

# INCREMENT CORES OF THE NATIONAL FOREST INVENTORY FROM ROMANIA

G. MARIN<sup>1,2</sup>, I.V. ABRUDAN<sup>2</sup>, B. STRIMBU<sup>3,\*</sup>

<sup>1</sup>*Faculty of Silviculture and Forest Engineering, Transilvania University, Brasov, Romania.*

<sup>2</sup>*National Institute for Research and Development in Forestry “Marin Drăcea”, Romania.*

<sup>3</sup>*For. Eng., Res. & Manage. Department, College of Forestry, Oregon State University, Corvallis, OR, USA.*

\* *Corresponding author.*

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**ABSTRACT.** Dendrochronological data provides insight in the tree development, and used in conjunction with forest inventory, can supply inputs for growth and yield modeling. However, accurate and precise measurements of a large number of incremental cores require significant resources. One possible source of valuable tree ring data are national forest inventories (NFI), which process a large amount of data annually. A NFI that places a significant effort on dendrochronological data is the Romanian NFI, which, to date, collected, measured, and cross-dated more than 50,000 incremental cores. This amount of incremental cores makes Romania the holder of the largest dendrochronological NFI library. The present article presents the method of processing the incremental cores and makes available to the interested entities the tree ring data for the three main species from Romania, namely Norway spruce, European beech, and Sessile oak. To ensure utility, the dataset is limited to pure (i.e., one species) strict even-aged stands (i.e., age difference  $\leq 5$  years), that were un-thinned (i.e., no active forest management). The data is stored as an ASCII file, and contains six fields: ecoregion, species, year, age, average ring width, and variance. To ensure privacy of information, the average ring width was estimated over a 5 years interval, for which the variance is also computed.

**Keywords:** crossdating, micrometer precision, *Picea abies*, *Fagus sylvatica*, *Quercus petraea*.

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## 1 INTRODUCTION

Tree rings have been used for forest modeling for more than a century, but significant advancements in computer science and sensors placed dendrochronology at the center of the current numerical analysis in forestry. The information used in dendrochronology usually comes from two sources, cross sectional disks, also known as “cookies”, and incremental cores, or simply cores. The vast majority of data is acquired through cores, as they are simple to extract, and most importantly, no dedicated approvals are needed (i.e., to extract cookies, permits for falling trees are usually required). However, incremental cores can pose two disadvantages in respect with cookies, both rooted in the absence of an inside view of the tree. First issue with cores acquisition consists in misaligning the bore with the pith of the tree because of the eccentricity of the stem. Absence of the pith on the core lead to the usage of assumptions, which diminishes the value of the core. Secondly, is the local aspect, as a core supplies only a minute perspective of the cross-section of the tree. The punctual [i.e., confined

to a narrow part of the stem cross-section (the diameter of the increment borer)] collection of information is partially alleviated through cross dating, but again, assumptions are used in interpretation and analysis (Douglas, 1941; Schweingruber et al., 1990; Wigley et al., 1987). The main assumption driving the usage of incremental cores in size estimation is that the stem of the tree has a circular cross section. This circularity assumption is not confined to dendrochronology, taper modeling is another research area that considers the stem being a solid of revolution (Brooks et al., 2007; Cushman et al., 2014; Garber and Maguire, 2003; Kozak, 2004; Lenhart et al., 1987).

Usually, incremental cores are obtained through dedicated studies, but national forest inventories (NFIs) can supply also a significant amount of cores. The cores acquired during the national forest inventory process are opportunistic, as it does not target a specific research question, but their value rests in the consistent procurement across large tracts of land. Most of the NFIs had the theoretical framework updated in the last

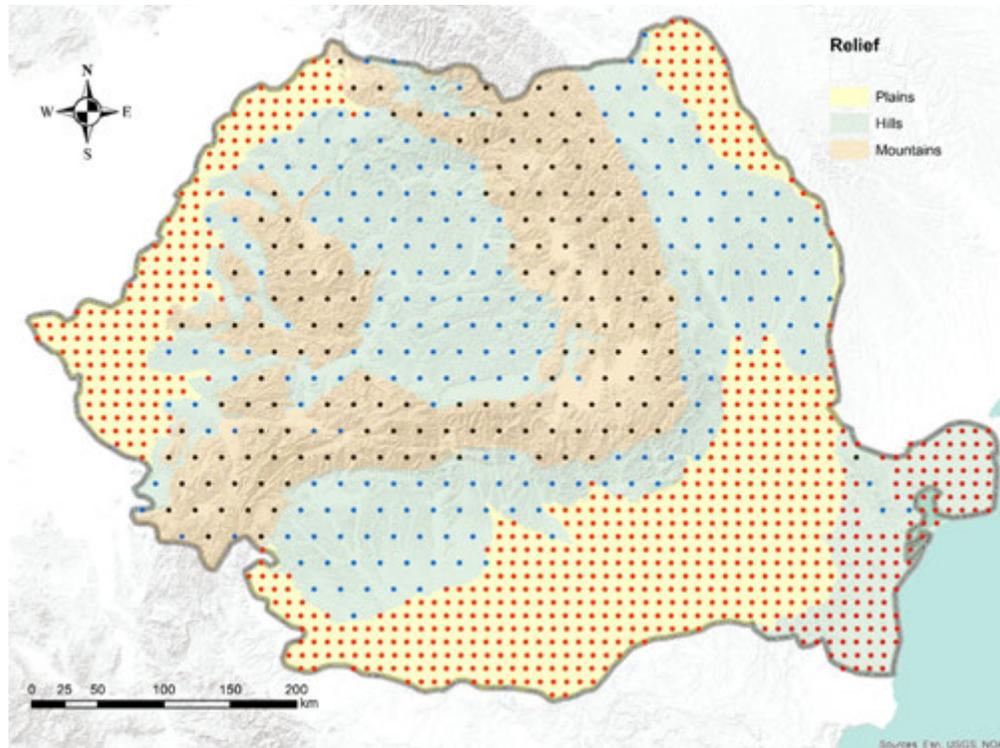


Figure 1: The PSC of the Romanian NFI overlaid on the Romanian geomorphology (i.e., plain, hill, mountain) and topography. The color of the PSC reflects the geomorphology: red for plains, blue for hills, and black for mountains. The spatial distribution of the PSCs does not reflect the actual density.

30 years (Bechtold and Patterson, 2005; Tomppo et al., 2010). The updates were focused either in changing the method of acquiring the data, such as the USA and France, or in establishing a new system, the case of eastern European countries. Regardless the age of NFI, only a few are continuously collecting incremental cores, one of them being the Romanian NFI. In the last decade, the Romanian NFI acquired more than 50,000 cores. The great amount of cores make Romania the holder of the largest incremental cores among all European NFIs (Schadauer, 2019). Therefore, the objective of the present data-in-brief paper is to present the dendrochronological efforts of the Romanian NFI, and to offer access to one of the European dendrochronological datasets.

## 2 METHODS

### 2.1 Romanian NFI

The Romanian NFI is a continuous forest inventory based on a systematic sampling design (Tomppo et al., 2010). The NFI measures permanent sample clusters (PSC) of four sample plots (SP). The inventory covers the entire country during a 5-year cycle. The PSC

were positioned in a quadratic scheme, according to the general landscape classification of mountains, hills, and plains. In the mountains and hills regions, the NFI grid has cells of 4 km x 4 km, whereas in the plains region the cells are 2 km x 2 km (Fig. 1).

The differential design of Romanian NFI captures the relevant information while considering the density of the forest within the general landscape (Fig. 2). In total, the Romanian NFI has 31,201 PSC and 124,804 SP.

### 2.2 Extraction of the incremental cores

Since 2008 more than 50,000 incremental cores were collected by the Romanian NFI. The cores were extracted with a Pressler increment borer having the internal diameter 5 mm and the length 40 cm. The cores were bore at breast height, namely 1.3 m from the ground, parallel with the contour line. The number of trees cored from each SP depends on the number of species: when only one species was present then 3-4 cores were extracted, otherwise 2-3 cores / species were collected. For each cored tree only one incremental core was extracted. When two cohorts for the same species were present, two increment cores/cohort were extracted. The trees from

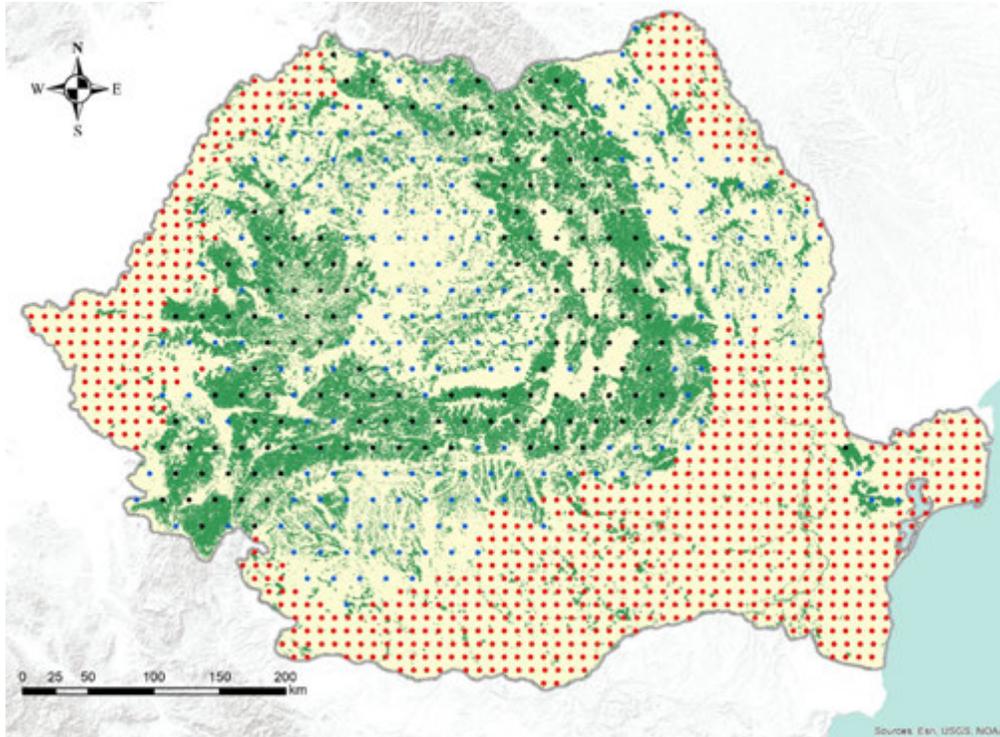


Figure 2: The PSC of the Romanian NFI overlaid on the general location of the forest, in green, and topography. The color of the PSC reflects the geomorphology: red for plains, blue for hills, and black for mountains. The spatial distribution of the PSCs does not reflect the actual density.

which cores were extracted were selected randomly, conditioned to the following constraints:

- The trees are located within a 25 m radius from the center of the SP
- The trees belong to the dominant and co-dominant canopy class (Nyland, 1996)
- The diameter at breast height (dbh) should be equal or larger than the average dbh of the SP and larger than 12 cm;
- The trees do not exhibit exterior damages, exposure to diseases, or significant ellipticity.

After extraction, the increment cores were stored in a rigid plastic case to avoid damage during transportation. On each plastic case were recorded the PSC, sample plot, species, and two dbh of each cored tree (measured with a 1 mm precision caliper), one measured on the direction of the core and one perpendicular to the core.

### 2.3 Processing of the incremental cores

The main information extracted from the incremental cores is the width of each ring and their succession. To

obtain this information, the incremental cores were processed using a four step procedure, similar to Lebourgeois and Merian (2012) and Kuniholm (2001). The steps supplying the width of each ring and their relative location within a core are mounting, sanding, measurement, and cross-dating.

#### 2.3.1 Mounting of the incremental cores

The first step in measuring the ring width consists in mounting the incremental cores on a solid support, on which physical enhancements are executed. The support of the incremental cores was a wooden board with the dimensions of 31 cm x 9 cm x 1.8 cm. On each side of a board, eight circular channels were carved (i.e., 16 channels/board), with the width of 5 mm and depth of 3 mm. Vinyl acetate wood glue was applied to each channel using a paint brush to ensure that the incremental cores are not moving once mounted. The increment cores were mounted on one board if less than 16 cores/ PSC were collected or on two boards otherwise. If the incremental core was received broken, the parts were mounted on the board in the order mirroring the age. After mounting, the glue was left to dry for at least eight hours.

### 2.3.2 Sanding of the incremental cores

After the glue dried, the incremental cores were sanded to enhance the differences among the rings. The sanding was executed in three phases: coarse sanding, with a sandpaper grit of 80, fine sanding, with a sandpaper grit of 240, and extra-fine sanding with a sandpaper grit of 400. The coarse sanding stops when the support wooden board is reached by the sanding paper. The fine sanding prepares the core for extra-fine sanding, which reveals the cellular anatomic level details. The extra-fine sanding also allows identification of very small annual rings, which are encountered in Norway spruce (*Picea abies* (L) H.Karst) or Scots pine (*Pinus sylvestris* L). For very narrow rings a fourth sanding is executed with a 600 or 800 grit sandpaper. After the final sanding, the wooden board is cleaned by blowing air from an air-compressor.

### 2.3.3 Measurement of the ring width

The width of each annual ring was measured using a graphical procedure (Lebourgeois and Merian, 2012), based on high resolution scans of incremental cores. A ring was defined as the area between the beginning of the earlywood to the very end of the latewood. After the extra fine sanding, each wooden plate was scanned with the flatbed scanner Epson XL1000 at 1200 dpi (Fig. 3).

Individual increment cores were delineated from scanned wooden board, and the annual rings were identified and measured using CDendro (Larsson, 2015a) and CooRecorder (Larsson, 2015b). The width of each ring was measured with a precision of 22 micrometer (Fig. 4).

The measurements are stored in a Heidelberg file. In the file header, measurements details are recorded (such as units, species or increment core id), while the ring width are stored in the body of the file as a continuous string of numbers. An edited example of such recording is:

HEADER:

KeyCode=I1000056

Length=89

DateEnd=2008

Unit=1/100 mm

CDendro=8.1

Comment=Sondaj 14206006

Comment=SP 3

Comment=Arbore 01

Comment=Specie GO

DATA: Tree 107 73 44 88 55 27 10769 71 52 103 78  
147 113 74 186 75 7181 96 63 80 51 49 81 69 53 32 37 44  
69104 22 56 38 58 101 71 48 55 87 28 16 15 23 28 37 55  
39 28 31 25 31 24 44 45 76 82 58 76 106 61 47 25 27 22  
26 26 50 45 34 44 69 40 11 30 24 19 25 40 34 55 49 36  
47 43 45 27 33 0

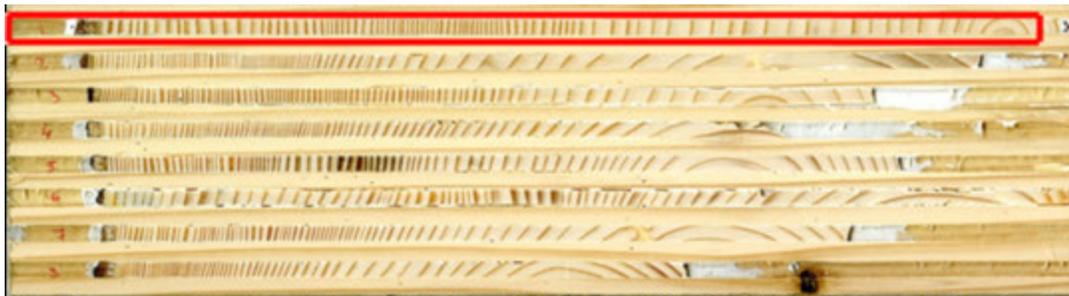


Figure 3: Wooden board with eight increment cores, identified on the left side of the image. The red rectangle identifies the core number 1.

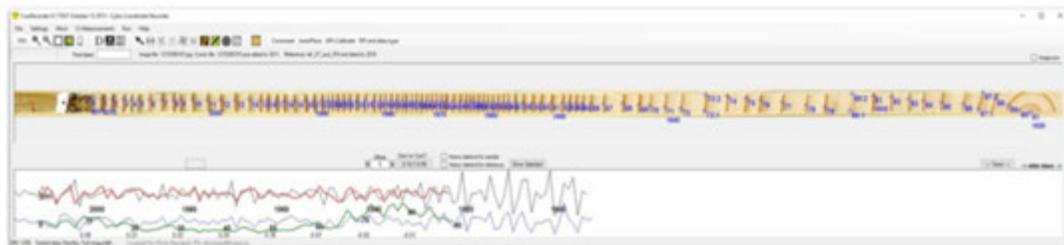


Figure 4: Rings width measurements using the CDendro.

### 2.3.4 Cross-dating incremental cores

Cross-dating represents the final step in producing the data for dendrochronological studies. Cross dating is a method of ensuring that each measured ring is allocated to the correct year. The task of pairing the ring with the year is achieved by matching the ring width pattern among trees. The procedure used by the Romanian NFI for cross-dating is the one recommended by Holmes (1983), Schweingruber et al. (1990), Wigley (1987), Grissino-Mayer (2001), and Bunn (2010). Reference curves were developed iteratively by pooling series of rings with high inter-correlation. A first reference curve was obtained from cores with clearly visible rings and a coefficient of correlation larger than 0.75. In many cases, the initial reference was relatively short, which required the addition of more series to expand the time windows. A minimum of 10 cores were used for development of a reference curve. The cross-dating process was implemented in CDendro, which displays during the measurement process the piece-wise (10 years) and series-wise correlation between the measurements and the reference. Therefore, the cores are being cross-dated while measured. Any missing or false rings were shown with a poor correlation, which triggered their investigation with various statistical tests and using pointer years (Schweingruber et al., 1990). A low correlation (e.g. less than 0.4) did not automatically disqualify a particular measurement or invalidated the cross-dating if a good

match of the pointer years was available (Neuwirth et al., 2007). Accurate assignment of each ring to a year through cross-dating allowed determination of the age and of the growth of a tree.

## 2.4 Dendrochronological data

Each cross-dated incremental core is uniquely identified, which allows estimation of an average ring width for each PSC and SP species, and consequently for each ecoregion of Romania. To ensure the privacy of information, the measurements of individual incremental cores are not available to the public. However, summary statistics by ecoregion, species, year, and ring age can be made available to the public.

### 2.4.1 Ecoregions

An ecoregion is defined as an homogeneous area from geomorphological and climatic perspective, which is aligned with the common understand of an ecoregion (Omernik and Griffith, 2014). The Romanian ecoregions were developed from the geomorphological and climatic maps of the Romanian Academy, and lead to 21 distinct ecoregions (Fig. 5).

The ecoregions, which follows the geomorphologic and climatic criteria as well as the historical provinces of Romania, vary in size from 161,904 ha (i.e., Maramures Plateau) to 2.79 mil. ha (i.e., Transylvania Plateau) (Tab. 1).

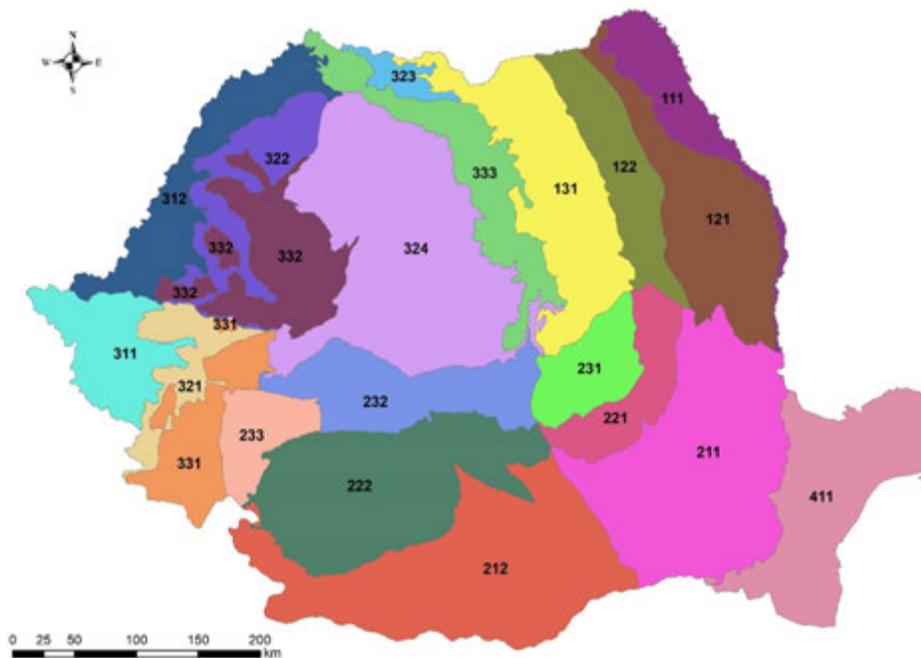


Figure 5: Romanian ecoregions delineated according to the geomorphological and climatic maps of the Romanian Academy.

Table 1: Romanian Ecoregions

No.	Ecoregion Name	Ecoregion Code	Area (ha)
1.	Eastern Romanian Plane	111	620,246
2.	Moldavian Plateau	121	1,352,075
3.	Moldavian Hills	122	806,488
4.	Eastern Carpathians	131	1,546,525
5.	Baragan Plain	211	2,439,615
6.	South Romanian Plain	212	2,499,007
7.	Buzau-Vrancea piedmonts	221	595,917
8.	Getic plateau	222	1,934,478
9.	Buzau-Vrancea mountains	231	550,591
10.	East Southern Carpathians	232	1,028,094
11.	West Southern Carpathians	233	449,804
12.	Western Plain	311	735,329
13.	Nerthwestern Plain	312	975,282
14.	Caras Hills	321	444,045
15.	Cris Hills	322	679,685
16.	Maramures plateau	323	161,904
17.	Transylvania Plateau	324	2,798,764
18.	Banat Mountains	331	708,961
19.	Western Carpathians	332	1,054,126
20.	Volcanic ridge	333	950,029
21.	Dobrogea	411	1,507,302

### 2.4.2 Species and forest management

The incremental cores are collected for all major trees species in Romania. However, the data-in-brief paper contains information only for three species: Norway spruce (*Picea abies* (L) H.Karst), European beech (*Fagus sylvatica* L) and Sessile oak (*Quercus petraea* (Matt.) Liebl), which cover approximately 60% of the Romanian forests. Furthermore, to ensure the usability of the data in growth and yield modeling, we have included only the incremental cores that were extracted from pure species stands, meaning stand only with Norway spruce, European beech or Sessile oak. Evermore, to avoid inclusion of trees growing in significantly different ecosystem conditions in models assuming similar stand developments, we have restricted the data set only to even-age stands. An even-aged stand is defined according to the Romanian guidelines as a forest stand on which the age of the trees does not differ by more than 5 years (Munteanu et al., 1980). We should point that the definition of an even age-stand enforced in Romania differs than the commonly accepted definition, which consider an even-aged stand as a “stand of trees containing a single age class in which the range of tree ages is usually less than 20% of rotation” (US Forest Service, 2019), which is similar to the definition of Nyland (1996) and Smith

(1997). The general understanding of an even-age stand is termed “relative even-age” by the Romanian guidelines (Munteanu et al., 1980). To ensure compatibility among various ecoregions and a meaningful number of cores, only the stand with no thinning were considered. We identified thinning by an obvious large increase in the width of the annual rings in respect with the previous and the subsequent rings.

### 2.4.3 Years, annual rings, and ages

For many growth and yield applications, the ring width, and consequently the dbh, is important to be traced through the life of the tree not through the calendar years. To ensure that each year and ring age would have at least one record, we summarized the increment cores values for five consecutive years. We have chosen a quinquennial interval for two reasons: first, we assumed that the climate during five consecutive years would not significantly change, and second, a 5-years interval is common in forest management and growth and yield modeling (Bettinger et al., 2009; Davis et al., 2001; Rucareanu and Leahu, 1982; Vanclay, 1994). Therefore, the dataset would contain the mean and variance of each ring age for a particular year, written as a multiple of 5 [i.e., 5 x (floor of the year divided by 5)]. To ensure con-

sistent site measurements, in the sense that no changes occurred in site productivity, we have included only the portion of the incremental cores less than 100 years old.

### 3 RESULTS

#### 3.1 Summaries

From the 50,000 cores collected by the Romanian NFI, only 6,536 belonged to the three species considered fit the condition mentioned in Section 2.4, namely were extracted from pure un-thinned even-aged stands. The dataset presented in this paper is based on 427,635 ring widths, out of which 136,904 rings are for Norway spruce, 241,240 rings for European beech, and 49,491 rings for Sessile oak. The age of the rings varies from 1 to 99 years. The number of rings decreases with age, from 6,536 rings for trees less than 10 years old to 2,011 at age 99. The number of rings for each ecoregion also varies significantly according to the species (Tab. 2), from 272 (i.e., European beech in the Maramures plateau) to 49,576 (i.e. Norway spruce in the Eastern Carpathians). A similar situation is encountered for the incremental cores, which range from less than 10 in the Maramures plateau (for European beech) to almost 1,000 in the Eastern Carpathians (for Norway spruce).

#### 3.2 Access to data and metadata content

The data containing the average ring width for each ecoregion, species, year, and age from the Romania NFI completed in 2012 is hosted by the Schol-

arArchive@OSU, a digital service supported by Oregon State University. The data can be accessed at the persistent URL <https://ir.library.oregonstate.edu/concern/datasets/8336h726s?locale=en> (Strimbu and Marin, 2019), and the corresponding DOI <https://doi.org/10.7267/8336H726S>. The metadata is located at the same URL address, and are stored in the README NFI .txt. The data can be used without restrictions, but acknowledgement of their origin is necessary.

The data is stored as an ASCII file with six fields: Ecoregion, Species, Year, Age, Mean.Width, Variance. The ecoregion field stores the codes of the 15 ecoregions on which the three species making the objective of the present study, namely Norway spruce, European beech, and Sessile oak, are encountered. The codes, which are stored as integers, are detailed in Table 1, and also in the metadata file. The species field identifies the species for which the incremental core was extracted using a two-letter code, standard in Romania: **MO** for Norway spruce (i.e., “Molid” in Romanian), **FA** for European beech (i.e., “Fag” in Romanian), and **GO** for Sessile oak (i.e., “Gorun” in Romanian). The year field is a number that identifies the calendar year of each ring within the incremental cores. The year is computed as the product between 5 and floor of the year divided by 5. The age field is an integer that identifies the age of each ring. The unit for age is the year. The Mean.Width field is a single precision number that represent the average of the ring width for the same species growing in the same ecoregion at the same age, and is in the same quinquennial year. The units for Mean.Width are micrometers, or

Table 2: Variation of the number of annual rings and incremental cores across ecoregions and species

Ecoregion Code	Number of rings			Number of incremental cores		
	Norway Spruce	European beech	Sessile oak	Norway Spruce	European beech	Sessile oak
121		2,881	6,575		41	93
122		8,687	2,385		112	29
131	49,576	28,286		986	332	
221		11,572	4,400		142	87
222		15,496	13,962		223	219
231	15,749	24,447		336	292	
232	27,969	30,700		506	387	
233	4,259	20,280		84	258	
321		1,577	1,419		20	17
322		2,379	2,969		31	44
323		272	706		4	11
324		13,763	17,075		187	253
331	1,654	36,007		47	427	
332	9,102	21,448		228	285	
333	28,595	23,445		568	287	
Total	136,904	241,240	49,491	2,755	3,028	753

$10^{-6}$  m. The variance field is a single precision number that represents the variance of the width of the annual rings from the same ecoregion, species, year and age. The units for variance are pico-squared meters, or the square of micrometers, namely  $10^{-12}$  m<sup>2</sup>.

The metadata contains only the information relevant to the stored data, not the details on how the data was obtained, which is presented in this article.

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