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

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

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

Content

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

Session III - Surface coating and bonding characteristics of hardwoods

Session IV - Hardwood structure and properties

Session V - Hardwoods in composites and engineered materials

Session VI - Modification & functionalization

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

Péter Farkas[1]*, Zsolt György Tóth[1], Huba Komán[2]

[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
Softwoods (conifers)	- 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 ≥ lumen[1] - visibly darker colour (in multiple species)
Ring-porous hardwoods	- 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
Semi-ring and semi-diffuse porous hardwoods	- 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	
Diffuse-porous hardwoods	- 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/m^3, 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).

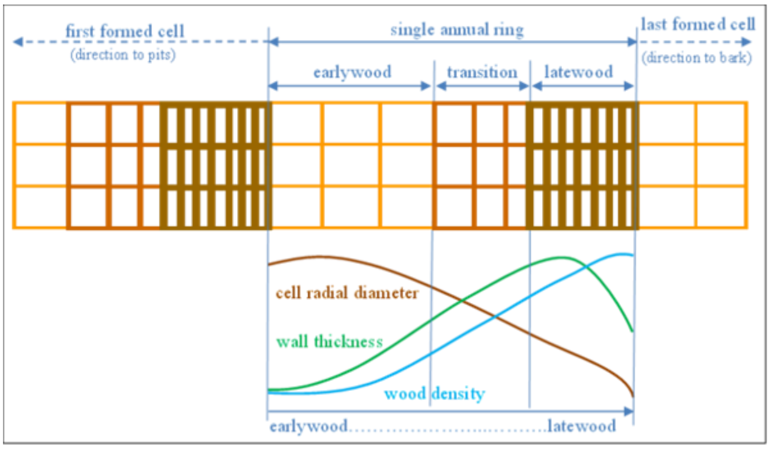

Figure 1: Relationship between tracheid cell wall thickness, radial diameters, and wood density in the annual rings of conifers. Adapted from Cuny et al. (2014).

"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):

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

where $\bar{T}_{July-Aug}$ is the average temperature from July to August (℃) 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), Gálos 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 Gálos 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.

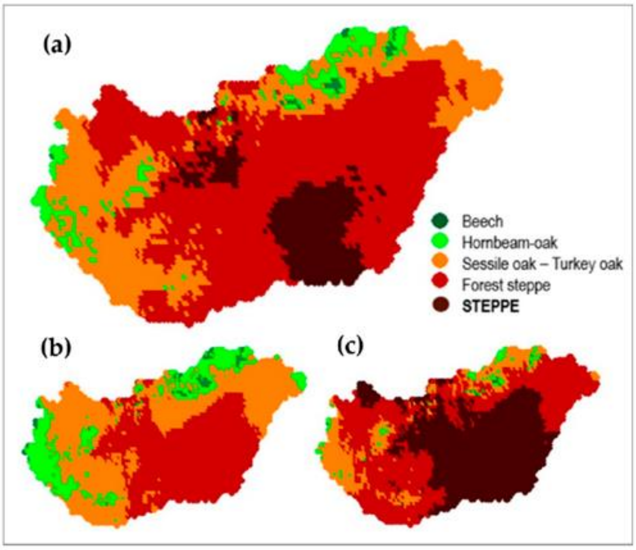

Figure 2: Simulated shift in macroclimate classes in Hungary, 2021–2050. Defined by the Forestry Aridity Index. (a) Mean of the simulation; (b) optimistic result; (c) pessimistic result of simulation (b, c: 66% range of the simulation results, emission scenario: A1B). Adapted from B. Gálos in Mátyás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

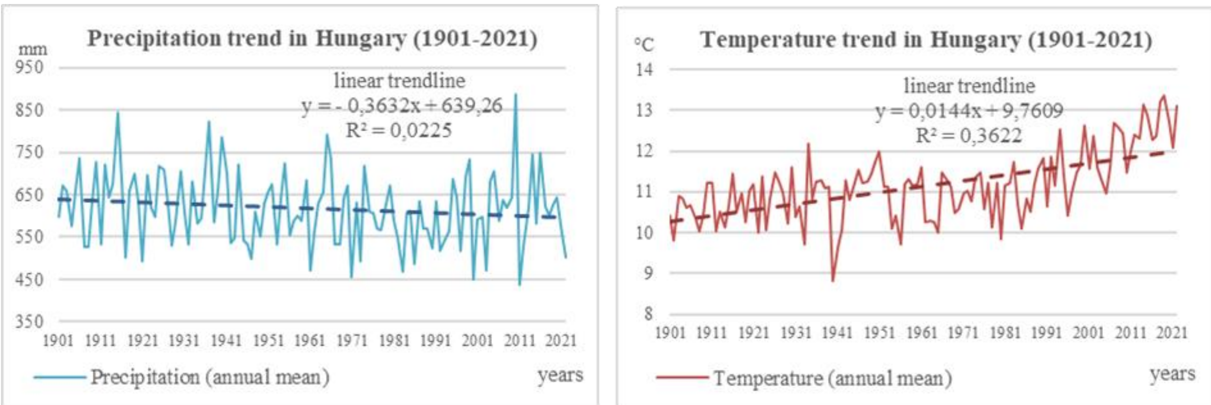

Figure 3: Precipitation (3a) and temperature (3b) change trends between 1901 and 2021 in Hungary. Own edited figure based on dataset of World Bank Group, CCKP (2024), license: (CC BY 4.0)

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 gerecsei 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, Rasztovits 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 előrevetítése. 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