Image 1. Method 1: taking a tree core from a black spruce tree using an increment borer. Photo by S. Dumont (2024)

GLOSSARY

- **Dendrochronology**: dating and analyzing growth rings in trees to determine the exact year each ring was formed.

- **Dendroecology**: the study of ecological processes and environmental changes, such as climate, soil, competition and disturbances like fires or insect outbreaks, using dendrochronological methods.

- **Dendroclimatology**: reconstructing past climate conditions and analyzing tree-ring patterns. Climate variables can include temperature, precipitation and humidity to infer past climate variations to understand long-term climate trends and their impacts on forests.

CLIMATE CHRONICLES IN WOOD: HOW DENDROCLIMATOLOGY INFORMS ADAPTIVE SILVICULTURE

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Dendroclimatology, the study of tree rings to understand past climates, merges elements of botany, ecology, and climatology to offer a comprehensive view of historical climate conditions. By analyzing the width, density, and composition of annual growth rings, scientists can reconstruct past temperature, precipitation, and atmospheric patterns, making trees valuable natural archives. This field is instrumental in identifying specific climatic events and establishing long-term trends, which are essential for predicting future climate scenarios. Dendroclimatology not only provides critical data for climate models but also informs forest management practices. It highlights the importance of understanding climate-growth relationships, contributing to the development of adaptive silviculture strategies aimed at enhancing forest resilience in the face of changing climates. Through its unique methodologies and tools, dendroclimatology differentiates itself from other dendrological fields by its focus on the intricate relationship between climate and tree growth.

Image 2. Method 2: cutting a tree disc by felling a tree with a chainsaw. Photo by S. Dumont (2024),

WHAT IS THE DIFFERENCE BETWEEN DENDROCHRONOLOGY AND DENDROECOLOGY?

Whereas dendrochronology focuses on dating and studying tree-ring sequences as time markers, dendroecology uses these methods to study the spatiotemporal relationships between woody plants and their habitat that influence their distribution and abundance. Dendroclimatology, on the other hand, specifically investigates climate-related factors affecting tree growth. It bridges the gap between climatology and tree-ring science, offering insights into historical climate conditions.

DIFFERENT WAYS TO COLLECT AND ANALYZE TREE RINGS

SAMPLING

Sampling involves selecting appropriate trees, collecting samples, and ensuring their proper storage. Samples are typically taken using an increment borer, extracting core samples that, ideally, contain the tree pith (Image 1). Two cores per tree are usually collected to ensure data reliability. Cross-sections can also be collected (Image 2), although this method is more destructive and often results in killing the tree. However, it carries less risk of errors in dating the growth rings compared to core samples because missing or incomplete rings are more easily identified. Proper storage and labeling of samples are essential to maintain their integrity.

SAMPLE PREP

In the laboratory, samples undergo preparation involving drying, mounting and finely sanding to reveal the ring structure. Mounting stabilizes the cores, and sanding removes surface irregularities, allowing for clear visibility of the wood cells and the delimitation of growth rings.

TREE RING MEASUREMENT

Growth rings are first visually identified and marked on each radius using a binocular. Measurements can then be taken primarily two ways: by using a binocular and a sliding-stage micrometer connected to a computer, or by analyzing high-definition scanned images of the samples with a specialized software. Ring widths can then be transformed into basal area increments (BAI), which are an estimation of the area of growth rings. It is a method more and more used in dendrochronological and dendroclimatological analyses.

CROSS-DATING

Cross-dating is a precise method used to assign exact calendar years to each ring. This process involves comparing ring patterns from different trees of the same species and region to identify matching growth sequences, ensuring accurate dating. It can be done either visually, using the skeleton plot method or by identifying diagnostic rings (such as narrow rings, light rings, frost rings, incomplete or absent rings, false rings or rings with traumatic resin ducts), or statistically, after standardization of the individual tree-ring series.

STANDARD-IZATION

Standardization aims to convert tree-ring measurements into uniform indices. This process seeks to normalize growth variations regardless of differences in age and growth among sampled trees. It enables the creation of average series from individual indexed series. A second objective of standardization is the removal of non-climatic growth trends from the data to isolate climate-related growth variations. Some methods of standardization include the use of cubic splines, Regional Curve Standardization, negative exponential models, GAMMs, and more.

CLIMATE-GROWTH RELATIONSHIPS

Dendrochronological series are quantitatively associated to climate which can either positively or negatively impact radial growth. These relationships can be investigated using various methods, typically categorized into linear and nonlinear models. Linear models include correlation and response functions, whereas nonlinear models consist of options such as mixed models and neural networks.

Image 3. Seven different types of tree rings that can be found when analyzing tree cores under the microscope. Photo by E. Baby-Bouchard (2024)
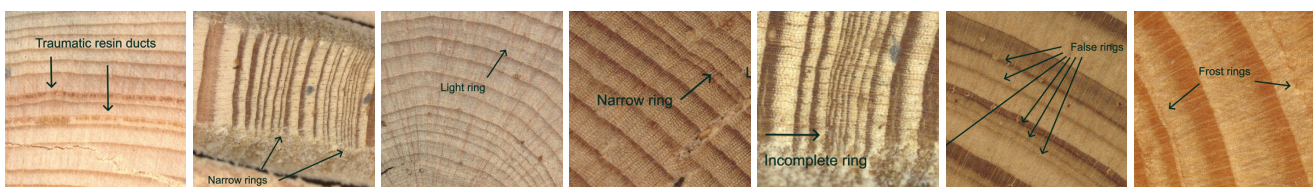
RECOMMENDED TOOLS FOR ANALYZING YOUR TREE RING DATA

RECOMMENDED SOFTWARE:

1. **ARSTAN** is a popular software program widely used in dendrochonology for standardizing tree-ring series and offers many options for detrending and modeling data, which is also helpful for climate reconstruction.
2. **COFECHA** is a common quality control program that helps to cross-date tree tree-ring measurements to verify accuracy and identify potential errors in the measurement series.
3. **DENDREOCLIM2002** is a package that can be used for climate-growth analysis. It calculates correlation and response functions to assess the relationship between tree-ring data and climate variables which are particularly useful when wanting to identify climatic factors that influence tree growth.

Image 4. Professor Alexandre Morin-Bernard examines a tree core taken in the field. Photo by S. Dumont (2024).

RECOMMENDED R PACKAGES:

1. **dplR -** includes functions for reading, processing and analyzing tree-ring data and can perform functions such as detrending, standardizing and cross-dating while also containing tools for climate-growth relationships and creating graphs of the data.
2. **Treeclim -** designed for dendroclimatological analyses in R to assess climate-growth relationships using correlation and response functions and visualize the response.
3. **TRADER -** detects and analyzes growth changes or anomalies in tree-ring data caused by abrupt growth changes caused by environmental disturbances or climatic events.
4. **Climwin -** analyzes the temporal windows where climate variables most strongly influence growth. This is helpful for identifying optimal time periods when the climate has the greatest impact on tree-ring formation and understanding seasonal climate effects.

GLOSSARY continued

- **Spline**: mathematical function used to fit a smoothed curve to a set of data points to isolate and analyze the climatic signal in the tree-ring data.

- **Ring width index (RWI)**: indexed measure of annual tree-ring width that accounts for age-related growth trends and other non-climatic factors. Observed ring width / expected ring width based on a growth model. RWI values provide a standardized representation of tree growth that highlights the influence of climatic variables to compare growth patterns across different trees and time periods.

- **Basal area increment (BAI):** measure of the increase in cross-sectional area of a tree trunk over a specific period (usually one year). BAI is calculated by converting tree-ring widths into corresponding increments of basal area. BAI is then used to assess tree growth dynamics, productivity and the influence of environmental factors on tree growth. By accounting for the increasing girth of the tree over time, it provides a more accurate representation of tree growth rather than tree-ring width alone.

APPLICATIONS TO SILVICULTURE

Dendroclimatology helps detect past climatic extremes such as droughts, floods and heatwaves. Understanding these events and trees' growth response allows forest managers to determine historical baseline response for different species. This information can guide them in identifying species that are the most resistant and resilient to changing climates and aid in making informed decisions about species selections for different climate regimes. This, in conjunction with monitoring long term future climate trends, can ensure adaptive forest management to maintain robust and healthy forests.

Image 5. M.Sc student Philippe Riel uses an increment borer to extract a tree core from a black spruce tree

SUGGESTED READINGS THAT USE TREE RINGS TO STUDY....

THE EFFECTS OF WARM TEMPERATURES:
- Girardin, M. P., Hogg, E. H., Bernier, P. Y., Kurz, W. A., Guo, X. J., and Cyr, G. (2016). Negative impacts of high temperatures on growth of black spruce forests intensify with the anticipated climate warming. Global Change Biology.

THE EFFECTS OF COLD TEMPERATURES:
- Girardin, M. P., Guo, X. J., Gervais, D., Metsaranta, J., Campbell, E. M., Arsenault, A., Isaac-Renton, M., & Hogg, E. H. (2022). Cold-season freeze frequency is a pervasive driver of subcontinental forest growth. Proceedings of the National Academy of Sciences.

GROWTH DECLINE:
- Payette, S., Fortin, M.-J., & Morneau, C. (1996). The recent sugar maple decline in southern Quebec: Probable causes deduced from tree rings. Canadian Journal of Forest Research.

THE EFFECTS OF THINNING:
- Wotherspoon, A.R., Duchesne, L., Barrette, M., Houle, D. (2022). Pre-commercial thinning could mitigate drought stress of black spruce stands. Forest Ecology and Management.

GROWTH, WITH REMOTE SENSING:
- Morin-Bernard, A., Achim, A., Coops, N.C., White, J. (2024). Integration of tree-ring data, Landsat time series, and ALS-derived topographic variables to quantify growth declines in black spruce. Forest Ecology and Management