Dendrochronology

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Dendrochronology (or **tree-ring dating**) is the scientific method of dating tree rings (also called growth rings) to the exact year they were formed in order to analyze atmospheric conditions during different periods in history. Dendrochronology is useful for determining the timing of events and rates of change in the environment (most prominently climate) and also in works of art and architecture, such as old panel paintings on wood, buildings, etc. It is also used in radiocarbon dating to calibrate radiocarbon ages.[1]

Drill for dendrochronology sampling and growth ring counting

The growth rings of a tree at Bristol Zoo, England. Each ring represents one year; the outside rings, near the bark, are the youngest.

New growth in trees occurs in a layer of cells near the bark. A tree's growth rate changes in a predictable pattern throughout the year in response to seasonal climate changes, resulting in visible growth rings. Each ring marks a complete cycle of seasons, or one year, in the tree's life.[1] As of 2013, the oldest tree-ring measurements in the Northern Hemisphere extend back 13,900 years.[2]
Dendrochronology derives from Ancient Greek: δένδρον (*dendron*), meaning "tree limb", χρόνος (*khronos*), meaning "time", and -λογία *(-logia*), "the study of".

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History

The Greek botanist Theophrastus (ca. 371 – ca. 287 BC) first mentioned that the wood of trees has rings.[3][4] In his *Trattato della Pittura* (Treatise on Painting), Leonardo da Vinci was the first person to mention that trees form rings annually and that their thickness is determined by the conditions under which they grew.[5] In 1737, French investigators Henri-Louis Duhamel du Monceau and Georges-Louis Leclerc de Buffon examined the effect of growing conditions on the shape of tree rings.[6] They found that in 1709, a severe winter produced a distinctly dark tree ring, which served as a reference for subsequent European naturalists.[7] In the U.S., Alexander Catlin Twining (1801–1884) suggested in 1833 that patterns among tree rings could be used to synchronize the dendrochronologies of various trees and thereby to reconstruct past climates across entire regions.[8] The English polymath Charles Babbage proposed using dendrochronology to date the remains of trees in peat bogs or even in geological strata (1835, 1838).[9]

During the latter half of the nineteenth century, the scientific study of tree rings and the application of dendrochronology began. In 1859, the German-American Jacob Kuechler (1823–1893) used crossdating to examine oaks (Quercus stellata) in order to study the record of climate in western Texas.[10] In 1866, the German botanist, entomologist, and forester Julius Ratzeburg (1801–1871) observed the effects on tree rings of defoliation caused by insect infestations.[11] By 1882, this observation was already appearing in forestry textbooks.[12] In the 1870s, the Dutch astronomer Jacobus C. Kapteyn (1851–1922) was using crossdating to reconstruct the climates of the Netherlands and Germany.[13] In 1881, the Swiss-Austrian forester Arthur von Seckendorff-Gudent (1845–1886) was using crossdating.[14] From 1869 to 1901, Robert Hartig (1839–1901), a German professor of forest pathology, wrote a series of papers on the anatomy and ecology of tree rings.[15] In 1892, the Russian physicist Fedor Nikiforovich Shvedov (Фёдор Никифорович Шведов) (1841–1905) wrote that he had used patterns found in tree rings to predict droughts in 1882 and 1891.[16]

During the first half of the 20th century, the astronomer A. E. Douglass founded the Laboratory of Tree-Ring Research at the University of Arizona. Douglass sought to better understand cycles of sunspot activity and reasoned that changes in solar activity would affect climate patterns on earth, which would subsequently be recorded by tree-ring growth patterns (*i.e.*, sunspots → climate → tree rings).

Growth rings

Growth rings, also referred to as *tree rings* or *annual rings*, can be seen in a horizontal cross section cut through the trunk of a tree. Growth rings are the result of new growth in the vascular cambium, a layer of cells near the bark that is classified as a lateral meristem; this growth in diameter is known as secondary growth. Visible rings result from the change in growth speed through the seasons of the year; thus, critical for the title method, one ring generally marks the passage of one year in the life of the tree.

The rings are more visible in temperate zones, where the seasons differ more markedly. The inner portion of a growth ring is formed early in the growing season, when growth is comparatively rapid (hence the wood is less dense) and is known as "early wood" (or "spring wood", or "late-spring wood"[17]); the outer portion is the "late wood" (and has sometimes been termed "summer wood", often being produced in the summer, though sometimes in the autumn) and is denser.[18]

Many trees in temperate zones make one growth ring each year, with the newest adjacent to the bark. Hence, for the entire period of a tree's life, a year-by-year record or ring pattern is formed that reflects the age of the tree and the climatic conditions in which the tree grew. Adequate moisture and a long growing season result in a wide ring, while a drought year may result in a very narrow one.

Direct reading of tree ring chronologies is a learned science, for several reasons. First, contrary to the single ring per year paradigm, alternating poor and favorable conditions, such as mid-summer droughts, can result in several rings forming in a given year. In addition, particular tree species may present "missing rings", and this influences the selection of trees for study of long time spans. For instance, missing rings are rare in oak and

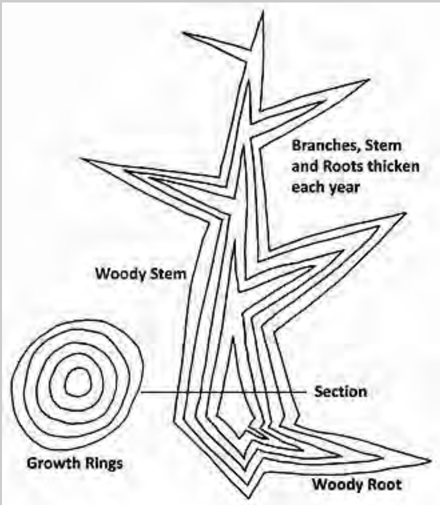

Diagram of secondary growth in a tree showing idealised vertical and horizontal sections. A new layer of wood is added in each growing season, thickening the stem, existing branches and roots, to form a growth ring.

elm trees.[19]


Pinus taeda Cross section showing annual rings, Cheraw, South Carolina.

Critical to the science, trees from the same region tend to develop the same patterns of ring widths for a given period of historical study. These patterns can be compared and matched ring for ring with trees growing at the same time in the same geographical zone (and therefore under similar climatic conditions). When these tree-ring patterns are carried back, from tree to tree in the same locale, in overlapping fashion, chronologies can be built up—both for entire geographical regions and sub-regions. Moreover, wood from ancient structures with known chronologies can be matched to the tree ring data (a technique called *cross-dating*), and the age of the wood can thereby be determined precisely. Cross-dating was originally done by visual inspection; more recently, computers have been harnessed to do the task, applying statistical techniques to assess the matching. To eliminate individual variations in tree-ring growth, dendrochronologists take the smoothed average of the tree-ring widths of multiple tree samples to build up a ring history, a process termed replication. A tree-ring history whose beginning and end dates are not known is called a *floating chronology*. It can be anchored by cross-matching a section against another chronology (tree-ring history) whose dates are known.

A fully anchored and cross-matched oak and pine chronology in central Europe extends back 12,460 years,[20] and an oak chronology goes back 7,429 years in Ireland ,and 6,939 years in England.[21] The consistency of these two independent dendrochronological sequences has been supported through comparison of their radiocarbon and dendrochronological ages.[22] Another fully anchored chronology that extends back 8500 years exists for the bristlecone pine in the Southwest US (White Mountains of California).[23]

Sampling and dating

Dendrochronology makes available specimens of once-living material accurately dated to a specific year.[24] Dates are often represented as estimated calendar years B.P., for before present, where "present" refers to 1 January 1950.[24]

Timber core samples are sampled and used to measure the width of annual growth rings; by taking samples from different sites within a particular region, researchers can build a comprehensive historical sequence. The techniques of dendrochronology are more consistent in areas where trees grew in marginal conditions such as aridity or semi-aridity where the ring growth is more sensitive to the environment, rather than in humid areas where tree-ring growth is more uniform (complacent). In addition, some genera of trees are more suitable than others for this type of analysis. For instance, the bristlecone pine is exceptionally long-lived and slow growing, and has been used extensively for chronologies; still-living and dead specimens of this species provide tree-ring patterns going back thousands of years, in some regions more than 10,000 years.[25] Currently, the maximum span for fully anchored chronology is a little over 11,000 years B.P.

In 2004 a new radiocarbon calibration curve, INTCAL04, was internationally ratified to provide calibrated dates back to 26,000 B.P. For the period back to 12,400 B.P., the radiocarbon dates are calibrated against dendrochronological dates.[26][27]

Dendrochronology practice faces many obstacles, including the existence of species of ants that inhabit trees and extend their galleries into the wood, thus destroying ring structure.

Reference sequences

European chronologies derived from wooden structures initially found it difficult to bridge the gap in the 14th century when there was a building hiatus, which coincided with the Black Death,[28] however there do exist unbroken chronologies dating back to prehistoric times, for example the Danish chronology dating back to 352 BC.[29]

Given a sample of wood, the variation of the tree-ring growths provides not only a match by year, it can also match location because the climate across a continent is not consistent. This makes it possible to determine the source of ships as well as smaller artifacts made from wood but which were transported long distances, such as panels for paintings and ship timbers.

Applications

Radiocarbon dating calibration

Dates from dendrochronology can be used as a calibration and check of radiocarbon dating[24]

Climatology

In areas where the climate is reasonably predictable, trees develop annual rings of different properties depending on weather, rain, temperature, soil pH, plant nutrition, CO_2 concentration, etc. in different years. These variations are used in dendroclimatology to infer past climate variations.

Examples:

- by applying an isotopic approach that circumvents high-frecuency climatic irregularities and genetic variabilities in growth rings of perennial trees from the Southern Atlantic Europe, a dendrochronological study examines the tree-ring ^{13}C evolution over a 25-year-long period (1978-2002) to perform the deconvolution of past atmospheric composition as well as to evaluate the biome sensitivity to ^{13}C atmospheric changes (Cabaneiro, A. & Fernandez, I. Environmental Technology and Innovation 4, 52-61 (2015))[30]

Art history

Dendrochronology has become important to art historians in the dating of panel paintings. However, unlike analysis of samples from buildings, which are typically sent to a laboratory, wooden supports for paintings usually have to be measured in a museum conservation department, which places limitations on the techniques that can be used.[31]

In addition to dating, dendrochronology can also provide information as to the source of the panel. Many Early Netherlandish paintings have turned out to be painted on panels of "Baltic oak" shipped from the Vistula region via ports of the Hanseatic League. Oak panels were used in a number of northern countries such as England, France and Germany. Wooden supports other than oak were rarely used by Netherlandish painters.[32]

A portrait of Mary Queen of Scots, determined to date from the 16th century by dendrochronology.

Since panels of seasoned wood were used, an uncertain number of years has to be allowed for seasoning when estimating dates.[33] Panels were trimmed of the outer rings, and often each panel only uses a small part of the radius of the trunk. Consequently, dating studies usually result in a "terminus post quem" (earliest possible) date, and a tentative date for the actual arrival of a seasoned raw panel using assumptions as to these factors.[34] As a result of establishing numerous sequences, it was possible to date 85–90% of the 250 paintings from the 14th to 17th century analysed between 1971 and 1982;[35] by now a much greater number have been analysed.

A portrait of Mary, Queen of Scots in the National Portrait Gallery, London was believed to be an 18th-century copy. However, dendrochronology revealed that the wood dated from the second half of the 16th century. It is now regarded as an original 16th century painting by an unknown artist.[36]

On the other hand, dendrochronology was applied to four paintings depicting the same subject, that of Christ expelling the money-lenders from the Temple. The results showed that the age of the wood was too late for any of them to have been painted by Hieronymus Bosch.[37]

While dendrochronology has become an important tool for dating oak panels, it is not effective in dating the poplar panels often used by Italian painters because of the erratic growth rings in poplar.[38]

The 16th century saw a gradual replacement of wooden panels by canvas as the support for paintings, which means the technique is less often applicable to later paintings.[39] In addition, many panel paintings were transferred onto canvas or other supports during the 19th and 20th centuries.

Building history

The dating of buildings with wooden structures and components has also been done by using dendrochronology. While archaeologists can date wood and when it was felled, it may be difficult to definitively determine the age of a building or structure in which the wood was used; the wood could have been reused from an older structure, may have been felled and left for many years before use, or could have been used to replace a damaged piece of wood. The dating of building via dendrochronology thus requires knowledge of the history of building technology.[40]

Examples:

- cliff dwellings of Native Americans in the arid U.S. Southwest.
- The Fairbanks House in Dedham, Massachusetts. While the house had long been claimed to have been

built circa 1640 (and being the oldest wood-framed house in North America), core samples of wood taken from a summer beam confirmed the wood was from an oak tree felled in 1637–8. An additional sample from another beam yielded a date of 1641, thus confirming the house had been constructed starting in 1638 and finished sometime after 1641 as wood was not seasoned before use in building at that time in New England.[41]

- The burial chamber of Gorm the Old, who died c. 958,[42] was constructed from wood of timbers felled in 958.[40]

Related chronologies

Similar seasonal patterns also occur in ice cores and in varves (layers of sediment deposition in a lake, river, or sea bed). The deposition pattern in the core will vary for a frozen-over lake versus an ice-free lake, and with the fineness of the sediment.

Some columnar cactus also exhibit similar seasonal patterns in the isotopes of carbon and oxygen in their spines (acanthochronology). These are used for dating in a manner similar to dendrochronology, and such techniques are used in combination with dendrochronology, to plug gaps and to extend the range of the seasonal data available to archaeologists and paleoclimatologists.

A related technique is used to analyse fish stocks through the analysis of growth rings in the otolith bones of fish.

Further reading

- "Tree Ring Science", the academic site of Prof. Henri D. Grissino-Mayer, Department of Geography, The University of Tennessee, and the Laboratory of Tree-Ring Science, see [1] (http://web.utk.edu/~grissino/index.htm)

See also

- Acanthochronology
- Baumkuchen, cake that resembles growth rings
- Dendroarchaeology
- Dendroclimatology
- Dendrology
- Herbchronology
- Paleoclimatology
- Post excavation
- Sclerochronology
- Timeline of dendrochronology timestamp events
- Varve

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3. Theophrastus with Arthur Hort, trans., *Enquiry into Plants*, volume 1 (London, England: William Heinemann, 1916), Book V, p. 423. (https://archive.org/stream/enquiryintoplant01theouoft#page/422/mode/2up) From p. 423: "Moreover, the wood of the silver-fir has many layers, like an onion; there is always another beneath that which is visible, and the wood is composed of such layers throughout." Although many sources claim that Theophrastus recognized that trees form growth rings annually, this is not true.
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5. See:
   - Leonardo da Vinci, *Trattato della Pittura* ... (Rome, (Italy): 1817), p. 396. (https://archive.org/stream/trattatopittura01leon#page/396/mode/1up/) From p. 396: *"Li circuli delli rami degli alberi segati mostrano il numero delli suoi anni, e quali furono più umidi o più secchi la maggiore o minore loro grossezza."* (The rings around the branches of trees that have been sawn show the number of its years and which [years] were the wetter or drier [according to] the more or less their thickness.)
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7. du Hamel & de Buffon (4 May 1737) "Observations des différents effets que produisent sur les végétaux les grandes gelées d'hiver et les petites gelées du printemps" (http://gallica.bnf.fr/ark:/12148/bpt6k3534v/f425.image.r=l%27aubier.langEN) (Observations on the different effects that the severe frosts of winter and the minor frosts of spring produce on plants), *Mémoires de l'Académie royale des science*, in: *Histoire de l'Académie royale des sciences* ..., pp. 273–298. Studhalter (1956), p. 33, stated that Carl Linnaeus (1745, 1751) in Sweden, Friedrich August Ludwig von Burgsdorf (1783) in Germany, and Alphonse de Candolle (1839–1840) in France subsequently observed the same tree ring in their samples.
8. Alexander C. Twining (1833) "On the growth of timber — Extract of a letter from Mr. Alexander C. Twining, to the Editor, dated Albany, April 9, 1833" (https://books.google.com/books?id=COpQAAAAYAAJ&pg=PA391#v=onepage&q&f=false), *The American Journal of Science*, **24** : 391–393.
9. See:
   - (Anon.) (1835) "Evening meeting at the Rotunda" (https://books.google.com/books?id=dfNPAAAAMAAJ&pg=PA116#v=onepage&q&f=false), *Proceedings of the Fifth Meeting of the British Association for the Advancement of Science held in Dublin during the week from the 10th to the 15th of August, 1835, inclusive*, pp. 116–117.
   - Charles Babbage (1838) "On the age of strata, as inferred from rings of trees embedded in them" (https://books.google.com/books?id=y_ERAAAAYAAJ&pg=PA256#v=onepage&q&f=false), *The Ninth Bridgewater Treatise: A Fragment*, 2nd ed. (London, England: John Murray, 1838), pp. 256–264.
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   - Jacob Kuechler (August 6, 1859) "Das Klima von Texas" (The climate of Texas), *Texas Staats-Zeitung* [Texas state newspaper] (San Antonio, Texas), p. 2.
   - "The droughts of western Texas", *The Texas Almanac for 1861*, pp. 136–137 ; see especially p. 137. (http://texashistory.unt.edu/ark:/67531/metapth123767/m1/137/)

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16. See:
    - Шведов, Ф. (Shvedov, F.) (1892) "Дерево, как летопись засух" (The tree as a record of drought), *Метеорологический Вестник* (Meteorological Herald), (5) : 163–178.
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External links

- Nottingham Tree-Ring Dating Laboratory (http://www.tree-ringdating.co.uk/)
- Video & commentary on Medullary Rays, heart wood and tree rings. (https://www.youtube.com/watch?v=5iVrhCV-N2E)
- Video & commentary on Tree Rings - Formation and Purpose (https://www.youtube.com/watch?v=qvT_aGjdI8M)
- Oxford Tree-Ring Laboratory (http://www.dendrochronology.com/)
- Bibliography of Dendrochronology (http://www.wsl.ch/dienstleistungen/produkte/glossare/dendro_bibliography/index_EN)
- Multilingual Glossary of Dendrochronology (http://www.wsl.ch/dienstleistungen/produkte/glossare/dendro_glossary/index_EN)
- Digital Collaboratory for Cultural Dendrochronology (DCCD) (http://dendro.dans.knaw.nl)
- International Tree-Ring Data Bank (http://www.ncdc.noaa.gov/paleo/treering.html)
- Ultimate Tree-Ring Web Pages (http://web.utk.edu/~grissino/)
- Laboratory of Tree-Ring Research University of Arizona (http://www.ltrr.arizona.edu)

The Wikibook *Historical Geology* has a page on the topic of: ***Dendrochronology***

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