial growth based on climate conditions. *Dendrochronologia* 39:42–50. <https://doi.org/10.1016/j.dendro.2015.10.001>
- World Bank Group (2024) World Bank Climate Change Knowledge Portal (CCKP). <https://climateknowledgeportal.worldbank.org/>. Accessed 11 Apr 2024