Do Trees Tell About the Past?

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Realizing the consequences of global warming, scientists are currently engaged in understanding the causes and mitigation measures of this phenomenon. One of the important criteria to understand the present pattern of climate is the study of past climate. To reconstruct past climate, analysis of ice cores, lake sediments, peat bogs, ocean floor and trees is necessary. This article explains how the anatomical features of trees can throw light on past climate.

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Dendrochronology

The study of trees is called *Dendrology*, which is derived from Greek (*dendros* = trees or wood, *logos* = study). The science of dating of wood or trees is called *Dendrochronology, dendros* = Tree, *chronos* = time, *logos = study*. Dendroclimatology is the study of climate with the help of tree rings.

Dendrochronology or tree-ring dating is a scientific method of dating trees based on annular rings of wood developed during the early 20th century. A E Douglass, the founder of tree-ring research laboratory, Arizona, USA pioneered this technique. Now many laboratories in the world use this technique to understand variations in the growth of individuals of same species, reconstruction of past climate and to trace the wildfire history, etc.

How Trees Grow in Girth?

Growth in trees is associated with horizontal increment in size. Vertical growth of trees slows down after some stage. Horizontal increment in size is a result of production of wood year after year. As fresh wood is formed, the earlier formed wood becomes non-functional. This non-functional wood is a dead tissue. A trans-section of the stem that has acquired considerable secondary growth in girth reveals the following tissue layers. The outer zone

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Growth in girth of dicotyledonous trees is accomplished by the addition of tissues, particularly secondary xylem, a process facilitated by cambium.

is the multi-layered bark, which acts as a protective layer against extreme weather conditions. It also helps the trees in retaining the moisture during dry season and offers resistance to insects and diseases. Inner to the bark is the cortex. Inner to the cortex is the secondary phloem followed by a fascicular cambium (a meristem dedicated to produce the vascular tissues, the secondary phloem and secondary xylem) and the secondary wood progressively towards the inside. Phloem is complex tissue that conducts metabolites. Phloem tissue of some species has elongated thick-walled fiber cells which are called bast fibers or phloem fibers which are non-functional phloem cells. Cambium is an actively dividing tissue that provides precursors for both secondary phloem and secondary xylem continuously until death in the majority of dicotyledonous trees.

Leaf buds produce growth hormones called auxins during the spring. Auxins get transported through phloem to the cambium that results in the secondary growth. Recently formed xylem is a complex tissue made up of tracheids and xylem vessels with their walls heavily lignified, xylem fibers and xylem parenchyma. They conduct water and mineral nutrients from the soil. Xylem fibers are primarily responsible for rendering wood hard and heavy. Newly produced xylem is the sapwood that provides a pipeline for water and mineral salts. As new rings of sapwood[1] are laid, the older sapwood looses its vitality and turns into heartwood[2]. Heartwood is the core tissue that supports trees. Though

[1] Sapwood is younger and outermost growing wood in a tree. It is a living wood and its function is to conduct water. Sapwood is the first wood that is formed which later gets transformed into heartwood.

[2] The wood which occurs as a result of natural chemical transformation and is more resistant to decay. Heartwood is a dead wood and generally dark in colour. Formation of heartwood happens spontaneously. It is also technically called as duramen.

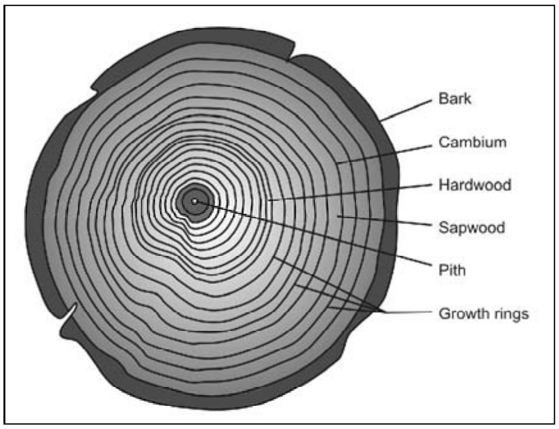

Figure 1. Cross-section of a tree trunk.

it is made of dead cells, it never disintegrates as long as sapwood and bark are intact. For a detailed account of wood anatomy, refer to Katherine Easu's standard book on plant anatomy [1].

As more and more xylem is added in growing trees, the earlier formed xylem comes to lie towards the centre of the trunk and is often deposited with secondary metabolic products. This heartwood largely adds to the mechanical strength of the tree.

Properties of Wood

The chemical composition of wood of all trees is very similar. They are basically made up of cellulose, lignin and deposits of metabolic wastes. Lignin predominates the other components of the walls of xylem elements. It gives rigidity to cells. Ash obtained by burning wood contains minerals such as calcium, potassium, magnesium, manganese and silica. Extractives[3] are made up of a wide range of organic compounds. The various extractives impart characteristics through which we can identify some woods. Extractives in the intact wood give resistance to fungal and insect attack of wood. They also give color and aroma to several woods. Some of the physical properties that characterize wood are color, texture, hardness, grain and pores.

[3] Chemical compounds in wood with relatively small molecules and comprise about 1–5% of wood. Examples are resins and tannins.

In most woods, cross-sections of the logs show two more or less distinct regions based on the color. The outer lighter-colored zone of sapwood of varying size and colour, and the inner or central dark-colored heartwood constitute the wood of trees. The heartwood in many species has different colors and hues. The ratio of sapwood to heartwood varies across species. Some of the climate change models that use tree physiology for predicting the vegetation type as influenced by climate have used this ratio to characterize the initial vegetation type.

Based on hardness, woods are classified as softwood[4] and hardwood[5] species (*Box* 1). Hardness is the resistance offered by a wood to indentation or penetration. Hardwood species contain thick-walled fiber cells along with water-conducting xylem vessels in their wood, eg., *Tectona grandis*, *Lagerstroemia microcarpa* and *Mesua ferrea*, etc. This feature is lacking in softwood species. Some of the softwood species include *Bombax cieba* and *Ailanthes malabarica*. Woods are also classified as heavy, medium and light woods depending on their density.

[4] Generally wood from gymnosperms are referred to as softwood. They are softer (less dense), less durable and have high calorific value. Softwoods may not be softer than hardwoods per se.

[5] Wood from non-monocot angiosperms.

Box 1.

Specific gravity (SG) of wood is a measure of its hardness. SG is expressed on a numerical scale based on 1.0 for pure water. SG of a substance can be easily calculated by dividing its density (grams per cubic centimeter) by the density of pure water (one gram per cubic centimeter). It is based on the principle of buoyancy discovered by Archimedes. The principles of buoyancy and specific gravity are used in many ways. Some of the heavy woods still float on water. Even the world's heaviest woods have specific gravities less than 1.5 due to the pores present in their cell walls, though the density of a pure cell is about 1.5 grams per cubic centimeter. Some of the heaviest woods in India are those of *Mesua ferrea, Xylia xylocarpa, Diospyros ebunum, Tectona grandis, Anogeissus latifolia* and *Terminalia crenulata*. Specific gravity is used to convert bio-volume of wood to biomass.

The 'texture' of wood depends upon size, distribution and proportion of various types of cells that go into its composition. The 'grains' of wood usually refer only to the general direction or alignment of cells.

Woods are classified on the basis of porosity of xylem (the relative diameter of the luminance[6] of the xylem vessels). They are classified into two major groups, namely porous[7] and non-porous woods[8]. Porous woods are produced by dicotyledonous trees such as *Tectona grandis* (teak), *Shorea robusta* (sal) or *Mangifera indica* (mango). They are called hardwoods while non-porous woods are produced by coniferous trees or trees with needle-like leaves (gymnosperms) such as *Cedrus deodara* (deodar) or *Pinus wallichii* (Chir pine). Porous woods are more complex than non-porous woods in their structure.

[6] Optical shining of unfinished wood. It depends on the kind of material deposited.

[7] Wood having vessels that appear as pores.

[8] Wood having no vessels and hence no pores.

In India alone we have over 1600 different wood types which show remarkable variation in their physical properties and in their anatomical features.

How to Assess Age of a Tree?

Trees growing in a seasonal climate produce distinct growth rings. Counting of wood rings gives the age of a tree.

For estimating the age, samples are normally collected from healthy trees having a straight trunk preferably without any external injury to the trunk. While collecting, we need to gather information on the size of the tree, local site characters, vicinity to the water source and local neighborhood as these factors affect the growth of the tree. This information will help us to understand if there is any anomaly in tree growth. A sample of the wood is taken with the help of increment borer, an instrument that can be driven into the trunk, and a long cylindrical column or core of wood is obtained. The diameter of the sample depends on the diameter of the increment borer. The sample is sealed in specially -designed plastic tubes to be analyzed later in the laboratory.

The age of a tree and nature of annular wood rings are assessed from core samples obtained by using a device known as increment borer.

Samples are mounted with adhesives in wooden channels which are designed according to the core diameter. Then they are polished both mechanically and by hand. Polishing is carried out until the rings are clearly visible. These polished samples are mounted on a platform which is fitted with a microscope and computer.

The distance between each ring is measured and stored in the computer for further analysis.

While reading the rings, extreme care is taken in identifying correct rings as there could be anomaly in ring formation due to environmental factors. Following are the anomalies in ring formation:

(i) False rings: They are bands that appear to be latewood followed by earlywood and a true latewood band. All these bands appear within a true ring boundary. They are caused by stress during the growing season and can cause significant changes in size and shape of the rings. Nevertheless these false rings can be identified by careful observation.

(ii) Absent rings: Occasionally ring does not appear during a given year.

Tree ring just below the bark is considered as latest growth ring and subsequent rings are dated backwards. Rings are counted till the pith is encountered. This gives the age of the tree.

Box 2. Lack of Visible Rings in Tropical Trees

Many tropical trees have no distinctly visible annual growth rings. Species such as *Tectona grandis* and *Cedrela toona* produce growth rings in tropics. The difference between wet and dry seasons for most of the species is too subtle to make noticeable differences in the cell size and density between wet and dry seasonal growth. Hence they have no rings or have 'invisible rings'. Efforts are being made to study many tropical species that have invisible rings by using differential levels of calcium deposition during wet and dry season. X-ray beams are being used to study the differences between wet and dry season deposition of calcium which compares favorably with carbon isotope measurements.

Wood rings are distinctly seen in conifers that grow in temperate and sub-tropical regions, where growth is distinct as per the season. Many tropical trees do not produce distinct rings as tropics lack extreme seasonality in climate. But there are tropical species such as teak (*Tectona grandis*) which show annual rings. Attempts are being made to look for another species that has distinct rings and can be used in climate reconstruction. However, presently teak is the one which is used in dendro-climatic studies.

Climate Reconstruction

One of the important applications of dendrochronological research is to reconstruct past climate. Since climate models are inconsistent in predicting the rainfall pattern in tropics, paleo-proxy[9] perspective such as wood is very important. The annular growth rings produced by both gymnosperms (conifers) and angiosperms such as teak are used to reconstruct past rainfall and temperature trends. The width of growth rings can serve as natural records of climate. Besides the ring width, climatic condition at the time of ring formation can influence cell size, cell-wall thickness and the corresponding density of the woody tissue in the ring. Further, cells may have been destroyed or distorted by extreme events such as frost, extensive fire and floods. These events leave a signature in the wood and capturing these events also helps in reconstruction of time series. In tropical climates where there is no strong diurnal variation in the temperature, rainfall could be the limiting factor for growth and hence it would be an obvious choice to study the relationship between variability

[9] Old record that can be used to reconstruct past events.

The width and nature of annular growth rings serve as natural records of the past climate and forest fire history. The cell size of xylary elements as well as the density of wood also provide information on the event that help in the reconstruction of chronology.

Box 3. Principles in Dendrochronology

1. The uniformitarian principle which states that the physical and biological processes that link current environmental processes with current patterns of tree growth must have been in operation in the past.
2. The principle of limiting factors states that the rate of plant process constrained by the primary environmental variable that is most limiting. For example rainfall could be a limiting factor for growth in arid and semi-arid areas.
3. The principle of aggregate tree growth states that any growth series can be decomposed into an aggregate of environmental factors that influence the tree growth over time. Tree growth is the aggregate of the following factors: i) Age-related growth processes due to normal physiological state; ii) Climate of that year; iii) Occurrence of disturbance within the stand; iv) Occurrence of disturbance in the surroundings (outside); v) Random process not accounted by the above processes.
4. The principle of ecological amplitude states that species may occur and reproduce over a wide range of habitats.
5. The principle of site selection states that a dendrochronologist must select a site based on criteria that produces growth rings sensitive to environmental variable being examined.
6. The principle of cross dating states that matching patterns of tree rings or other ring patterns across several ring series allow identification of the exact year in which each tree ring was formed. This is an important principle in dendrochronology.
7. The principle of replication states that the environmental signal can be maximized by sampling more trees and cores per trees and amount of noise can be minimized.

in rainfall and growth. However in temperate regions, temperature seasonality influences tree growth. The successful recovery of information on climate from the tree rings is just not counting rings but involves application of dendrochronological principles (See *Box* 3). It is known that there is a differential activity of cambium tissue along the length of the tree and these changes are associated with age and stem height. Generally the year-to-year variations in ring width are more closely associated with macroclimatic variation than the ring width changes in the upper regions of the stem which are more influenced by the microenvironment of the individual branches.

It is necessary to make an appropriate choice of site based on the parameter that is to be reconstructed. Appropriate selection of trees from limiting sites maximizes ring-width variability (or the signal representing the climatic input) and minimizes the ring-width variation that may be arising from non-climatic factors (or the noise). It is useful to obtain more samples for a given area to analyze the signal and noise in the data. Such data provides an objective means of evaluating the quality of ring-width record and helps in better reconstruction of climate. The amount of signal and noise in a given sample can be assessed by the analysis of variance and other statistical procedures including regression and time-lag correlations. The variability in the ring width is one of the best indicators of climatic stress. This variability is called 'sensitivity' by dendrochronologists.

There is a standard set of programs available for free download from the Tree-Ring Research Laboratory, University of Arizona that are employed in tree-ring analysis. Ring-width measurements are corrected by the computer program COFECHA[10] which yields master correlation and inter-core correlation. Data with high inter-core correlation is good for detecting climate trends. COFECHA is run using both raw ring-width measurements and transformed measurements. Correlations with transformed ring measurements are considered to be standard. Another standard practice to determine the chronology is the skeletal plot method. In this method ring widths are represented graphically for each core sample and a common trend among the cores such as narrow rings is used to fix the calendar date of each ring. Corrected ring widths are standardized by using another computer program ARSTAN[11] which removes growth trends related to age and stand dynamics[12] while retaining the maximum common signal to form tree-ring indices. Tree-ring chronologies with high mean sensitivity, low autocorrelation, high signal to noise ratio and high correlation between and within trees are suitable for climate reconstruction. These ring-width chronology statistics such as mean sensitivity, common variance, expressed population signal and signal-to noise ratio indicate a strong environmental influence on the growth of a tree. PDSI (Palmer's Drought Sensitivity Index) which is a proxy for soil moisture and stream flow is also used in the analysis to reconstruct climate. This index was

[10] It is a computer program to measure the quality and accuracy of tree-ring measurements. It is a Spanish word meaning 'co-date' or 'cross-date'.

[11] It is a computer program that produces chronologies from tree-ring measurements after detrending and standardizing the series and applying a robust estimation of mean value function to remove effects of endogenous stand disturbances. It is used in getting the climate signal that influences the growth. Developed by Dr. Edward R Cook at Columbia University.

[12] Stand dynamics is explained as the process of mortaility, recruitment and growth of individual in a given patch of forest under consideration.

developed by Palmer in 1965 and calculated based on rainfall, temperature and local available water content of the soil. Extreme values of the index suggest either drought (extremely dry) or high rainfall (extremely wet) conditions. A quantitative relationship between tree growth and climate is generally built through response function analysis which is a regression analysis available in DPL (Dendro Program Library) of University of Arizona. This analysis is normally performed on both raw ring-widths and transformed ring-width series. Climate variable (temperature, PDSI and precipitation) for different months is used as statistical predictors and ring with variations are the predictands. The sign and magnitude of the coefficients of the regression are interpreted as response of growth to the particular monthly climate. Recently isotopes of carbon and oxygen present in the ring tissue were also used to reconstruct past trends in rainfall and temperature.

The analytical procedures give a scope for looking at influence of climate on growth in different seasons such as pre-monsoon, monsoon and post-monsoon. However, a word of caution here is that growth in plants is not fully influenced by climate. Physiological factors play a significant role. Sometimes climate reconstruction based on tree rings may be difficult because of these endogenous factors [5].

Research in India

The research concerning dendrochronology in India is in its infancy. There are two national institutes, Indian Institute of Tropical Meteorology (IITM), Pune and Birbal Shani Institute of Paleobotany (BSIP), Lucknow which are involved in the research. Most dendrochronology research in India has utilized coniferous trees in Himalayan region or teak and toon trees in tropical climate. Research on tree rings has been initiated at the Indian Institute of Science, Bangalore (*Box* 4). The primary interest in tree rings is to relate variability in growth to annual rainfall and dry season ground fires and also reconstruct rainfall and temperature pattern in recent times over peninsular India. Target species for tree-ring research is *Tectona grandis* which

Box 4. Work Done with Teak at IISc, Bangalore

Currently, work is underway to study dendrochronology of teak from the dry forests of Mudumalai. Our main objective is to understand the influence of rainfall on growth of trees. This study would supplement our long-term studies on dynamics of dry forest. Many studies in India and abroad have shown the influence of moisture on growth. We have taken several core samples from teak trees within a 50-hectare permanent forest dynamics plot and surrounding areas in the Kargudi range. We need to take samples from several trees spread across to account for spatial variability as growth is also influenced by site factors along with environmental factors such as rainfall, temperature and sunshine. After obtaining core samples and subjecting them to standard dendrochronological protocols our results can be briefly summarized as follows. Correlations with the master series are low, indicating these core samples may not have strong potential for climate reconstruction. Because Mudumalai has influence of both southwest and northeast monsoon, growth is influenced by both monsoons. Studies have shown that trees in highly seasonal rainfall zones have high climate reconstruction potential. We are also working on the Palmer's drought sensitivity index (PDSI) which is proxy for soil moisture of a given area across months in different years on growth.

We have also made observations on the incidences of past forest fires from these core samples. There are several ways trees manifest the incidences of forest fires. Fire normally affects the cambium resulting in some abnormality or deformity in the stem. These abnormalities depend on the intensity of fire. Our observation on forest fires in Mudumalai suggest that these forests have been subjected to ground fire and never/rarely experience the canopy fire. In the case of Mudumalai trees, fires leave a distinct black circle of carbon deposit at the ring boundary. Counting such circles, we can account for past fire history. Initial results suggest that fire frequency has increased since 1900. We may attribute this to intense management of Mudumalai forests for timber as the demand for timber increased many folds. Also the forest policy of the British was to raise plantations to meet the demand for timber. These results throw light on past events that the forest has experienced and tree response to those events.

produces annual rings. Attempt is also being made to explore several other species such as *Lagerstroemia microcarpa*, a dominant species in deciduous forests, *Cedrela toona*, a hardwood species that is known to produce rings and *Terminalia bellirica*, which is sensitive to climate. Efforts are also being made to explore several other species that might produce annual rings which are still unknown to the scientific world.

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Suggested Reading

[1] H C Fritis, Growth rings of trees: their correlation with climate, *Science*, Vol.154. pp.973–979, 1966.

[2] H C Fritis, Dendroclimatology and dendroecology, *Quaternary Research*, Vol.1, pp.419–449, 1971.

[3] Easu Katherine, *Plant Anatomy*. 2nd edn. Wiley (Pub). New York, London and Sydney, 1965.

[4] Dipanjan Ghosh, Bark is the Hallmark, *Resonance*, Vol.11, No.3, pp.41–50, 2006.

[5] A Fahn, Plant Anatomy 4th edn. Pergamon Press, Oxford. UK, 1990.

[6] Briffa *et al*, Trees tell of past climates: but are they speaking less clearly today? *Proceedings of Royal Society London*, (Biological Sciences) Vol.353, pp.65–73, 1998.

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