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Mauri Timonen, Finnish Forest Research Institute (METLA)
Past, Present and Future Climate from Tree-Rings
→ Part 2: Chronology building
Past, Present and Future Climate
From Tree-Rings
Part 2: Chronology building
II

Tree-Ring Laboratory: Measurements, Dating and Building Tree-Ring Chronologies

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A view to the tree-ring laboratory in the Kolari Research Unit of Metla (Finnish Forest Research Institute). We have there two types of tree-ring measurement equipment: Finnish KS-KINSYS and German Rinntech (Lintab + Tsap) systems. A Finnish one in the picture.
Tree-ring samples (cores, cross-sections) can be measured directly through a stereomicroscope or observing the ring-widths from a video screen. Each annual ring (white + brown section or early wood + late wood) is measured separately. Sometimes it is difficult to distinguish the point where old growth ends and new growth begins. This happens especially when ring-widths are very narrow, just some hundreds of millemeters, or less!

This almost 500 years long measurement series was measured from a sample cored from an old living pine growing in Iso-Syöte, a small mountain 200 km south-east of Rovaniemi. Note the almost zero-value widths (vertical axis in millimeter scale).
The basic idea in dendrochronological tree-ring dating (cross-dating) is to study the corresponding tree-rings of specific years. June-July temperature is the well-known minimum factor of pine growth in Finnish Lapland. This rule and the fact that summers are not "brothers", makes it possible to create a barcode like graphics for marking the exceptional years of growth. This method, called Skeleton Plotting, is a tool that only needs a pencil, magnifying glass and millimeter scale paper. No measurements are needed! Creating a barcode figure based on the narrowest ring-widths in relation to the neighboring ones, and doing the same to a master chronology, provides a comparison that shows the exact dating. If the ring-width measurement data are available, the easiest way of dating is to use some special software (e.g. the ITRDB DPL program Cofecha, available at [http://www.ncdc.noaa.gov/paleo/treering.html](http://www.ncdc.noaa.gov/paleo/treering.html)). Check a cross-dating example at [http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm](http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm).
What do tree-rings tell about climate?
How do trees react to temperature and precipitation?

- Many aspects define how sensitive trees are to temperature and precipitation, e.g. species, site and geographical location.
- Scots pine in Finnish Lapland is sensitive only to temperature. This is not the case in Southern Finland, where also precipitation plays an important role.
- Growing season starts at the 5 °C threshold temperature. Which conditions affect exceeding the threshold?
  - Temperature in spring (beginning)
  - Temperature and precipitation in summer
  - Light in autumn (end)
  - Coldness and snow in winter

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Cold and warm summers fingerprint the tree-rings of Finnish Scots pine by narrower or wider tree-rings. These two pine lived around two thousand years ago in Lake Kompsojärvi, close to Raja-Jooseppi, Eastern Lapland.
Crossdating tree-ring series (black lines) make it possible to build year-exact chronologies. This time window covers an interesting period of 501 BC to around 1325 AD. Each line represents one tree-ring measurement series. Overlapping the series using a dendrochronological method called cross-dating make it possible to build thousands of years long tree-ring chronologies. To a dendrochronologist, this kind of basic statistics, including the RBAR (Correlation BAR) and the EPS ((Expressed Population Signal) values, the number of replications (N) and the graphics in itself, is a great source of tree-ring information.
How many samples are needed to build a reliable tree-ring chronology for dendroclimatic purposes? Many! Tree-ring index is a common climat e proximator. It is a stable and useful tool for many purposes in dendrochronology. A thumb of rule is to sample about 30 cores per site to get minimum statistical accuracy for the index estimate. Is this true? We can assume a 10% accuracy of index estimate at 95% probability level to be statistically adequate. Considering the tree-ring index of timberline Scots pine ($C_v=40\%$) 30 cores is not enough; it would give only about a 14.5% accuracy. If we sample only 10 cores, the index estimate error is huge: 25%. No sense to use such kind of noisy estimate to any statistical analysis! Our timberline index estimate requires least 64 samples ($C_v=40\%$).

### Sampling size as function of accuracy request and coefficient of variation (95\% level)

<table>
<thead>
<tr>
<th>Accuracy request</th>
<th>Inari ($C_v=40%$)</th>
<th>Paljakka ($C_v=34%$)</th>
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<tbody>
<tr>
<td>1.0</td>
<td>6400</td>
<td>4624</td>
</tr>
<tr>
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<td>2844</td>
<td>2055</td>
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<td>28.0</td>
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</tbody>
</table>

$$n = \frac{t^2 C_v^2}{p^2}$$

- $p$: accuracy request
- $n$: sampling size
- $t$: probability, $t(95\%) = 2$
- $C_v$: coefficient of variation

### Sampling size at Inari and Paljakka

$C_v$ for timberline tree-ring index: 40\%
V

Long Tree-Ring Chronologies

Finnish 7642-yr (2008) supra-long Scots pine chronology, high and medium frequency variation
Sirén’s 780-year Scots pine timberline tree-ring chronology (1181-1960 AD)
Metla’s 1911-year Scots pine timberline tree-ring chronology (86-1996 AD)
Metla’s first long tree-ring chronology

Kari Mielikäinen, Professor of Growth and Yield Studies in Metla, launched a new tree-ring research project called “Variation in Tree Growth” in 1994. One of its subprojects focused on building a Scots pine ring-width chronology from living trees, snags, old building logs and megafossils. We succeeded in creating a 1911 years long tree-ring calendar (Mielikäinen & al. 1998).


Some characteristics describing Metla’s 1911 years long ring-width chronology of Scots pine.
Growth variation of Scots pine on the Finnish timberline during the last Millennium

• SOME CONCLUSIONS

• Finnish chronologies of timberline Scots pine tell about more or less cyclicly changing June-July mean temperatures.

• In a 1000-yr time perspective, the growth variations of the 1900s do not significantly differ from the previous centuries.

• In comparison to the warm period of the early 1900s, at least ten equal warm climatic periods have appeared. Correspondingly, cool periods have followed the warm ones.

• The June-July mean temperature that controls pine ring-width growth in Northern Finland, has remained quite unchanged during the last 100 years.

• Special attention is paid to cyclicity in our Finnish tree-ring chronologies. Possible break-through would provide a tool for predicting future natural climate.

• According to Sirén (1961, 1996) regeneration of timberline forests in Finnish Lapland is strongly correlated to favourable climatic conditions. Based on his data of some well-known pine regeneration years and his tree-ring index, he connected good seed years to maximum tree-ring index peaks or periods.

• Note that these interpretations are based on high and medium frequency filtering on the data. Exposing longer climatic trends like Medieval Warm Period and Little Ice Age needs low-frequency filtering.
This regional figure of ring-width variations for Scots pine and Norway Spruce (minimum and maximum years of growth, or pointer years) in the 1900s, indicate increased distribution of pointer years both for pine in Northern Finland and spruce in Southern Finland. This refers to the principle of minimum factor in growth: temperature in the previous and precipitation in the latter case.
Metla’s 1911-yr tree-ring chronology

Exceptional years of growth (pointer years) usually are hypothesized to be signs of extreme climatic conditions. That is, however, not the case always, because any disturbance caused by internal (endogenous-local) or external (exogenous-standwide) events may be the real cause of the event.

Anyway, skilful data selection and data analysis, no doubt, expose also the climatic signals from such kind of ’noisy’ data. The enclosed graph is a good example showing how timberline Scots pine in Northern Finland reacts to climatic extremes.

The left side of the graph shows the high-frequency variation of Scots pine on the Finnish timberline. The pointer years presented on the right side of the graph describe the cold (blue) and warm (red) periods. We easily can observe, how warm and cold periods repeat from one time to another. This graph is, however, does not reveal the whole scale of climatic variations: longer (low-frequency) periods do not appear in this kind of approach. Thus we can not see e.g. Medieval Warm Period and Little Ice Age. We need to use other kinds of tools like ”Age Banding” and/or the RCS method”.

![Tree-ring index Pointer years](image)
The Flagship of Climate Sensitive Tree-Ring Chronologies: The Finnish 7641-yr timberline pine tree-ring chronology
How the Finnish long pine chronology was built?

A breakthrough in developing the Finnish timberline pine supra-long chronology was achieved in 1999, as the missing data for the about 200 years long ‘gap’ around 370 - 165 BC was finally found. The new data made it possible connect the “absolute” younger part of the chronology and the “floating” older part. If the gap problem did not exist, the chronology from the subfossil forest-limit pines of northern Finnish Lapland would have been completed already in 1994. Closing the gap was really a big issue, because the chronology become year exact, which is a unique characteristic among a wide variety of world-wide collected proxy data.

Thanks and honour for the existence of the Finnish supra-long tree-ring definitely belongs to Professor Matti Eronen, who, as early as in 1974, started his quarter-century run to finish his project. He first sampled tens of megafossils for radio carbon dating along the Finnish pine timberline.

A decade later, he launched, with his 60 radio carbon dated samples, a project for establishing a year exact Scots pine chronology for Northern Finland. He succeeded in arranging several research projects and was also very active in field work.

Metla’s role in developing the supra-long chronology was smaller, focusing on closing a gap between 350 BC and 170 BC. Professor Kari Mielikäinen launched in 1992 a five-year project called ‘Variation in Tree Growth). One of its sub-projects was “Building a long tree-ring chronology for Scots pine”. Metla was successful to build a 1911-yr timberline Scots pine chronology. Next step was taken in 1996, as Metla participated in a four-year and European-wide ADVANCE-10K project, led by Dr. Keith R. Briffa. Mauri Timonen led Metla’s part of the project and Eronen coordinated the Finnish part of the nine-country project.
Eronen with his team was successful in building a continuous pine chronology for the last two millennia, reaching 165 BC (Zetterberg & al. 1994, Eronen & al. 1996). The next step in his project was to extend the chronology backwards in time as far as possible. The task proved to be tricky. An over 5000 years long part of the chronology, starting about 5500 BC and ending about 370 BC (based C14-dating, accuracy 100 years), was relatively easy to build. Unfortunately there was a time period between those two subsets (about 370 BC - 166 BC) without no samples found. We named it ”the Gap”

The Gap surprisingly delayed finishing the Finnish supra-long chronology building by almost 10 years. Samples for this period on and beyond the present timberline simply seemed to be missing. The same problem was also encountered in the corresponding Swedish and Mid-European oak chronology construction.

Closing of the gap became a great challenge both in the Finnish and Swedish teams. We found some new material filling the both edges of the Gap, but samples crossing over the whole Gap did not show up.

Tauno Luosujärvi and a muddy subfossil finding that dates back to -5000 BC. Salla 2005.

Deer hunters cut this tree down by an axe about 2600 years ago. Käsivarsi Pättikkä 1997
The Gap Problem became again active in the four-year EU project called Advance-10K, started in. The aim in one of its subprojects was to complete the supralong Scots pine. Metla joined the Finnish part of the project led by professor Matti Eronen. We had now also a possibility to use licenced scubadivers of our own team!

In order to finally fill the Gap, we established two parallel plans: Eronen’s group continued working at the pine timberline and Metla’s group focusing on more southern locations.

The both groups concentrated on finding samples in and around the Gap period. More than 1500 samples were collected from over 40 lakes. But what was the result? Next to nothing found after the two first summers of sampling! Luckily the third summer was finally successful by granting some old samples matching the Gap and providing the missing link over the Gap. The lake was lake Kompsojärvi, close to Raja-Jooseppi. A sample, coded to KOM6, was excavated from deep mud. Dated to 379 –181 BC, it bridged nicely the continuous part (from the present to 231 BC and the radio carbon dated floating part (from 350 100 BC to 5500 BC 100). Another important sample in bridging the Gap was FIL6201 (512- 231 BC) that Eronen had unearhed many years earlier from Lake Aligasjärvi in Utsjoki. The gap was thus solved!

The proper dating of the Finnish chronology was tested by a Swedish sample around 400 BC. Håkan Grudd, the developer the Swedish over 7400-yr Tornetrask pine chronology, had a Wiggle match dating on it. To be a radio carbon dating, the accuracy of this type of dating, is amazing: in this case the dating error was only 8 years! Comparison of the results confirmed that the Finnish Gap, finally, was closed.

The present supralong chronology is a composite of 1487 samples. A major part of the data, about 75 %, was collected in the Silmu Project (Zetterberg et al. 1994, 1995, 1996) and in the Advance—10k-project (Eronen et al. 2000). The rest of the data, about 25 %, was provided by 1) Metla (from their 1911-yr Scots pine chronology for Finnish Lapland (Mielikäinen et.al. 1998) and 2) the Saima Group’s (Jouko Meriläinen, Markus Lindholm) 2000-yr pine chronology for Finnish Lapland (Lindholm et.al. 1999).
The Finnish supralong chronology is a mixture of many sources: living pines, snags, old buildings and subfossil wood excavated from lake bottoms and swamps.

The 7642-yr (length in 2008) Finnish supralong timberline pine chronology possibly reaches the first pine forest generations appeared after the last glacial. This time series is the third longest year exact tree-ring chronology in the whole world. The longer ones are the Mid-European Oak chronology and the North American Bristlecone pine chronology.

In addition to the year accuracy, the Finnish supralong chronology is very climate sensitive. It means e.g. high correlation between ring-width and mean temperature of June-July. Considering in terms of wood density, Finnish Timberline pine records past climate even at April-October level!

The Gulf stream affects strongly to the Finnish climate. That is why it is a natural phenomenon that also timberline pines react to this phenomenon. There is e.g. statistically a significant correlation between ring-width and the NAO (North Atlantic Oscillations) index. This characteristic has made the Scots timberline pine from Northern Finland important also in the global scale climate change research.

Reference:

The statistical RBAR (Correlation bar) and EPS (Expressed population Signal) values are commonly used tools for estimating data quality, sufficiency and compatibility. The RBAR value (black line) shows the average correlation of all tree-ring series in the chronology. The EPS value (red line) tells whether sampling level is adequate. It should exceed a threshold value (red line) of 0.85 (dash line) for statistically acceptable minimum data compatibility. The "Gap", a time period between 370 and 170 BC, separated by two vertical lines.
This example data from lake Koierijärvi and Riekkovaara, close to the Saariselkä recreation area, demonstrates a regional sample distribution by calendar year. These data cover continuously a 1300-yr period for building a continuous tree-ring chronology. The EPS values, however, do not exceed the acceptable minimum level of 0.85, which suggests further sampling. At least five observations per calendar year should be sampled, and even a lot more, if aiming at dendroclimatic analyses.
These sites were investigated in the EU funded ADVANCE-10K Project.
SOME DETAILS:

Ring width:
- range 0.3 … 1.5 mm, on the average 0.6 mm

Index
- Scale for tree-ring indices: 50-150.
- Minimum and maximum values (pointer years) indicate cooler and warmer years (most likely abrupt changes in the June-July temperatures).

Number of replications
- Number of replications vary considerably: range here 8 – 60
- Difficult periods to find samples: 4400 BC, 3200 BC, 2050 BC, 600 – 100 BC, 80 AD

EPS
- Still some weakly replicated periods, e.g. 4400 BC, 2050 BC, 600 BC, 300 BC and 100 BC (compare to Number of Replications!)

RBAR
- Calculated in 21-yr windows
- Correlation between series on the average : 0.4

StDev Ind
- Standard deviation of index 20 – 40 %.

StErr Ind
- Standard error of index 5 -10 %

Download:
Data of the figure (5520 BC – 1997 AD) at http://lustiag.pp.fi/data/Advance/adv10sf1.exz
Non-standardized ring-width averages (green line) do not fit well in dendroclimatic analyses. Averaged ring-widths samples with different biological growth rhythms, i.e. starting from juvenile increasing growth, reaching maximum growth and finally turning to decreasing growth, cause false trends thus confusing climatic conclusions. These trends have to be removed from ring-widths using a procedure called standardization. Standardized values, or tree-ring indices, work much better, but still a lot of researcher’s skills are needed to make the right conclusions.
Other tree-ring chronologies: Chronology of living timberline pines
• Shows the typical high and medium frequency climatic variation observed in all climatically sensitive data sets at the Finnish timberline pine
• Generally can be said: warmer and cooler periods follow each other.
• Interesting conclusion: most of tree-growth in the 1900s shows a descending trend or no trend. The only warming trends took place in the 1910s-1920s and 1990s-2000s.
• The most recent growth level (index ca. 110) is clearly less than that of the 1930s (index 125).
• Ring-width index of Finnish timberline pine is closely related to June-July mean temperatures ➔