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The Budapest Tree-Ring Laboratory – Status report after 20 years of activity

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RESEARCH ARTICLE

ABSTRACT

The Budapest Tree-Ring Laboratory (BTRL) is a fully equipped dendrochronological laboratory, established in 2002 at the Department of Paleontology and currently hosted by the Department of Physical Geography, Eötvös University, Budapest, Hungary. The lab has the proper sampling equipment for field work, a sanding workshop to prepare tree-ring samples for measurement and measuring-stages with software for recording and analyzing tree-ring data. Throughout the first 20 years of activity the BTRL collected and analyzed ~360 living and ~470 relict samples (including historical and subfossil material) from more than 33 sites distributed mainly in Europe but including a few localities in Asia. The most represented genera are *Quercus* and *Pinus*, both among the living and the relic subsets. Open access publication of the essential ancillary scientific information of the stored material will make the sample archive of the BTRL an actual national research infrastructure.

KEYWORDS

tree rings, dendrochronology, dendrogeomorphology, dendroclimatology, Hungary

INTRODUCTION

Dendrochronology is a robust science and a powerful tool with the potential to answer questions across social and natural sciences through its substantial body of data and metadata (Pearl et al., 2020). The nature of dendrochronology, especially for chronology-building, often calls for the collection of a large quantity of specimens and their long-term curation (Stokes and Smiley, 1968; Baillie, 1982; Creasman, 2011). Most samples appear to be used only for the application for which they were initially collected, and subsequent loss is inevitable for a variety of reasons (National Research Council, 2002; Creasman, 2011). Indeed, following their initial use some tree-ring collections have been partially or destroyed due to a shortage of storage capacity, limited personnel resources, inadequate preservation technology, or lack of vision regarding potential future uses (e.g. Baillie, 2002; Dean, 2006).

Collecting and preparing a usable tree-ring specimen frequently requires considerable investment of time and funds; nevertheless, the physical specimens often remain largely inaccessible for other projects leaving untapped opportunities for further research (Creasman, 2011). Documentation of the technical metadata are crucial for re-analyses of existing tree-ring collections, considering either the physical samples or the obtained (ring width) data with new tools, techniques, or, considering subsequent discoveries, whatever can promote new scientific advances (National Research Council, 2002). There are special challenges in the curation of both physical samples and digital dendro data (Creasman et al., 2011; Frank et al., 2013; Guiterman et al., 2024). Properly curated and documented tree-ring

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archives are praised from time to time (e.g., Büntgen et al., 2022). Such dendrochronological archives can support the re-examination of previously studied materials (e.g., Suarez, 2014) or open opportunities for new approaches for tree-ring studies, owing to the appearance of improved analytical techniques and/or novel research questions (Eckstein and Schweingruber, 2009; Santiago-Blay et al., 2011; Pearl et al., 2020). For these reasons existing tree-ring collections will be increasingly valuable in coming decades and centuries for study by archeologists, biologists, chemists, and a variety of earth scientists (Creasman, 2011).

The Budapest Tree-Ring Laboratory (BTRL) was established in 2002 at the Paleontological Department of the Eötvös Loránd University and developed a close collaboration with the Hungarian Dendrochronological Laboratory specialized in dendroarchaeological research (Grynaeus, 2009). An instantaneous report of the BTRL has been released in the first issue of the newsletter of the Association of Tree-Ring Research presenting the very first results following the first year of activity (Kázmér and Grynaeus, 2003). However, this newsletter report could not go into many essential technical details about the operation of the lab, nor could it provide guidance on the collection of the archived samples. The scientific publications of the following years were limited to the technical description most necessary for the given research result, and hitherto a comprehensive description of the protocol of sample preparation and processing used in the laboratory and, maybe most critically, sample storage, has not been published yet.

BTRL moved to the Department of Physical Geography of the Eötvös Loránd University in 2019. It was necessary to create an inventory of the samples collected during the operation of the lab. Initialized by this inventory, this paper provides a brief summary of the activity of the BTRL and basic metadata about the collected archive material, especially for those samples which have not been published due, for instance, to insufficient replication, so future findings should help to reach the critical mass resulting in novel scientific achievements. Open access publication of the essential ancillary scientific information (sensu National Science and Technology Council, 2009) of the stored material is a great step to make the sample archive of the BTRL an actual scientific collection and a valued national research infrastructure.

LAB FACILITIES AND THE PROTOCOLS APPLIED

Field sampling and field protocol

BTRL was established with a complete set of sampling devices prepared for all manner of sampling challenges related to tree-ring fieldwork. Living trees are commonly sampled using Pressler manual increment borers (Pressler, 1866) with different helical screw heads designed for different wood types, such as two-thread corers for hardwood, and three-thread corers for softwood (Grissino-Mayer, 2003). Normally, two cores from the opposite sides of the bole are collected at breast height with an increment borer.

For sampling from building timbers and dry archaeological timbers, a borer driven by a machine drill is used (Grynaeus, 2015). Traditional manual saws and two machine-operated chainsaws (Stihl MS260 and Stihl MS 661) were purchased to sample fallen logs and relict material (Fig. 1). When subfossil wood is recovered from fluvial deposits, a chainsaw is usually operated using a Duromatic guide bar and a special Vidia-hardened chain, because a normal chain can wear out rapidly due to the frequent contact with sand and gravel. Chainsaw application is carried out considering the occupational safety and health regulations in force, as well as the principles of environmental awareness (Major and Kozák, 2022).

BTRL applies a sample coding system. A unique sample code consisting of three letters and three numbers are already assigned at sampling, for each sample selected for transportation to the lab. The three letters refer to the site, usually the first three letters of the site name. The three numbers refer to the sampled specimen at the given site. If a certain site is visited multiple times, the new samples are coded using the same letters and continued numbering. Field observations (e.g., taphonomical, stratigraphic information) are linked to samples using the same sample codes in the field notes.

The date and place of sampling were always recorded in the field notes, but the designation of the geographic location was not uniform, occasionally using local co-ordinate systems or narrative description of the site. Therefore, for all sampling locations, the geographic coordinates were now converted to decimal degrees and will be reported uniformly

Fig. 1. Sample collection using an increment borer from a living Turkey oak (A) and using a chainsaw from a gigantic subfossil oak trunk (B)

in a simple [dLat, dLong] scheme as a comma-separated decimal pair (Whalley, 2023) in the location descriptions.

Lab facilities and the sample preparation protocol

A workshop to process the collected increment cores and disk samples was established (Fig. 2A). The workshop is equipped with the required machinery to prepare wood samples for dendrochronological analysis. The sample preparation protocol is designed taking into consideration available sample preparation guidelines and well-established practices (Stokes and Smiley, 1968; Popa, 2004).

Increment cores are fixed into grooved softwood holders using water soluble glue. The groove is cut lengthwise along the center of each holder and its width is about the same as the diameter of the core; the depth is about one-half of the core to protrude above the block (Krusic et al., 1987).

An electric saw (Bosch GFZ 14-35A) is used to flatten protruding parts and step-like irregularities at the surface of the rough-cut cross-section samples in the workshop, and for the trimming of unnecessarily thick wood disks. Tangential cut is also frequently applied for cutting away unnecessary wood, or for minimizing the amount of wood in a sample (Minor and Arizpe, 2015). Trimming and adjusting sample sizes, and removing excess wood, can be critical during post-research sample archiving, when space considerations and their associated square-footage costs become important (Creasman, 2011; Minor and Arizpe, 2015). Decayed disk samples are occasionally impregnated with wood glue to be preserved and prepared for tree-ring measurement (Krusic and Hornbeck, 1989).

Increment cores and cross-sectional samples are prepared for measurement by mechanically sanding or planing a radial surface (Krusic et al., 1987). Both increment cores and cross-sectional samples are sanded or surfaced until the tree-ring boundaries and important ring features that aid in visual cross-dating are clearly distinguishable (Orvis and Grissino-Mayer, 2002). To hold cross-sectional samples in place during sanding, samples are placed on a workbench and a home-made pegboard table fixed using wooden dowels to prevent the cross-section from moving underneath the machinery. Sanding usually begins with P60 (~269 μm) or P80 (~201 μm) sandpapers depending on the roughness of the sawn surface; progressively finer sizes (Orvis and Grissino-Mayer, 2002), such as P120 (~125 μm), P180 (~82 μm) or P220 (~68 μm), are applied, ultimately

Fig. 2. Workshop for wood sample preparation and tree ring measurement stations of the Budapest Tree-Ring Laboratory. A: The workbench with the pegboard table, the sanding papers, and the sanding machine on the right side, while processed and wrapped unprocessed samples are stored on the left side of the workshop. B: The linear measuring table (LINTAB™5) with the binocular microscope as installed at the Department of Paleontology (Eötvös University) and used between 2003 and 2019. C: The tree-ring analysis instruments installed at the Department of Physical Geography (Eötvös University) and used since 2020

finishing with P400 (33.5–36.5 μm). In the case of extremely dense ring structure additional sanding is performed by hand, using sandpapers with P800 (20.8–22.8 μm) or P1200 (14.3–16.3 μm). Dust control is an essential consideration for dendrochronological sample preparation areas, similarly to carpentry workshops, as dust production can increase fire and explosion hazards, and can impair worker health (Minor and Arizpe, 2015). Wood dust is collected using an industrial dust extractor with “L” dust-class certification (Bosch, GAS 25 L SFC, filtering area: 4,300 cm^2, Max air flow: 61 L s^{-1}) allowing vast amounts of dust and waste to be extracted quickly and efficiently.

Measurement devices and software

A binocular stereo microscope and a LINTAB digital-positioning table (Fig. 2B and C) are available to analyze the tree rings on the polished cross sections. The width of the annual increment is measured by TSAP Win 4.68 software (Rinn, 2005). The precision is usually set to 0.01 mm considering the uncertainty of the positioning of the crosshair of the binocular and the subjectivity of the operator. TSAP Win 4.68 software provides an option to measure the seasonal components of the annual increment, i.e., latewood and earlywood, separately and compute their cumulated value to get the traditional total ring width together with the latewood width and earlywood width in a single file. In addition, it enables users to carry out graphical and statistical comparison of the ring-width series against each other.

ACHIEVEMENTS OF THE BUDAPEST TREE-RING LABORATORY AFTER 20 YEARS OF ACTIVITY

An annual course was held for students of the Eötvös Loránd University and attended mostly by geology, geography, biology, and environmental science students. Xylotomy and physiology of conifer and deciduous trees and their reaction to environmental variables were studied, both in theory and in practice. Archaeological, (paleo)climatological, and geomorphological applications were discussed. Up to 16 students attended the course in any one year, and 1 to 2 of them started a Bachelor, Master, or PhD topic in the field of dendrochronology. Successfully defended theses (two BSc, six MSc, and two at PhD level) are listed in Table 1.

Some scientific results based on the collected tree-ring data are presented in ~20 research papers published between 2002 and 2022 (see the references in the next section). Researchers of the lab also utilized the expertise gained in tree-ring analysis in sclerochronological studies (Kern et al., 2012; Németh and Kern, 2018).

Table 1. Theses and dissertations prepared in the Budapest Tree-Ring Laboratory between 2002 and 2022 listed in chronological order. Language was Hungarian (English translation of titles provided in italic)

Author	Defense	Title
Dávid, Szilvia	MSc, 2004	Dendrokronológiai vizsgálatok a Tési-fennsíkon és a Keleti-Gerecsében *Dendrochronological studies on the Tés plateau and in the eastern Gerecse*
Kóródy, Gergely	MSc, 2006	A lineáris erózió vizsgálata a Mórágy-Geresdi-dombságban *Linear erosion in Mórágy-Geresd Hills*
Hatvani, Tibor	MSc, 2008	A gyapjaslepke (*Lymantria dispar*) levélrágásának nyoma tölgy évgyűrűiben *Gradation of gypsy moth (*Lymantria dispar*) recorded in fine structure of oak*
Kern, Zoltán	PhD, 2010	Éghajlati és környezeti változások rekonstrukciója faévgyűrűk és barlangi jég vizsgálata alapján *Climate and environmental reconstructions inferred from tree rings and cave ice*
Patkó, Mónika	MSc, 2011	Tölgy alapkronológia a Nyírségből *Oak tree-ring chronology from Nyírség, eastern Hungary*
Árvai, Mátyás	MSc, 2013	Egy máramarosi tőzegláp famaradványainak környezettörténeti szempontú faévgyűrű vizsgálata *A study of peat bog woody remains from an environmental historical perspective*
Garamszegi, Balázs	BA, 2013	Erdő és klímaváltozás – éghajlati és bükk évgyűrű-növekedési vizsgálatok egy bükki mintaterületen *Forest and climate change – studies on climate and tree-ring growth in beech (Bükk Mts, Hungary)*
Garamszegi, Balázs	MSc, 2015	Magyarországi bükkösök dendroklimatológiai vizsgálata *Dendroclimatology of beech forests in Hungary*
Mihály, Enikő	BA, 2018	Balaton-felvidéki és déli-bakonyi kocsánytalan tölgyek korai és kései pászta változásai az éghajlati paraméterek tükrében *Early and late wood variation by climatic parameters in sessile oak tree rings at Balaton Highlands and Southern Bakony*
Árvai, Mátyás	PhD, 2019	Holtfaanyag évgyűrűvizsgálatával nyert információk környezettörténeti szempontú értelmezése egy hegyvidéki és egy alluviális lelőhely példáján *Landscape evolution through complex evaluation of tree-ring evidence of deadwood assemblages -examples from mountain and lowland sites from East Central Europe*

Collections of the Budapest Tree-Ring Laboratory

Researchers of the BTRL collected samples from living, historical, and sub-fossil samples at 34 sites during the bidecadal activity of the laboratory (Tables 2 and 3). BTRL members were eager to ensure the long-term care, cataloguing, and proper storage of the specimens they collect, including data and metadata.

In the following brief descriptions of the collected material and essential metadata or ancillary scientific information (sensu National Science and Technology Council, 2009), including the geolocation and collection date of the samples for further usage of the material, are presented. Where relevant, sampling design is described concisely since it has been altered to improve the usage of tree-ring datasets for ecological syntheses (Sullivan and Csank, 2016). The brief descriptions are arranged in alphabetical order of the site codes for Hungarian sites (Table 2) and localities outside of Hungary (Table 3).

Data form Hungarian sites can be especially interesting since Hungary is a blank area in the coverage map of the International Tree-Ring Data Bank (ITRDB) providing a global compilation of thousands of tree-ring sites and datasets worldwide (Grissino-Mayer and Fritts, 1997; Guiterman et al., 2024). The data and sample archive of BTRL in this respect fills a gap in the global dendrochronological network.

Metadata of the dendrochronological samples collected across Hungary and stored in the archive of the Budapest Tree-Ring Laboratory

BTRL collected samples from 23 sites across Hungary during the first 20 years of activity (Table 2). The spatial distribution of the collection sites is skewed toward the western part of the country (Fig. 3A).

BAB: Cross-sectional disk samples were sawn from sub-fossil trunks exposed in the eroding left bank of Drava River near Babócsa [45.9875°, 17.3005°] at 19.07.2017 ($n = 14$) and 26.10. 2018 ($n = 13$). Based on the xylotomical characteristics, pedunculate oak (*Quercus robur)*, Scots elm (*Ulmus scabra)*, European beech (*Fagus sylvatica)*, European white elm (*U. laevis*), European larch (*Larix decidua),* and poplar (*Populus* sp.) were identified among the samples (Árvai et al., 2018a). The ring width series of four oak samples were successfully cross-dated, creating a 249-yr-long floating chronology, which could not yet be synchronized with surrounding reference chronologies.

BLH: Cross-sectional disk samples were sawn from the trunks of 11 dominant pedunculate oak (*Q. robur)* trees in August 2009 in the Bakta Forest [47.992°, 22.048°] near Baktalórántháza. The cross-dated ring-width series covers the 1731–2009 CE period (Kern et al., 2013).

Table 2. Site code and sampled taxa in the archive of the Budapest Tree-Ring Laboratory collected across Hungary until 2022. The type and species of the available material is indicated in the last three columns.[a]: reference(s) provided in the brief description for sites except if code typed in italics which indicates that the data are still unpublished

Code[a]	Living trees	Dead trees	Timber
BAB	X	*Quercus* sp., *Fagus sylvatica, Ulmus* sp., *Populus sp., Larix decidua*	X
BLH	*Quercus robur*	X	X
DEB	*Q. robur*	X	*Quercus* sp.
DEV	*Q. robur, Quercus cerris*	X	*X*
GAR	X	*Quercus* sp., *Ulmus* sp. *Pinus sp.*	X
GES	X	*Quercus* sp., *Ulmus* sp. *Prunus avium*	X
GYL	X	X	*Picea abies*
HER	X	*Quercus* sp., *Ulmus* sp.	X
KOH	X	X	*Quercus* sp.
KOK	X	X	*Quercus* sp.
KOV	*Quercus petraea, Q. cerris, Pinus sylvestris*	*Q. petraea, P. sylvestris*	X
MOB	*Quercus* sp.	X	X
ORV	X	X	*Quercus* sp.
PUL	*Q. robur*	X	X
SZK	X	X	*Quercus* sp.
TES	*Q. petraea, Quercus pubescens*	*Q. petraea, Ulmus* sp.	X
UVH	*Q. petraea, F. sylvatica*	*Q. petraea, F. sylvatica*	X
VAP	*Q. petraea, Q. cerris*	X	X
VIG	X	X	*Q. petraea, F. sylvatica*
VOR	*Q. petraea, Q. pubescens*	X	*Quercus* sp., *Ulmus* sp. *P. abies*
VRG	X	X	*Quercus* sp.
ZEN	X	*Q. petraea,*	X
ZSU	X	*Quercus* sp., *Ulmus* sp.	X

Table 3. Site code and sampled taxa in the archive of the Budapest Tree-Ring Laboratory collected at sites outside of Hungary until 2022. Two-letter country codes defined in ISO 3166-1. The type and species of the available material is indicated in the last three columns. [a]: reference(s) provided in the brief description for sites except if code typed in italics which indicates that the data are still unpublished

Code[a]	Country	Living trees	Dead trees	Timber
BOR	RO	*Picea abies, Abies alba*	*P. abies, A. alba, Fagus sylvatica*	X
CAL, KEL	RO	*Pinus cembra, Juniperus sibirica*	*P. cembra, P. abies*	X
CHI	JP	*Juniperus taxifolia, Pinus luchuens, Allocasuarina verticillata*	*J. taxifolia, P. luchuens*	X
COR	FR	*Pinus nigra, A. alba*	*P. nigra*	X
ESK	RO	*P. abies, A. alba, F. sylvatica*	*P. abies, A. alba, F. sylvatica*	X
LAL	RO	X	*P. cembra*	X
MAR	RO	X	*P. abies, F. sylvatica*	X
MUR	RO	X	*Quercus* sp., *Ulmus* sp., *F. sylvatica, Populus* sp., *A. alba*	*Quercus* sp., *Ulmus* sp.
RAD	RO	*P. abies, Pinus mugo, J. sibirica*	X	X
SMM	CN	*Pinus tabulaeformis, Quercus wutaishanica*	X	X
VUK	HR	*P. abies*	*F. sylvatica*	X
ZAN	RO	*P. cembra*	*P. cembra*	X
ZNG	IN	X	X	*Juniperus tibetica, Populus sp.*

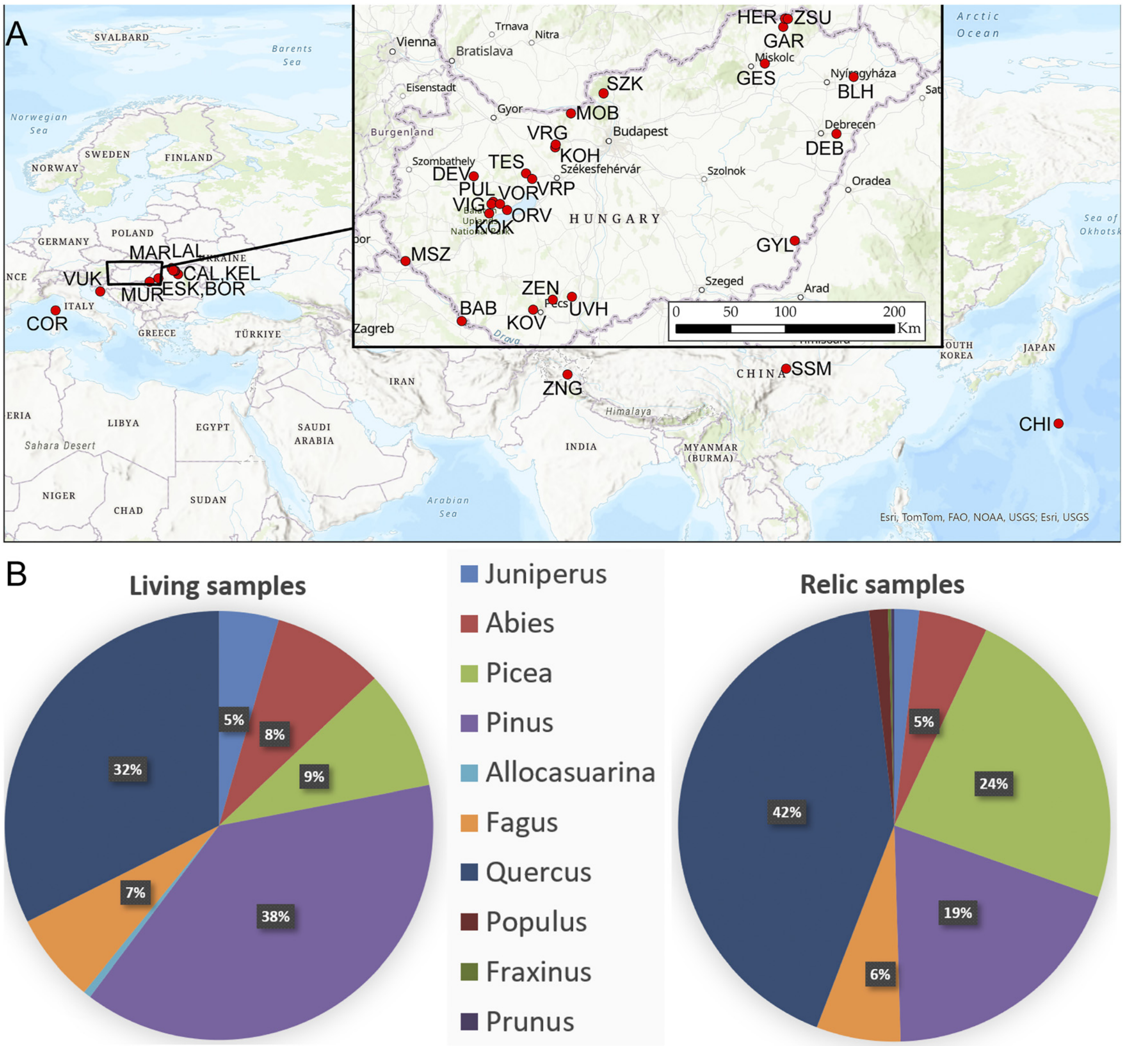

Fig. 3. Geographical and botanical distribution of the sample archive collected during the first 20 years of activity of the Budapest Tree-Ring Laboratory. A: Spatial distribution of the sample sites. Zoomed inset shows the sample sites in Hungary. B: Pie charts show the distribution of the genera of the samples among the living (left) and relic (right) subset of the sample archive. Relic samples aggregates historic timber and subfossil wood

DEB: Cross-sectional disk samples sawn from the trunks of 10 dominant pedunculate oak (*Q. robur)* trees in August 2009 southeast of Debrecen [47.525°, 21.811°]. The cross-dated ring-width series cover the 1904–2009 CE period (Árvai et al., 2018b). Ten oak beams were sampled in the historical roof truss of the so-called “Novella csapszék” (Kígyó street 55., Debrecen) on 11 February 2020. Their cross-dated ring-width series provided a 37-yr-long floating chronology. Three samples were collected from the oak timber of a door in the cellar. Their cross-dated ring-width series provided a 49-yr-long floating chronology.

DEV: Two cores taken from 10 trunks each of Turkey oak (*Quercus cerris*) in 2006 from Káptalanfa Forest, defoliated by *Lymantria dispar* in 1994 and in 2004. Another set of cores ($n = 10$) taken from pedunculate oak from Doba forest. A ten-year cyclicity of *Lymantria* infestation was demonstrated back to the 1940s (Hatvani, 2008).

GAR: Cross-sectional disk samples ($n = 15$) were sawn from piled subfossil trunks at a gravel pit on the right bank of Hernád/Hornád river near Garadna [48.427°, 21.201°] 0n 05 July 2007 and additional seven subfossil trunks were sampled on 01 September 2017. Based on the xylotomical characteristics the wood is identified as oak (*Quercus* sp.), elm *(Ulmus* sp.), and pine (*Pinus* sp.).

GES: Cross-sectional disk samples were sawn from four subfossil logs exposed in the eroding right bank of Hernád/Hornád river between Gesztely and Ócsanálos [48.125°, 20.961°] on 02 September 2017. Based on the xylotomical characteristics the wood is identified as *Quercus sp.*, *Ulmus sp*, and a smaller sample was identified as wild cherry (*Prunus avium* L.).

GYL: Disks ($n = 17$) were sawn from the removed timber of the historical roof truss of the so-called “Máriás ház” (Gyula). The samples were collected by Mihály Braun and donated to the BTRL on 11 February 2020. Based on the xylotomical characteristics the wood is identified as Norway spruce (*Picea abies*).

HER: Cross-sectional disk samples were sawn from piled subfossil trunks on 05 July 2007 in a gravel pit near Hidasnémeti [48.494°, 21.225°] along the Hernád/Hornád river. Based on the xylotomical characteristics *Quercus sp.* ($n = 3$) and an *Ulmus sp.* were identified among the samples. There was no successful synchronization among the relatively short ring-width series.

KOH: Disks ($n = 5$) were sawn from the oak timber of historical stairs removed during the renovation works of an old building in Kőhányáspuszta [47.443°, 18.390°] in the winter of 2005. Their cross-dated ring-width series provided a 102-yr-long floating chronology.

KOK: A disk sample was sawn from a beam removed during the renovation works of an old wine cellar in Köveskál [46.885°, 17.604°]. The sample was collected by Zoltán Siklósy and donated to the BTRL in 2008. The timber is oak, and 157 rings were counted in the disk.

KOV: This site code was assigned to several closely located sites around Kővágószőllős. Increment cores were first collected from living Scots pine (*Pinus sylvestris*) ($n = 3$) and sessile oak (*Quercus petraea*) ($n = 4$) individuals on 26 May 2008 at Jakab Hill [46.098°, 18.135°]. At the end of the same year, on 9 December 2008, additional increment cores were collected from living Scots pine ($n = 4$) individuals and a sessile oak located a few km westward [46.099°, 18.199°]. In addition, cross-sectional samples were cut from sessile oak ($n = 2$) and Scots pine ($n = 2$) trunks. The cross-dated ring-width series of the pine samples cover the 1897–2008 CE period (Siklósy et al., 2011).

Disk samples were collected from fallen individuals of sessile oaks ($n = 10$) and a Turkey oak from an unmanaged compartment [46.091°, 18.144°] on 02 December 2015. The cross-dated ring-width series of the living and relic oak samples cover the 1768–2014 CE period but are still unpublished.

MOB: Increment cores were collected from sessile oaks (*Q. petraea*) at two nearby sites [47.727°, 18.579°] ($n = 10$) and [47.725°, 18.573°] ($n = 8$) between the villages of Mogyorósbánya and Bajót on several occasions from the autumn of 2002 to the spring of 2003 (Dávid and Kern, 2007). The cross-dated ring-width series cover the 1872–2002 CE period.

MSZ: Cross-sectional disk samples were sawn from piled subfossil trunks in a gravel pit near Muraszemenye [46.471°, 16.615°]. The first field work was carried out on 09 May 2004, and the site was revisited later on 19 March 2015 and 19 July 2017. Based on the xylotomical characteristics *Quercus sp.* ($n = 22$) and *Ulmus sp.* ($n = 8$) were identified in the collected assemblage. The dataset is still unpublished.

ORV: Four drill cores were collected from the wooden structure of a historic water mill at Örvényes and two cores were extracted from the roof truss of the barn near the water mill on 25 May 2005. The samples are determined as oak based on the observed anatomical features. Cross-dated ring-width series of the samples of the water mill provided a 157-yr-long floating chronology while the series collected from roof truss of the barn provided a 59-yr-long floating chronology.

PUL: A disk sample was collected in 2004 from a gigantic solitary pedunculate oak (*Q. robur)* felled in the Tálod Forest near Pula few years before the sampling date.

SZK: Four disk samples were collected from the replaced pedestals of a wooden belfry at Szokolya Királyrét [47.894°, 18.977°] in 2012 by Mr. Zsolt Barton and donated to the BTRL. The timber was determined as oak. Their cross-dated ring-width series provided a 98-yr-long floating chronology and synchronized to 1803–1901 CE (Kern et al., 2014) compared with the Central Hungarian Oak Reference chronology (Grynaeus, 2015).

TES: Increment cores were collected from living trees ($n = 23$) and disk samples from dead wood ($n = 10$) near the village of Tés [47.224°, 18.040°] on several occasions from the autumn of 2002 and the spring of 2003. The living and relic trees belonged predominantly to sessile oak (*Q. petraea*) with two exceptions both in the living (*Quercus pubescens*) and the relic (*Ulmus* sp.) subsets (Dávid and Kern, 2007). The ring-width series of a set of sessile oaks ($n = 20$) and the pubescent oaks ($n = 2$) were strongly cross-dated and covered the 1740–2003 CE period.

UVH: Increment cores were collected from dominant sessile oaks (n = 5) and European beech (n = 10), in addition to some fallen oak (n = 2) and beech (n = 2) trunks near to Bátaapáti-Üveghuta during several field campaigns in April and May of 2003. The cross-dated ring-width series provided datasets covering the 1899–2002 and 1913–2002 CE periods for oak and beech, respectively. The ring-width data of the beech samples were used in a regional assessment of climate-growth sensitivity of the species (Garamszegi et al., 2020), while the ring-width data of the oaks remained unpublished. Exposed roots were used to date gully erosion (Kóródy et al., 2009).

VAP: Increment cores from Turkey oak (n = 5) and sessile oak (n = 2) were collected near Várpalota [47.179°, 18.114°] between December 2009 and February 2011 by Dénes Saláta while studying the succession of abandoned pastures (Saláta et al., 2015; Saláta, 2017) and donated to the BTRL. The cross-dated ring-width series cover the 1871–2010 CE period.

VIG: Nine drill cores were collected from the roof truss of the Catholic church of Vigántpetend and ten samples were collected from the timber material of the partly collapsed barn of the clergy house on 02 October 2004. Most of the samples are determined as oak (n = 16) but three belong to European beech based on the observed anatomical features. The cross-dated ring-width series of the oak samples provided a 197-yr-long mean ring-width chronology and synchronized to 1731–1927 CE compared with nearby local oak chronologies (Kern et al., 2009), while the ring-width series of the beech samples provided a 104-yr-long floating chronology.

VOR: Increment cores were collected from sessile oaks (n = 7) at an abandoned pasture [46.965°, 17.732°] south of the village of Vöröstó and from sessile oaks (n = 3) and pubescent oaks (n = 2) at Fekete Hill [46.929°, 17.587°] on 21 November 2003. Beside these living trees, disk samples (n = 15) were sawn from the timber of a historical roof truss and a partly collapsed barn (n = 9) in Vöröstó on 07 April 2004. The timber was determined as oak (n = 17), Norway spruce (n = 6), and elm (n = 1) based on the observed anatomical features. The cross-dated ring-width series of the living and historic oak samples cover the 1766–2003 CE period (Kern, 2007). The other samples have not been analyzed yet.

VRG: Two highly degraded pieces of wood were found in a wall-section of the castle of Várgesztes [47.468°, 18.396°] in the winter of 2007. The timber of both pieces is oak with 43 and 47 measurable annual rings, respectively.

ZEN: Cross-sectional disk samples were sawn from fallen sessile oak (n = 2) and common ash (*Fraxinus excelsior*) trunks near Zengő (Mecsek) [46.177°, 18.376°] on 02 December 2015.

ZSU: Cross-sectional disk samples were sawn from three subfossil logs from piled subfossil oak trunks at a gravel pit near to Zsujta [48.492°, 21.262°] on 01 September 2017. The samples have not been analyzed yet.

Metadata of the dendrochronological samples collected outside of Hungary and stored in the archive of the Budapest Tree-Ring Laboratory

BTRL collected samples from 13 sites outside of Hungary during the first 20 years of activity (Table 3). These collection sites are distributed mainly in Europe, but three localities are in Asia (Fig. 3A).

BOR: Increment cores were collected from living silver fir (*Abies alba*) (n = 6), European beech (*F. sylvatica*) (n = 6), and Norway spruce (*P. abies*) (n = 5) individuals growing near Bortig Ice Cave [46.561°, 22.694°] in the Apuseni Mts (Romania) during two sampling campaigns carried out on 18 September and 14 October 2005. Cross-sectional disk samples were collected from relic logs lying on the forest floor around the ice cave entrance and in the cave as well. Ring-width chronologies were developed for each species combining living samples from nearby BOR and ESK sites reaching back to 1785 CE for fir, 1795 CE for beech and 1815 CE for spruce (Kern and Popa, 2007). The relic samples have not been analyzed yet.

CAL and **KEL**: Increment cores were collected from 11 living Swiss stone pine (*Pinus cembra*) individuals and cross-sectional disk samples were collected from 53 dead logs lying on the ground in the Rachiţis Cirque, Călimani Mts (Romania) during several campaigns between 07 December 2003 and 25 June 2006. Based on the xylotomical characteristics all but one of the relic samples were identified as stone pine. Ring-width series both of living and relic samples were synchronized and contributed to a larger dataset defining the regional stone pine mean ring-width chronology covering the 996–2005 CE period (Popa and Kern, 2009). In addition, cross-sectional disk samples were collected on 04 August 2009 at the nearby Pietricele Peak from two juniper (*Juniperus sibirica*) individuals that colonized an inactive debris tongue.

CHI: Disks and increment cores were sampled from living individuals (n = 30) and snags (n = 8) of an endemic conifer species of shimamuro (*Juniperus taxifolia* Hook. et Arn), the historically introduced Okinawa pine (*Pinus luchuens* Mayr.), and a recent invasive species (*Allocasuarina verticillata*) on Chichi-jima Island, Ogasawara (Bonin) Islands, Japan, ca. 1,000 km to the south of Tokyo in the Pacific Ocean. Sampling sites were scattered between [27.122°, 142.207°] and [27.077°, 142.227°]. Sampling campaigns were conducted, in 2006 and in 2010. A short report on the growth rings of juniper and pine samples has been published. Low-growing Juniperus trees are up to ca. 250 years old, but irregular ring growth challenged cross-dating (Sho and Kázmér, 2011).

COR: Overwhelmingly increment cores were collected from Corsican black pine (*Pinus nigra* laricio) at 6 sites across Corsica (France) between 18 and 30 June 2003. The cross-dated ring-width series cover the 1707–2002 period at Monte D'Oro near Vizzavona, the 1581–2002 period from Col de Verde at Monte Renoso and 1234–2002 period in the Asco Valley. Increment cores were extracted from two silver fir (*Abies alba*) individuals as well. Furthermore, cross-sectional samples were collected from three relic pine trunks in the Golo Valley.

ESK: Increment cores were collected from living Norway spruce (*P. abies*) (n = 13), silver fir (*A. alba*) (n = 22), and European beech (*F. sylvatica*) (n = 8) individuals representing all phyto-sociological classes (dominant, codominant, suppressed) growing near Focul Viu Ice Cave [46.575°, 22.680°] in the Apuseni Mts (Romania). Cross-sectional samples were collected from the relics lying on the surface of the ice block or accessible sections of partly ice-covered logs. The assemblage of the relic samples is dominated by fir ($n = 16$), followed by spruce ($n = 11$) and beech ($n = 8$) based on the xylotomical characteristics. Sample collection campaigns were carried out between 13 July 2002 and 09 December 2003. Ring-width chronologies were developed for each species combining samples from nearby ESK and BOR sites (see above). Ring-width series of seven relic fir samples were successfully cross-dated to the living dataset defining a 402-yr-long site chronology covering the 1583–2003 CE period (Kern et al., 2004).

LAL: Cross-sectional disk samples were sawn from nine relic stone pine logs lying on the ground between 1,550 and 1,650 m asl on the eastern slope of the Lala Valley, Rodna Mts (Romania) on 09 August 2007. The samples have not been analyzed yet but are expected to be included in the local reference database (Popa and Bouriaud, 2014).

MAR: Sixty subfossil samples were collected between 2010 and 2014 from a peat bog located on the Vinderel Plateau, Maramureş Mts (Romania). The assemblage is dominated by Norway spruce ($n = 58$); however, European beech ($n = 2$) was also identified based on the xylotomical characteristics. The spruce samples could be arranged into seven floating chronologies, coded from MM1 to MM7 covering different periods between the 3rd and 11th centuries according to the ^{14}C ages (Árvai et al., 2016; Árvai, 2019). Beside this subfossil material two wooden constructions were also found in the peat. They were constructed from spruce timber and their cross-dated ring-width series provided a 69-yr-long floating chronology.

MUR: Cross-sectional disk samples ($n = 58$) were sawn from subfossil driftwood recovered from gravel pits and three natural outcrops across the Mureş/Maros Alluvial Fan in 2015 and 2016. Based on the xylotomical characteristics *Quercus* sp., *Ulmus sp.*, *F. sylvatica*, *A. alba* and *Populus* sp. were identified among the samples. Dendrochronological synchronization resulted in two oak chronologies covering 191 years (MURchr1) and 127 years (MURchr2), respectively (Kern et al., 2022). Cross-sectional disk samples ($n = 7$) were sawn from piles and beams of a wooden construction emerged at the eroding bank of the river near Zădăreni/Zádorlak [46.147°, 21.219°]. All but one of the samples is oak (*Quercus* sp.); the exception is elm (*Ulmus* sp.).

RAD: Increment cores were collected from 10 living Norway spruce (*P. abies*) individuals growing on rocky slopes or cliff sites near Cascada Cailor [47.589°, 24.800°]. In the following days samples were collected from 7 living and 3 dried dwarf pine (*Pinus mugo*) individuals and a living and a dried juniper (*J. sibirica*) at ~2 km SW from the first sampling site in the Gargalau Cirque [47.570°, 24.814°]. The field work was carried out in August 2003 in the Rodna Mts (Romania). The samples have not been analyzed yet.

SMM: Root disk samples were taken from Chinese pine (*Pinus tabulaeformis*) ($n = 27$) and Liaoning oak (*Quercus wutaishanica* Mayr.) ($n = 3$) in May 2010 in the Xiaolong Mts [34.441°, 106.125°] near Tianshui in eastern Gansu province (China). Increment cores form six of the pine trees were also sampled and analyzed (Fang et al., 2012a, 2012b).

VUK: Increment cores were collected from four living Norway spruce (*P. abies*) individuals near the entrance of Vukušić Ice Cave (Vukušić snježnica, [44.792°, 14.996°]) on 27 October 2007 in the Velebit Mts (Croatia). Their cross-dated ring-width series cover the 1855–2007 CE period but is still unpublished. At the accessible northern sidewall of the Vukušić Ice Cave three relic wood were sampled using a hand saw. They were identified as European beech (*F. sylvatica)* based on their xylotomical characteristics.

ZAN: Increment cores were collected from four living Swiss stone pine individuals and cross-sectional disk samples were sawn from eight relict Stone pine logs lying on the ground in the Zănoaga Valley, (Rodna Mts) Romania in August of 2008. Mean ring-width chronology of the living samples covers 1820–2007 CE. The relic samples have not been analyzed yet.

ZNG: Disks were sawn from the timber of the historical roof trusses of Zangla (Ladakh, India) in July of 2012. The samples were collected by Balázs Irimiás (Csoma's Room Foundation) and donated to the BTRL. Based on the xylotomical characteristics two samples were identified as Tibetan juniper (*Juniperus tibetica*) and three samples as poplar (*Populus* sp.). There was no successful synchronization among the ring-width series.

DISCUSSION ON THE REPRESENTATIVITY OF THE COLLECTION

There is a clear bias towards conifers (61%) among the living samples collected in the BTRL during its 20 years of activity, in particularly pines (*Pinus* sp.) representing the 38% of the sampled living trees (Fig. 3B). In turn, only a slight asymmetry can be seen in the relic material (timber and subfossil samples) toward broadleaf trees (55%) (Fig. 3B). The changed situation could be due the overwhelming representation of oak among the timbers (65%) and the large contribution of oak remains to the subfossil driftwood samples (Árvai et al., 2018a; Kern et al., 2022). The predominance of oak in timber or generally in the dendroarchaeological material is widely observed in Hungary (Grynaeus, 2015, 2020). Similarly, the overweight of oak and elm in the subfossil driftwood with the occasional appearance of poplar and beech in the collection of BTRL agrees well with the reported species composition of subfossil driftwood assemblages from East and Central Europe (Kern and Popa, 2016; Kolář and Rybníček, 2011; Rădoane et al., 2015).

ITRDB have been graciously provided by hundreds of researchers in the spirit of open exchange of scientific data (Grissino-Mayer and Fritts, 1997). Even though this collection was found not to be representative of the global forested areas (Zhao et al., 2019; Pearl et al., 2020), the species composition of the BTRL archive can be compared to this global dataset. The species of pine (*Pinus* sp.), spruce (*Picea*), and oak (*Quercus* sp.) are the most represented among the samples of ITRDB since these have historically dominated tree ring studies from heavily researched areas in Europe, Asia, and the Americas (Zhao et al., 2019; Pearl et al., 2020). Interestingly, these are also the three most represented genera in the collection of the BTRL (Fig. 3B). This suggests that sample and site selection of BTRL was in accordance with the mainstream of the international dendrochronological research.

A recently published regional tree-ring archive collecting data from the European part of Russia (hereafter ER) over 15 years of activity (Solomina et al., 2022) also offers an opportunity for comparison. The sample archive of the BTRL counts roughly half as many sites and dendrochronological samples as the ER (sites: 74, samples: 1680). However, a higher degree of difference is observed considering the species composition, since the most abundant species in the ER archive is Scots pine and the only broadleaf species in the ER archive are pedunculate oak and oriental beech (*Fagus orientalis* Lipsky) (Solomina et al., 2022). This difference with the most represented species can be plausibly explained by the difference between the native forest-forming species of the main collection areas of the two collections, such as the south-eastern Europe and the European part of Russia.

CONCLUSIONS

Long-term preservation and continued access to wood specimens and associated data/metadata are crucial to bring a compilation of dendrochronological samples to an actual scientific collection and a valued national research infrastructure. The potential use of the dendrochronological sample archive of the Budapest Tree-Ring Laboratory in conjunction with the metadata archive documented in this first detailed status report includes dendrochronological dating of historical and archaeological wood, palaeoclimatological and ecological studies, and a wide range of geologic applications. Because the dating of tree rings will remain the first and essential step for any further analysis, BTRL will continue building reference chronologies and improvement of the existing ones and dedicated to curate the digital and physical sample archive.

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