Faculty of Science

Dendrochronological investigations of forest fire, tree ring growth and climate west of Puostijärvi lake, northern Sweden

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Degree of Bachelor of Science
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Abstract

How trees respond to climatic factors such as temperature and precipitation is well documented but can be locally different when other factors play a part in the process. Forest fires have had a large influence in boreal zones around the world and in the boreal zone in Sweden where the study area between Överkalix and Övertorneå is located. The methods inherent to dendrochronology are adapted in this thesis to answer how climatic factors and forest fires influence tree growth and to build three chronologies. 26 samples were used to create a chronology without fire scars spanning the years 1352 - 1983 and a total of 9 samples for the fire scar chronology with documented fires spanning between the years 1567 - 1922. The use of TSAPWin and COFECHA softwares for measuring and dating the samples was implemented with further analyses using a Pearson correlation and a first difference estimator for climate correlation and superposed epoch analysis used in ring width and fire scar variance to examine changes in growth after and before a fire event. The resulting chronology without fire scars showed statistical detectable results while five fires had confirmed matching years dated. Running the statistical analyses presented no significant correlation, not against climatic factors or effected growth patterns in relation to fire event years. The results presented in this study does however show that more research in the field is necessary and that a multitude of factors could influence tree growth locally making it difficult to pinpoint a single limiting factor.

Keywords: Dendrochronology, climate, forest fires, superposed epoch analysis, climate correlation

Sammanfattning

Hur träd reagerar på olika klimatfaktorer som temperatur och nederbörd är väl dokumenterat, dessa kan dock skilja sig lokalt där flertalet andra faktorer kan spela roll. Skogsbränder har tidigare haft stor påverkan i boreala områden runt om i världen, likt det området mellan Överkalix och Övertorneå denna uppsats undersöker. De grundläggande principer och tekniker inom dendrokronologi används i denna uppsats och anpassas för att undersöka frågeställningarna kring skogsbränders påverkan på trädringar och för att bygga de kronologier som används. 26 prover användes för att bygga en kronologi utan brandljud mellan åren 1352 - 1983 och 9 prover för att bygga en med bränder från 1567 - 1922. Programvaror som TSAPWin och COFECHA användes för att mäta och korsdatera proverna. Ytterligare användes Pearsons korrelation och första skillnadestimator för att undersöka klimatkorrelationer och en superposed epoch analysis för att undersöka varians på trädringar till följd av skogsbränder innan och efter en skogsbrand. Kronologin utan brandljud visade statistiskt goda resultat i TSAPWin och fem daterade brandljud matchade med tidigare dokumenterade bränder. De statistiska analyserna påvisade ingen signifikant relation, varken till klimatfaktorer eller tillväxtmönster i relation till skogsbränder. Resultaten understryker dock möjligheten till ytterligare studier i området då flertalet faktorer influerar den lokala tillväxtgraden av träd, vilket gör det svårt att bestämma enbart en faktor av vikt.

Nyckelord: Dendrokronologi, klimat, skogsbränder, superposed epoch analysis, klimatkorrelation

Preface

This is a Bachelor's thesis in Geography, carried out at the Department of Earth Sciences, University of Gothenburg during the spring of 2022.

A big thank you goes out to our supervisor Professor Hans Linderholm who through his long experience and great expertise have been of the utmost assistance and support throughout the project. Another big thank you goes out to our second supervisor Doctor Mauricio Fuentes, who has spent long and patient hours with us in the lab introducing and helping us in our first steps in the field of dendrochronology. A final thank you goes to the course leader Professor Sofia Thorsson and our classmates for invaluable support and feedback both at the scheduled seminar opportunities and outside. Without the support of these groups of people this bachelor's thesis would not be nearly what it is today.

Table of contents

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2018) states with high confidence that global temperatures will exceed pre-industrial temperature by 1.5°C between 2030 and 2052. The anthropogenic emissions already emitted are likely to persist and affect the global climate systems for centuries to millennia. These changes are projected to increase several climate extremes such as extreme heat and an increased probability of droughts. Even at 1.5°C warming changes in ecosystems and biodiversity are also projected to increase bringing related risks such as forest fires with it.

Forest fires have historically been one of the large influences of forests in boreal zones such as Sweden, creating changes in biodiversity, forest dynamics and further increasing greenhouse gasses and aerosols in the atmosphere. The northern hemisphere's forest fires are still primarily driven and influenced by climatic factors which is evident by recent dry summers in Sweden such as 1992, 2002, 2008, 2014 and 2018 with a high frequency of forest fires (Drobyshev, Niklasson & Linderholm, 2012; Lidskog & Sjödin, 2015; Krikken, Lehner, Haustein, Drobyshev & van Oldenborg, 2018). A previous study showed how the combination of positive temperature anomalies and negative precipitation anomalies were evident in large fire years in northern Scandinavia (Drobyshev, 2014). With human deaths caused by forest fires exceeding 10.000 individuals annually and globally, particulate matter spreading from fires affecting respiratory health among elders and negative impacts on water availability, creating a greater understanding of forest fires interactions could help mitigate issues such as these (Tošić, 2019; George, 2014; Dai, Aipassa, Kustiawan & Kaisman, 2020).

Trees can play a vital part when it comes to understanding the connection between climate and forest fires. Trees store historical data of how and when fires have spread, in what conditions fires are prone to happen and its influence on the local ecosystems. This thesis aims to with dendrochronological methods examine the relationship between forest fires, temperature and precipitation while also examining how forest fires influence the growth rate of trees (Brown, 2013). With the projections of changes in temperature and precipitation a greater understanding of its influence on fire probability and its dire consequences could further motivate action against climate change.

2. Aim

The purpose of this thesis was to assess how the occurrence of forest fires relates to the climatic conditions west of Puostijärvi lake, Norrbotten, Lappland in northern Sweden. This was done through dendrochronological and statistical methods. Further the thesis examined how forest fires influence tree ring growth and how this could affect dendrochronological studies. This will aid in the understanding of how temperature and precipitation influences forest fire occurrence historically and if forest fires could create undetected errors in the field of dendrochronology.

3. Questions at issue

- How would a general chronology and a chronology containing fire scars look in the selected study area?
- How is the relationship between tree growth and climate variables such as temperature and precipitation?
- Can changes in tree growth caused by fires be detectable with dendrochronological methods in the local chronology of Puostijärvi lake.

4. Theory

4.1 Dendrochronology and its basic principles and concepts

Dendrochronology derives from the Greek language where *dendro* means tree and *chronology* refers to the study of time (Speer, 2012, p. 1). Dendrochronology is the scientific method of analyzing tree-rings for dating and works by looking at the patterns found in the tree-rings. This is known as tree-ring dating (Cormack, Haldon, & Jeffreys, 2012). This is made possible due to the ability of trees to constantly record in their growth patterns effects of growth - limiting factors and environmental conditions (Speer, 2012, p. 1-3). It is however important to highlight the fact that these applications only work with trees having annual growth rings, making the method geographically limited (Cormack, Haldon, & Jeffreys, 2012). To be able to analyze these factors several basic principles are followed by dendrochronologists. One of these is the principle of limiting factors, this principle states that it is the limiting environmental factor that controls the growth of the organism. It is due to this that information on different environmental variables can be extracted and analyzed from tree samples. This also means that the variable that can be extracted is dependent on the trees geographical location, for example trees in an arid climate zone would record historic precipitation. Another fundamental principle is that of crossdating which is a technique making the science of dendrochronology possible. Crossdating uses the various widths related to the tree growth in the area, trees with the same pattern indicate similar growth during the same period which can be used to match the patterns of different samples and establish an absolute date to every year ring and to find errors such as missing rings. This can be done through many different methods ranging from a more manual and analog approach to digital and statistical methods (Speer, 2012, p. 11-17).

After dating the tree samples through the method of crossdating another important concept comes into play; the concept of standardization. Standardization is applied to remove age-related growth trends, where a tree usually forms wider rings due to the lower diameter of the tree trunk in its early years, this is done to be able to study other influences such as climate. One of the more common and also most conservative methods is the application of a negative exponential curve (Speer, 2012, p. 23-27).

4.2 Tree ring formation and anomalies

Conifer trees that are growing in seasonal climates that limit growth and enable the production of tree rings usually have two different types of growth in a yearly ring, early and late season growth that are referred to as earlywood and latewood. Most tree types with the exception of monocots (for example palms) produce one ring per year where the earlywood usually forms during spring and early summer and the latewood during late summer, although this somewhat changes depending on the geographic location. The earlywood is characterized by cells that have a larger space inside of the cell wall (larger lumen) while the latewood has a more compact lumen and also appears darker in color due to its smaller lumen and thicker cell walls, the difference can be seen on figure 1.

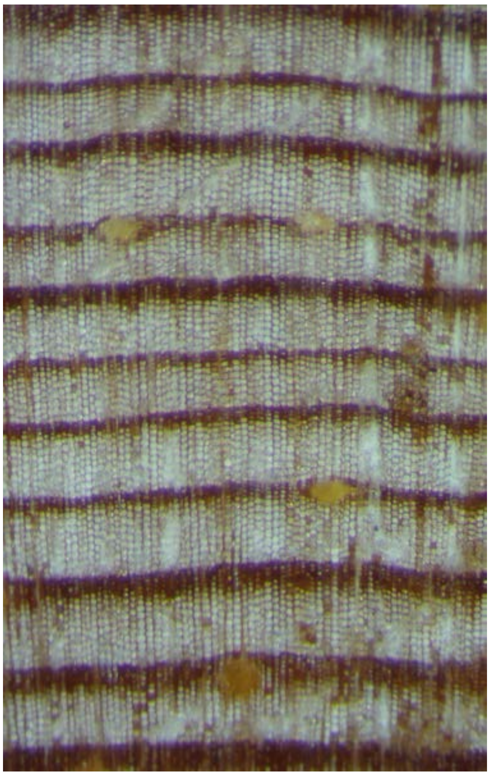


Figure 1. Section of a wood sample of Pinus sylvestris visualizing earlywood and latewood. Earlywood being the lighter areas with a larger lumen and thinner cell walls. Latewood being the darker areas with smaller lumen and thicker cell walls. One earlywood and one latewood is one year of tree growth.
(Photo: Erik Janvik Kardell & Tobias Roslund).

Figur 1. Visualisering av vårved och höstved från ett prov av Pinus sylvestris. Vårveden är det ljusa området med större lumen och tunnare cellväggar medans den mörka delen är höstveden med mindre lumen och tjockare cellväggar. En vårved och höstved indikerar ett år. (Foto: Erik Janvik Kardell & Tobias Roslund).

Tree rings are not always as clear and visible as seen in figure 1 since the tree growth can be affected by several environmental factors. For example the location of the tree affects how the rings form. When situated on a sloping surface the trees produce something called reaction wood where the pith of the tree is displaced due to trees forming either compression or tension wood to try and keep the tree growing straight. Other, more climate induced anomalies can also appear such as micro rings, diffuse ring boundaries, false rings, frost rings and missing rings. Micro rings are very small rings where the latewood and earlywood are only one cell wide each, these can easily be missed without a very well sanded sample, high-resolution measuring and other proper samples to compare with. A false ring is somewhat the opposite where the tree experiences a period of limiting growth and forms a ring during the normal growing period, then returning to favorable growth conditions continuing the normal growth. Frost rings can form in the higher latitudes, for example where the samples for this thesis have been collected and form when the temperature drops below 0°C during a growing season (Speer, 2012, p. 43-48). Missing rings occur in unfavorable conditions such as droughts or very cold summers, where trees may not form a year ring through the whole perimeter of the tree, while discontinuous or partial rings are not completely formed rings such as in the one ring dividing into two separate in figure 2 (Lorimer, Dahir & Singer, 1999).

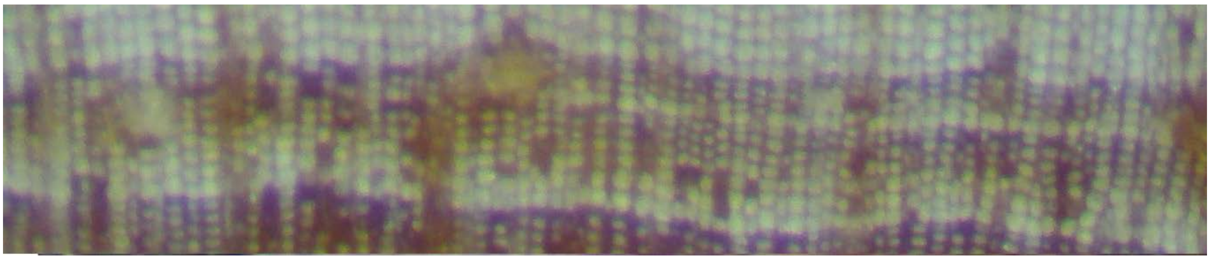


Figure 2: A partial ring in a sample of Pinus sylvestris where it looks like a single ring on the left which emerges into two rings on the right side. (Photo: Erik Janvik Kardell & Tobias Roslund).

Figure 2: En partiell ring från ett prov av Pinus sylvestris där det på den vänstra sidan ser ut som en ring men där den delas till två ringar på höger sida. (Foto: Erik Janvik Kardell & Tobias Roslund).

4.3. Dendrochronological applications

Dendrochronology has a wide array of different fields of study with several different applications. Such as, to study the impact of industrial pollution on the surrounding environment (Cook & Kairiukstis 1992, p. 11) and reconstructing fire history and influencing forest management practices (McEwan, Hutchinson, Ford & McCarthy, 2007). In this subchapter the two subdisciplines that will be used in this thesis are presented; dendroclimatology and dendropyrochronology.

4.3.1 Dendroclimatology

The use of tree rings to analyze and reconstruct the climate is called dendroclimatology. Climatic events influence the growth of the trees across different scales, both temporal and spatial. Doing so affects both the width and the physical and chemical composition of tree rings. Examples of climatic influences are variations in rainfall, temperature and wind (Speer, 2012, p. 174). To find these climatic influences dendroclimatologists removes the biological age-trends of the trees to ideally retain only the climatic influences, this can then be compared to climate data month by month to find the highest correlation. By doing this dendroclimatologists identify which climate factor influences the tree growth the tree at it most and reconstruct this climate variable back in time (Linderholm et al. 2014). It is therefore possible to reconstruct climatic factors such as moisture availability, temperature patterns and rainfall distribution among others (Sheppard, 2010; He et al. 2019).

4.3.2 Dendropyrochronology

Dendrochronology as a tool to reconstruct and analyze fires is called dendropyrochronology. A fire-prone landscape has a variety of features that provides clues for the fire regime in the area which can be examined through trees and tree ring morphology and then determining the range of variance. For example by describing past occurrences of fires, the frequency or the magnitude of fires. By using dendrochronology in this way, it is possible for forest managers to look at how fires have changed in the area (Speer, 2012, p. 194). Generally speaking there are three types of different fires that occur; *surface fire, stand replacing fires and ground fire*. Two of these types, surface fires and stand replacing fires are of relevance in this study. Surface fires burn across the ground surface sweeping through an area relatively quickly with a fairly low intensity and severity. Stand replacing fires are less frequent and occur in areas with an abundance of fuel often resulting in a high tree mortality, these types of fires are often referred to as *crown fires* due to its nature of burning through the canopy of trees (Speer, 2012, p. 194-195). The high temperature occurring during a fire event kills off the cambium layer of the wood. This leads to the living cambium from either part of the damaged area to grow quickly to cover the injury and sealing the scar (Speer, 2012, p. 49), leading to the distinctive look of a fire scar as seen in figure 3.

Figure 3: Example of a fire scar in a sample of Pinus sylvestris. (Photo: Erik Janvik Kardell & Tobias Roslund).
Figur 3: Ett exempel av ett brandljud i prov av Pinus sylvestris. (Foto: Erik Janvik Kardell & Tobias Roslund).

4.4 Factors influencing forest fire probability

Fire regimes are driven by a variety of environmental factors such as air temperature, precipitation, droughts, relative humidity and wind (Tošić, 2019) and have different components such as fire intensity and seasonality. Fire intensity can vary depending on for example topography and type of vegetation in the area while seasonality affects intensity due to the difference in the vegetation cover content during different seasons (Flannigan, Stocks & Wotton, 2000). This thesis focuses on air temperature and precipitation but acknowledges the importance of the other mentioned variables and the opening for further potential research. These two factors influence both the events of droughts and the relative humidity. Further, temperature and precipitation influence the availability of vegatative cover which serves as fuel during a forest fire. Živanović et al. (2020) argues that increased temperatures can increase presence of certain diseases in vegetation which could increase their susceptibility to forest fires.

5. Study area

The study area is located between Överkalix and Övertorneå, Norrbotten, Lappland in northern Sweden (66,361930°N, 23,269370°E), the specific location can be seen in figure 4.

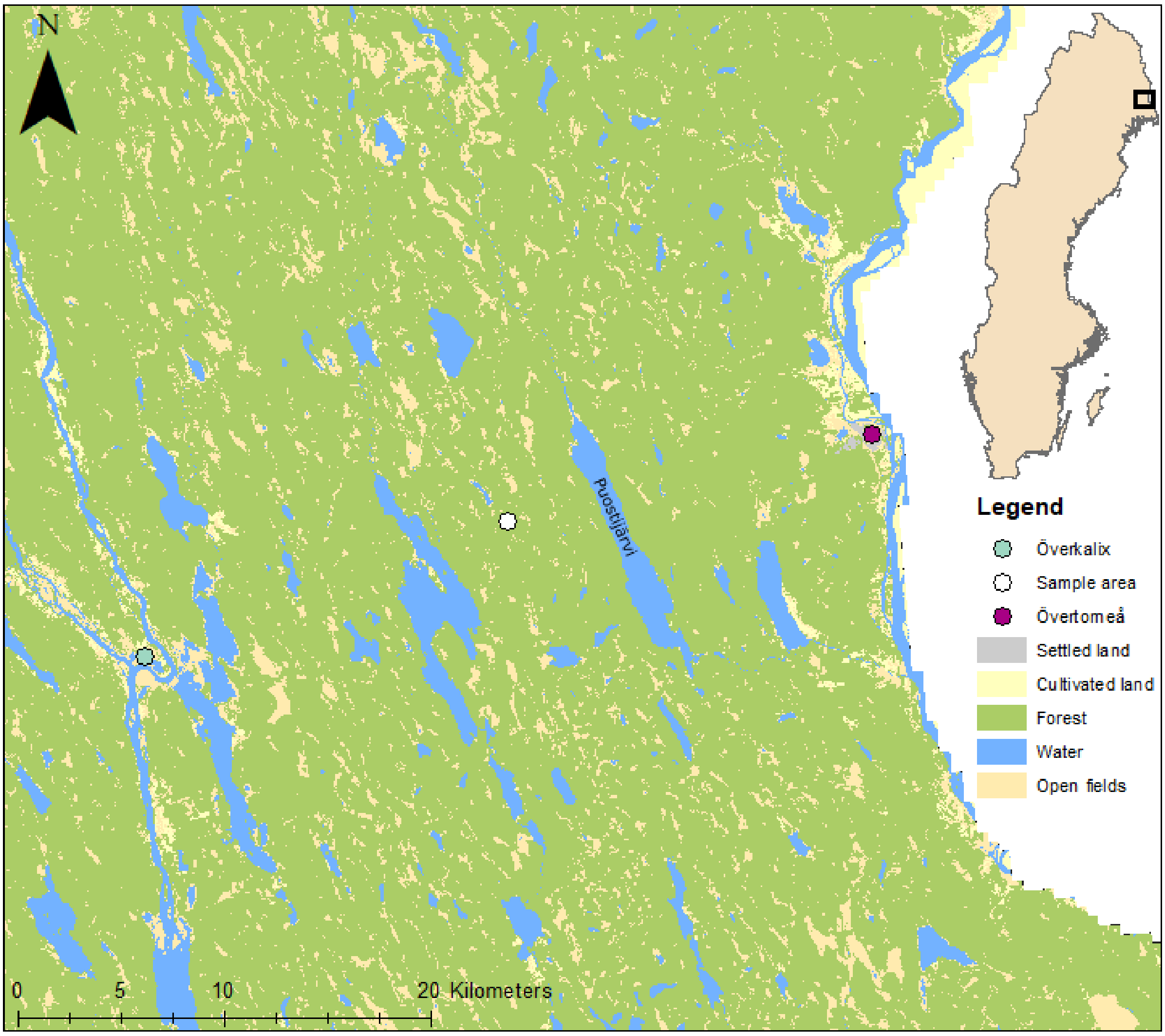


Figure 4. Sample area (ArcGIS. Lantmäteriet, Property map Land data. DIVA-GIS, Administrative areas).
Figur 4. Provområde (ArcGIS. Lantmäteriet, Fastighetskarta Markdata. DIVA-GIS, Administrative areas).

The study area is located in a boreal climate zone (Blennow, 2012) or more specifically in Köppens Dfc zone which constitutes a subarctic zone with cold winters and cool summers (Peel, Finlayson & McMahon, 2007; Rubel, Brugger, Haslinger & Auer, 2016). The average temperature in Övertorneå (Station number: 173810*)* recorded by Sveriges meteorologiska och hydrologiska institut (SMHI, n.d) during the last century was 0.94°C. The monthly average temperature and precipitation over Övertorneå is visualized in figure 5 showing high spikes in both temperature and precipitation during July and August and lower temperatures during December, January and February. The temperature and precipitation follow each other somewhat throughout the year with the highest temperature being in July and the most precipitation in August. Low points are further apart but still close to each other with the lowest temperature being seen in January and the least precipitation being in March.

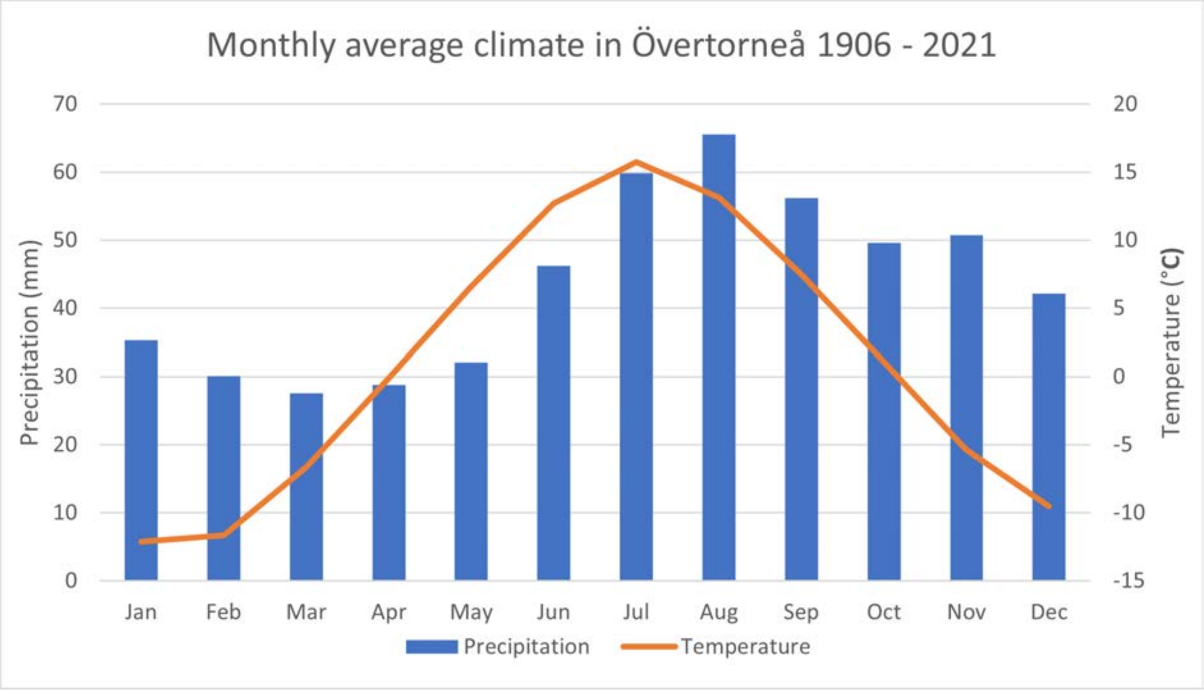


Figure 5. Climograph showing average temperature and precipitation in Övertorneå between the years 1906-2021 (Data: SMHI. Climate station number: 173810).

Figur 5. Klimograf som visar medeltemperatur och nederbörd i Övertorneå mellan åren 1906-2021 (Data: SMHI. Klimatstationsnummer: 173810).

Aforementioned area has a yearly average precipitation of around 520 mm and a growth period of approximately 150 days with average temperatures above 3°C (Engelmark, Hofgaard & Arnborg, 1998). Forests in the area are hosts of several different tree species with the dominant one being *Pinus sylvestris* (Scots pine) but also containing sparse amounts of both *Picea abies* (Norway spruce) and *Betula pubescens* (downy birch) (Engelmark, Hofgaard & Arnborg, 1998). These different tree species are and have been subject to different types of use with modern forestry mainly consisting of clear cutting. Studies conducted through the use of historical aerial photos show that this is true throughout history as well, where 10% of forests in northern Sweden were clear-cut by the early 1900s and increasing from there on (Lundmark, Östlund & Josefsson, 2021). Going further back using carbon dating, evidence shows the use of human induced fires for clearing forested areas as far back as 300 - 600 years ago (DeLuca, Zackrisson, Bergman & Hörnberg, 2013). Looking at more recent land use practices in the area, a more industrialized forestry and a larger usage of herbicides can be seen starting in 1948. This is believed to have still lasting ecological effects but needs more research (Östlund, Laestander, Aurell & Hörnberg, 2022). Historically the study area has been subject to forest fires which is shown both in literature and will be further presented in the results. Previous studies by Sjöström & Granström (2020) on forest fires in the area suggest that it is not subject to frequent forest fires when compared to other parts of Sweden but the forest fires that do occur tend to be more severe and cover a larger area than other parts of Sweden. Statistics also show that the amount of forest fires per capita is over-represented in the study area being about 70-90% higher than the rest of Sweden (Sjöström & Granström, 2020). Moreover, the Swedish civil contingency agency (2013) forecast increases of forest fires in the study area, showing higher likelihood in all three researched categories. Longer forest fire season, higher frequency and longer periods of high risk.

6. Methods

The thesis focuses on quantitative methods in the form of dendrochronology and statistical analysis. Literature has provided this thesis with a historical perspective of previous research as well as information of results, conclusions of similar studies done and been a guidance in relevant variables related to the issues at hand. The choice of dendrochronology is based on the absolute dating and wide use of the method. Generally where trees grow with the presence of annual growth rings these can be accurately dated (Pearson, Leavitt, Kromer, Solanki & Usoskin, 2021). Furthermore dendrochronology can analyze existing climate data and provide the tools for reconstring climate before existing records on many different timescales (Martinelli, 2004) as well as dating of historical forest fires before any written record exists. This combination of available data to be gathered through dendrochronological methods can provide an understanding of forest fires today through analysis of the climatological prerequisites impacting fire occurrence (Pinto, Niklasson, Ryzhkova & Drobyshev, 2020).

The following statistical analysis was chosen, a Pearson correlation and first difference estimator with the purpose of uncovering any correlations between climate and the created chronologies. Secondly, analysis of fires impact on tree ring growth is to be conducted, this was done through a superposed epoch analysis. A superposed epoch analysis is used to analyze anomalies before and after an event with a known date (Gillner, Bräuning & Roloff, 2014). The method has further been used by others looking at climate variables and forest fires, such as the work by Sàenz-Ceja & Pèrez-Salicrup (2019). Stephens et al. (2013) claimed how forest fires are not just dependent on the climate the year of the event but also climate factors in the years prior which further motivates the choice.

6.1 Tree-ring data

The tree samples used in this study have been provided by the University of Gothenburg and no field work has been conducted. The samples have been collected by Doctor Mauricio Fuentes west of lake Puostijärvi between the two villages of Överkalix and Övertorneå, prior to our initiation into the world of dendrochronological study. Although the samples have not been collected by us, they are unexplored and unprocessed and will provide new data for this thesis. The dendrochronological methods used are presented from start to finish below.

6.1.1 Sampling and sample preparation

Unprocessed tree-disks of *pinus sylvestris* were provided by our supervisors, and were of varied quality and not collected with fire scars in mind. The first step was to explore the samples, the nature of the thesis involving forest fires demanded certain qualities in the samples; the presence of fire scars. Firstly the samples were visually inspected and a table was created in Excel with the following parameters; amount of internal fire scars and presence of external fire damage. The samples were after this divided into the samples containing internal fire damage and the samples which did not. This was done to facilitate the creation of the two separate chronologies, one without fire scars and one with, and it also made it easier to work with and keep track of all the samples.

After inspection and classification (scars/ no scars) a total of 90 samples were sanded in a sanding machine to make the tree rings more clearly visible and remove any minor potential damage done during the sampling for easier measuring and crossdating later, of these 35 ended up being used. During this step it was important to visually examine the samples and decide which part of the samples to work with. This relates to the fact that not all of the samples were uniform, and more severely damaged parts and segments on a specific sample were decided not to be sanded, for example areas with deep cuts or cracks. A choice made to streamline the process and to save time without compromising the results. The samples were later sanded in a radius by hand with gradually finer sandpaper starting with P120 all the way up to P800 (P120, P240, P320, P400, P600 and P800) in the segment where measuring was intended to achieve visibility of the trees anatomical features. Sanding the samples to expose the cells was important when measuring to find the right angle and providing better visibility of the cells to get a more precise measuring result. A comparison between a non-sanded sample and a sanded sample can be seen below in figure 6 where a) is the non-sanded and b) is the sanded.

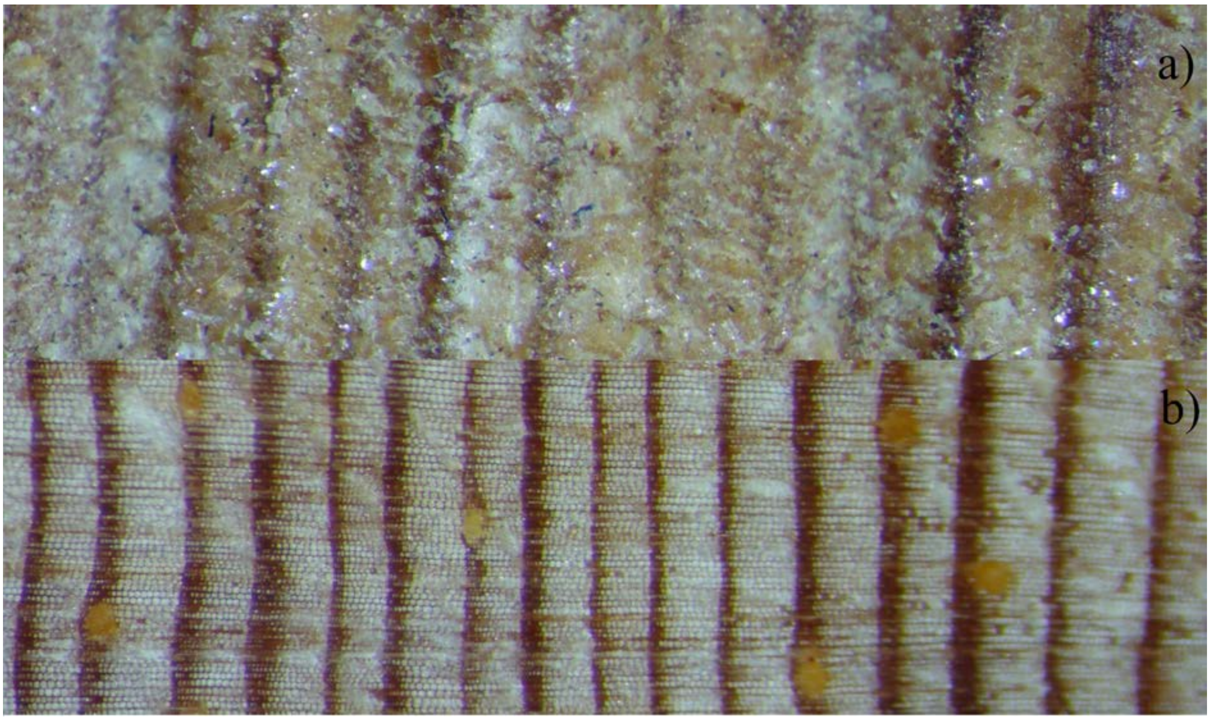


Figure 6. Showing the difference between a sanded sample of Pinus sylvestris and a non-sanded sample, a) being the non-sanded and b) being the sanded. (Photo: Erik Janvik Kardell & Tobias Roslund).
Figur 6. Visar skillnaden mellan ett slipat och icke slipat prov av Pinus sylvestris, a) visar det icke slipade och b) visar det slipade. (Foto: Erik Janvik Kardell & Tobias Roslund).

To class the fire scars which on first inspection was hard to categorize, further inspection was conducted with a microscope on selected tree samples. To be consistent in identifying the fire scars and separating them from other damages present in the tree, four demands were sourced from an article by McBride (1983, p. 57) first presented by Rowe et al. (1974) which can be seen below where at least three had to be fulfilled.

1. " Elongated or triangular in shape. The broadest part of the scar is usually at the base linkof the trunk.
2. Black charcoal flecks occur on the adjacent bark (first burns) and in the exposed scar wood (second and subsequent burns).
3. When viewed in cross -section, ring width usually increases or decreases dramatically immediately after a fire has occurred.
4. In cross-sections a black crust can be seen on scar margins, marking the outer margin of the annual ring which was formed in the year in which the fire took place"

6.1.2 Measuring and crossdating

The first step in measuring the sample was to draw a straight line with a pencil through the sanded area, trying to hit as many rings perpendicularly as possible. This worked as a reference line in the next step and allowed easier navigation when using the microscope. Next it was time to mark out every ring corresponding to decades, half-centuries and centuries with the following marking; one dot for every decade, two for a half-century and three dots for each century. These markings were done on the samples seen in figure 7, using the line as a guide, with a graphite pencil. This was done to further down the line facilitate where on the sample a certain year (ring) was located making it easier to quickly go back on the sample and visually examine interesting years.

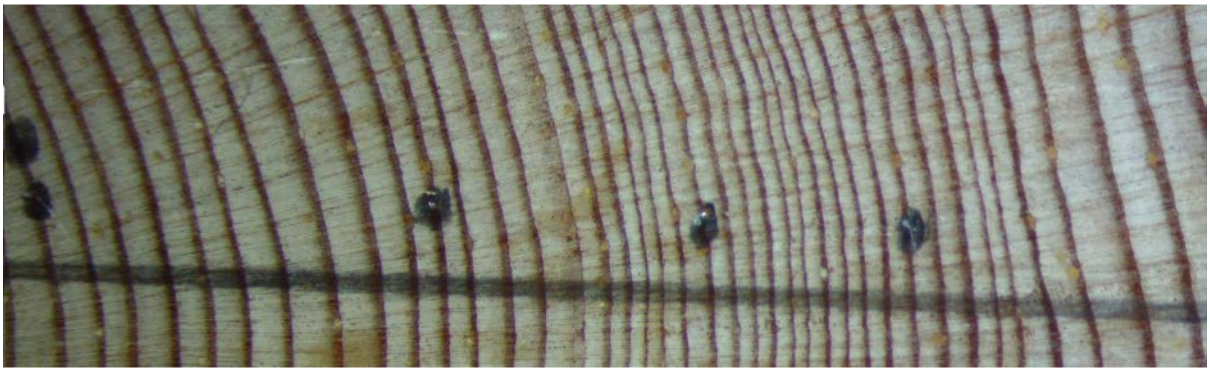
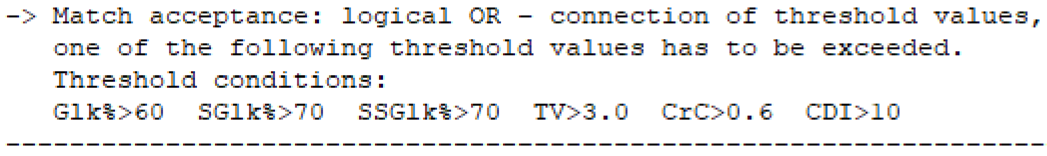


Figure 7: Showing the markings done for easier navigation a sample of Pinus sylvestris. (Photo: Erik Janvik Kardell & Tobias Roslund).

Figur 7: Visar markeringarna som gjorde för enklare navigation i ett prov från Pinus sylvestris. (Foto: Erik Janvik Kardell & Tobias Roslund).

Following step in the process was to count each ring and to measure its width, this was done in the program TSAPWin and with the LinTab version 5 and 6 measuring table. TSAPWin is a computer software program used to analyze tree rings and works in tandem with the LinTab measuring tool in order to allow the user to plot the time series and perform statistical analysis mentioned in the following sections (Heidelberg, 2011). Before starting to measure, a few things had to be decided. Apart from some general settings in the TSAPWin software, a decision in which end to start had to be made, the pith or the bark, where bark to pith was chosen.

The method of crossdating is used to analyze ring width patterns and to synchronize them. TSAPWin software was used for crossdating in this thesis, where tree-ring patterns are matched against a master chronology to date the samples used in this thesis. The software works by displaying the width of tree rings in line graphs, running a synchrony test for each of the rings and combining measurements of ring widths (Chan, Hu, Lin & Fujimoto, 2013). In total, 35 samples were used for chronology building and crossdating, 26 samples for the chronology without fire scars which hereafter will be specified as the KYLT chronology and nine samples for the chronology containing fire scars. The Torneträsk chronology located about 300 kilometers from the study area acting as the reference chronology with which the samples and chronologies were compared to (Grudd, 2008). If any errors were found, these were adjusted accordingly when possible by visual crossdating (Heidelberg, 2011). The statistical crossdating procedure used a number of tests which provided a number of parameters shown in figure 8.



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-> Match acceptance: logical OR - connection of threshold values,
   one of the following threshold values has to be exceeded.
   Threshold conditions:
   Glk%>60  SGlk%>70  SSGlk%>70  TV>3.0  CrC>0.6  CDI>10
-----------------------------------------------------------------
```

Figure 8: Correlation parameters and threshold values for comparison between chronologies.

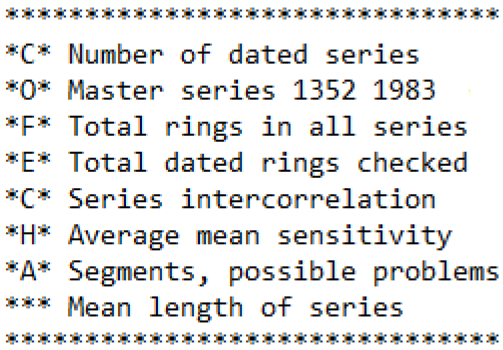
Figure 8: Korrelationsparametrar och tröskelvärde för jämförelse mellan kronologier.

The chronology from Torneträsk was used as a reference and six different parameters were taken into consideration when crossdating. **Gleichlaeufigkeit (Glk%)** also called the sign test, “calculating the sum of the equal slope intervals in %”. **Signature Gleichlaeufigkeit (SGlk.)** “sum of equal slope intervals in %, calculated referring to chronology signature years only”. **Signature-signature Gleichlaeufigkeit (SSGlk)** “ Sample = Chronology, Reference = chronology”. **T-value (TV)** “standard t-value”. **Cross correlation (CrC)** “Standard cross-correlation, range: -1…1”. **Cross date index (CDI)** “Date index, combined from t-values and Gleichlaeufigkeit, max=1.000”. The quality of crossdating between two time series uses the concepts; Gleichlaeufigkeit and/or t-value (Heidelberg, 2011). Gleichlaeufigkeit visualizes how well two series line up against each other looking at if the two chronologies decrease or increase in growth at the same time (Speer, 2012, pp. 107). The t-value parameter is more sensitive to extreme values, for example years with an event. Combining these two parameters results in the **Cross date index (CDI)** which is a very useful and powerful parameter (Heidelberg, 2011).

When building the fire scar chronology similar methods to the KYLT chronology was used, but another useful tool could be deployed here, crossdating known historical fires in the area. So in addition to using the TSAP and COFECHA statistics and visual inspection, a list of fires was compared. Here previously documented fires in the area could be used to further be sure that the statistical dating of the trees were correct.

6.1.3 Quality control and standardization - COFECHA & DplR

For quality controlling the measurements and crossdating the computer program COFECHA was used. COFECHA generates statistical data which then has to be analyzed, visually confirmed and altered in the tree samples if necessary. For example by finding possible missing, partial or false rings. The sample might also have to be remeasured. Figure 9 shows a summary of the statistics produced in cofecha, series intercorrelation (*C*) being one of the most important indicating how well the series of samples correlate with each other. A higher intercorrelation indicates more certainty and confidence in the measurements and crossdating.



```
*******************************
*C* Number of dated series
*O* Master series 1352 1983
*F* Total rings in all series
*E* Total dated rings checked
*C* Series intercorrelation
*H* Average mean sensitivity
*A* Segments, possible problems
*** Mean length of series
*******************************
```

*Figure 9: Showing the statistics in COFECHA, *C* being of significant interest showing how well the samples correlate with each other.*

*Figur 9: Visar den statistik COFECHA producerar, *C* är av signifikant intresse då den visar hur väl proven korrelerar mot varandra.*

After dating and quality control in COFECHA the next step was standardization, the process of removing unwanted signals such as age related growth spurts in the samples. This was done using Andy Bunn's R package DplR (Bunn, 2008) which collects many of the commonly used dendrochronological softwares into one programmable package. To get started, tutorials by Stockton Maxwell were used as well as sample code provided by him (Stockton, 2021, October 19). DplR provides the user with six different types of standardization methods which can be viewed in figure 10.

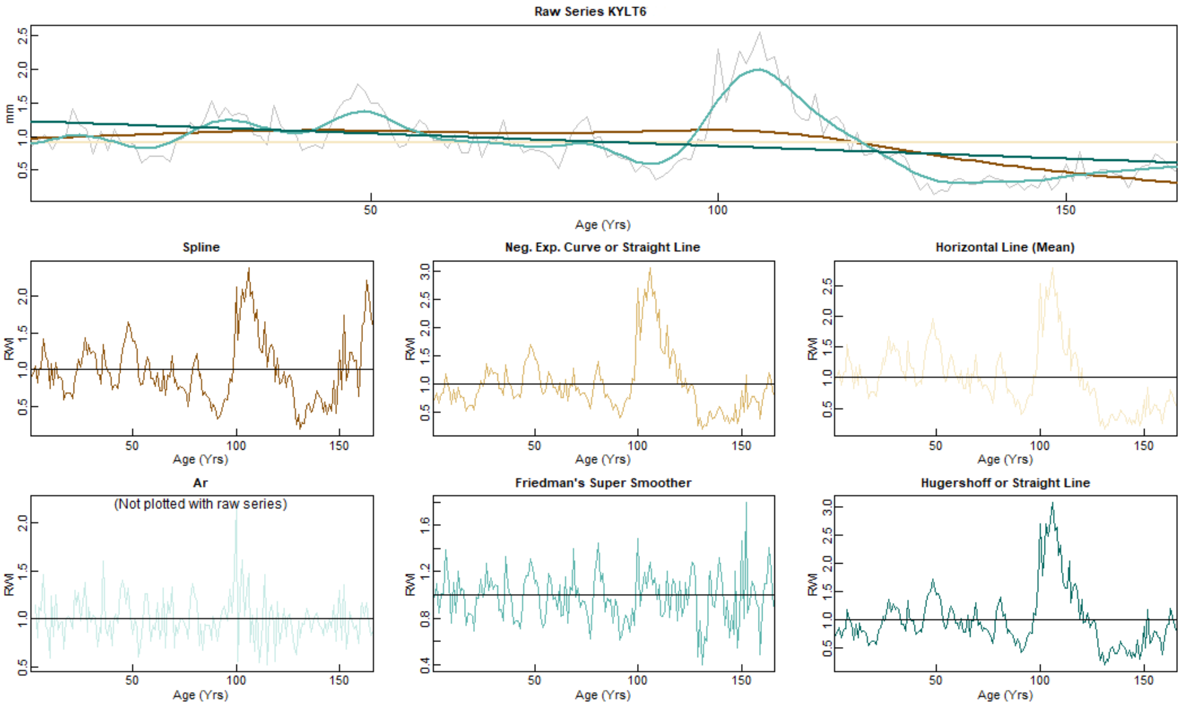


Figure 10. The six different methods of standardization provided by DplR visualized on the sample KYLT6. (R Development Core Team, 2009 ;Bunn, 2008).

Figure 10: Sex olika metoder av standardisering försedd av DplR visualiserad på provet KYLT6. (R Development Core Team, 2009 ;Bunn, 2008).

The detrending options negative exponential curve and spline were of relevance to the objectives of this thesis. The negative exponential curve is considered to be the most conservative of the methods, it follows a general predetermined model for tree growth. The spline on the other hand is a flexible curve that adjusts itself to the dataset (Speer, 2012, p. 23-27). In figure 10, the difference between spline and neg. exp. is apparent with the spline retaining more of the large fluctuations, especially at the end of the sample. With the interest being in examining historical climatic fluctuations in relation to forest fires the larger differences of the spline were deemed to be the most appropriate standardization method. The DplR standard of a 50-year cubic smoothing spline was used (Rdrr, 2021) which leaves 99% of variance between 12.67 - 19.01 years, 50% between 40 - 60 years and 1% at 126.17 - 189.26 years (Speer, 2012, p. 27). The code applied to do this to all the samples simultaneously can be viewed in appendix 1.

The next step was combining these into a chronology, which was also done using Andy Bunn's DplR package (Bunn, 2008). Two options are given, to develop the chronology with, or without an autoregressive model (AR model). Where an AR model takes into account past values in the chronology making it highly flexible over a wide array of different types of chronologies (Hyndman & Athanasopoulos, 2018). This was chosen and enabled when building the chronology by turning prewhiten to true in the code. The code to build and plot the chronologies can be examined in appendix 2.

6.2 Statistical analysis

To examine the correlation between the chronologies and the two climate variables a linear regression model was used in the software Microsoft Excel. Linear regression models are a widely used statistical method which examines the relationship between two variables, in this case ring width and one of the two climate variables (Montgomery, Peck & Vining, 2021). The linear regression model was used in several different tests, where all months' averages were organized into a pivot table for easier navigation. As no linear correlation was found a Pearson correlation was conducted. This was done in excel using the =CORREL formula where precipitation and temperature was compared to the KYLT chronology. The =CORREL formula differs somewhat from a linear regression only examining the relationship between two specified variables (Asuero, Sayago, González, 2007). To further improve the correlation temperature and ring width was visually compared and where ring width was decided to be shifted two years into the future, this was done after a suggestion from our supervisor. To further investigate if correlations could be improved a first difference estimator was also attempted. Where a one years average is subtracted from the other year's average to create a comparison of trends instead (Peterson, Karl, Jamason, Knight & Easterling, 1998). This was done to try to see if the correlations could be further improved when looking at how temperature changes, looking at positive and negative trends. To establish when the results were statistically significant a critical value was calculated. Subtracting the number of observations from the amount of datasets and comparing the number to a table of values a number for when the results were significant could be established (Niño-Zarazúa, 2012).

For the examination of the relationships between dates of forest fires and corresponding tree ring growth a superposed epoch analysis was conducted in the Fire History Analysis and Exploration System (FHAES) software. In FHAES two files were entered, one .CSV file of the ring width measurements as a complete and standardized chronology and one .TXT file containing the all the fire event years using a lag setting of -5 to +5. Here the purpose is to explore whether or not there is a variance from the norm such as increases or decreases in ring width before or after an event where 1 is the norm and the years can deviate either positively or negatively from that (Wanliss, Cornélissen, Halberg, Brown & Washington, 2017).

7. Results

The following chapter will present three different sections related to the three questions which this thesis centers around. Firstly two tree ring chronologies will be presented, one without a visible presence of fire scars and one with. The second subchapter will present the resulting statistical relationships between the chronology without fire scars and two climate variables, temperature and precipitation. The third and final subchapter will present how forest fires affect tree ring growth in the selected study area.

7.1 Chronologies

Figure 11 shows the KYLT chronology, comprising 26 individual samples dated from the year 1352-1983, compared to the reference chronology of Torneträsk. Visible similarities in the graph and a general curve that fits well into the reference graph indicating a chronology that has been dated within an accepted time span. This is further backed up by the correlation parameters statistics shown in table 1 resulting from the statistical crossdating procedure where high numbers indicate a better result from the crossdating procedure.

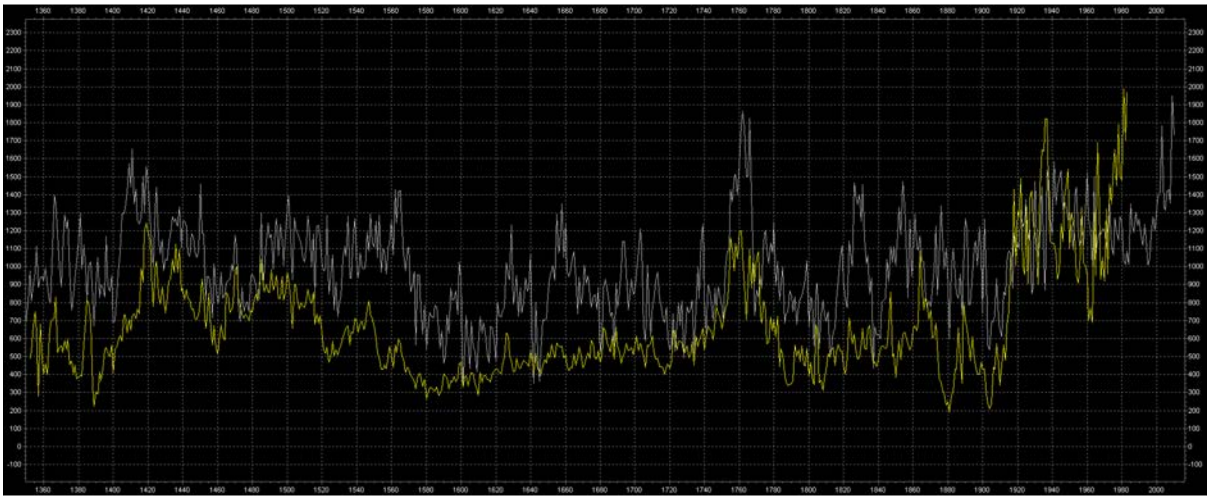


Figure 11: KYLT chronology (yellow) spanning the years 1352-1983 compared to the reference chronology of Torneträsk spanning 1352-2010 (white).

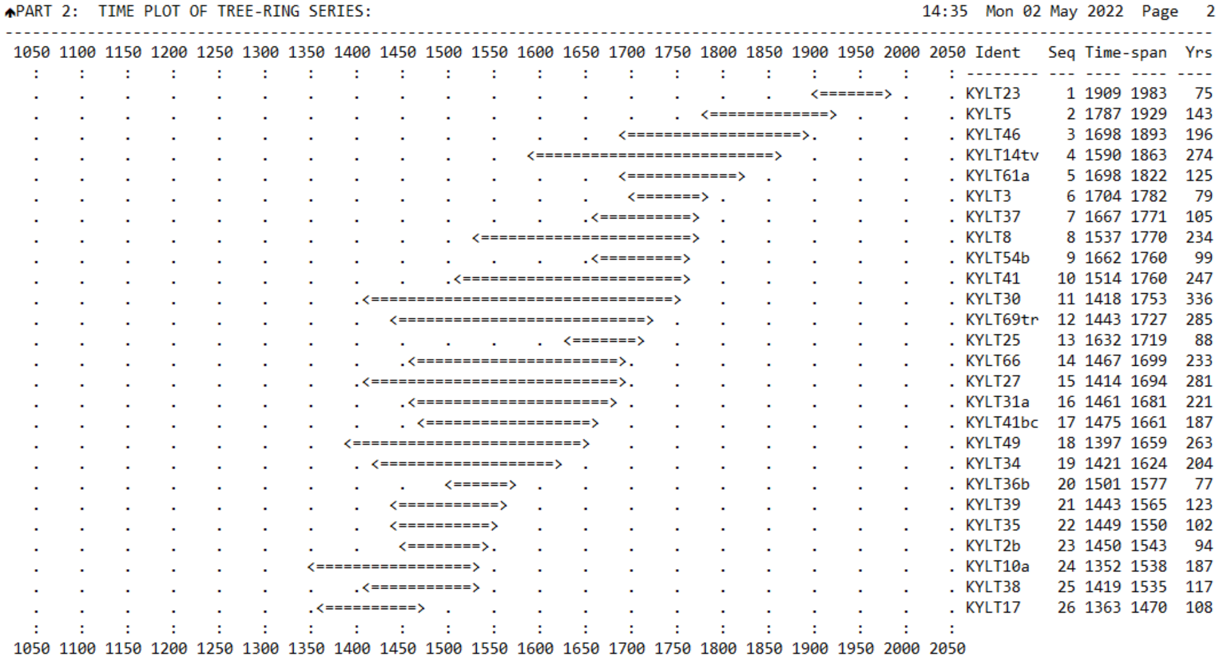
Figur 11: KYLT-kronologin (gul) mellan åren 1352-1983 jämförd med referenskronologin Torneträsk mellan 1352-2010 (vit).

Table 1. Summary statistics and the resulting values of the KYLT chronology.
Tabell 1. Statistisk sammanfattning och värdena resulterat av KYLT-kronologin.

Gleichläufigkeit (Glk)	Significance of Gleichläufigkeit (GSL)	Correlation coefficient (CC)	T-Value (TV)	Cross date index (CDI)
68%	***	56%	16.8	81

Table 1 presents the values of the correlation parameters of the KYLT chronology. The resulting values exceed the threshold values shown in figure 8 and explained in subchapter 6.1.2 indicating a statistically detectable result when crossdating against the reference chronology.

Each sample used to build the KYLT chronology is listed in figure 12 in descending order based on years from last to first year of the samples. All samples except "KYLT23" have multiple overlapping samples with some having more than others. A larger amount of dated samples overlapping each other indicates stronger evidence that the overlapping time-span is correctly dated and further results in a better correlation coefficient when quality checking in COFECHA.



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↑PART 2:  TIME PLOT OF TREE-RING SERIES:                                                            14:35  Mon 02 May 2022  Page   2
------------------------------------------------------------------------------------------------------------------------------------
 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050 Ident   Seq Time-span  Yrs
   :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    : -------- --- ---- ---- ----
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <=======> .    . KYLT23     1 1909 1983   75
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <=============>  .    .    . KYLT5      2 1787 1929  143
   .    .    .    .    .    .    .    .    .    .    .    .    .   <===================>.    .    .    . KYLT46     3 1698 1893  196
   .    .    .    .    .    .    .    .    .    .    .   <==========================>   .    .    .    . KYLT14tv   4 1590 1863  274
   .    .    .    .    .    .    .    .    .    .    .    .    .   <============>  .    .    .    .    . KYLT61a    5 1698 1822  125
   .    .    .    .    .    .    .    .    .    .    .    .    .    <=======> .    .    .    .    .    . KYLT3      6 1704 1782   79
   .    .    .    .    .    .    .    .    .    .    .    .    .<==========>  .    .    .    .    .    . KYLT37     7 1667 1771  105
   .    .    .    .    .    .    .    .    .    .  <=======================>  .    .    .    .    .    . KYLT8      8 1537 1770  234
   .    .    .    .    .    .    .    .    .    .    .    .    .<=========>   .    .    .    .    .    . KYLT54b    9 1662 1760   99
   .    .    .    .    .    .    .    .    .    .<========================>   .    .    .    .    .    . KYLT41    10 1514 1760  247
   .    .    .    .    .    .    .    .<=================================>    .    .    .    .    .    . KYLT30    11 1418 1753  336
   .    .    .    .    .    .    .    .   <===========================>  .    .    .    .    .    .    . KYLT69tr  12 1443 1727  285
   .    .    .    .    .    .    .    .    .    .    .    .  <=======>   .    .    .    .    .    .    . KYLT25    13 1632 1719   88
   .    .    .    .    .    .    .    .    .<======================>.    .    .    .    .    .    .    . KYLT66    14 1467 1699  233
   .    .    .    .    .    .    .    .<===========================>.    .    .    .    .    .    .    . KYLT27    15 1414 1694  281
   .    .    .    .    .    .    .    .    .<=====================> .    .    .    .    .    .    .    . KYLT31a   16 1461 1681  221
   .    .    .    .    .    .    .    .    . <==================>   .    .    .    .    .    .    .    . KYLT41bc  17 1475 1661  187
   .    .    .    .    .    .    .   <==========================>   .    .    .    .    .    .    .    . KYLT49    18 1397 1659  263
   .    .    .    .    .    .    .    . <===================>  .    .    .    .    .    .    .    .    . KYLT34    19 1421 1624  204
   .    .    .    .    .    .    .    .    .    <======>  .    .    .    .    .    .    .    .    .    . KYLT36b   20 1501 1577   77
   .    .    .    .    .    .    .    .   <===========>   .    .    .    .    .    .    .    .    .    . KYLT39    21 1443 1565  123
   .    .    .    .    .    .    .    .   <==========>    .    .    .    .    .    .    .    .    .    . KYLT35    22 1449 1550  102
   .    .    .    .    .    .    .    .    <========>.    .    .    .    .    .    .    .    .    .    . KYLT2b    23 1450 1543   94
   .    .    .    .    .    .    <=================> .    .    .    .    .    .    .    .    .    .    . KYLT10a   24 1352 1538  187
   .    .    .    .    .    .    .    .<===========> .    .    .    .    .    .    .    .    .    .    . KYLT38    25 1419 1535  117
   .    .    .    .    .    .    .<==========>  .    .    .    .    .    .    .    .    .    .    .    . KYLT17    26 1363 1470  108
   :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :
 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050
```

Figure 12: Samples analyzed and used to build the chronology with corresponding time-span and total years covered ordered in a time plot of the tree-ring series.
Figur 12: Proven som analyserades och användes för att bygga kronologin med korresponderande tidsspann och totalt antal år ordnade i en tidsserieplott av trädringsserien.

Below in figure 13 the final standardized KYLT chronology is shown. It shows fluctuations in ring width all throughout the chronology with some bigger spikes in the beginning and generally larger fluctuations from the 1800s till the end of the chronology, likely due to lower sample depth leading to greater variance.

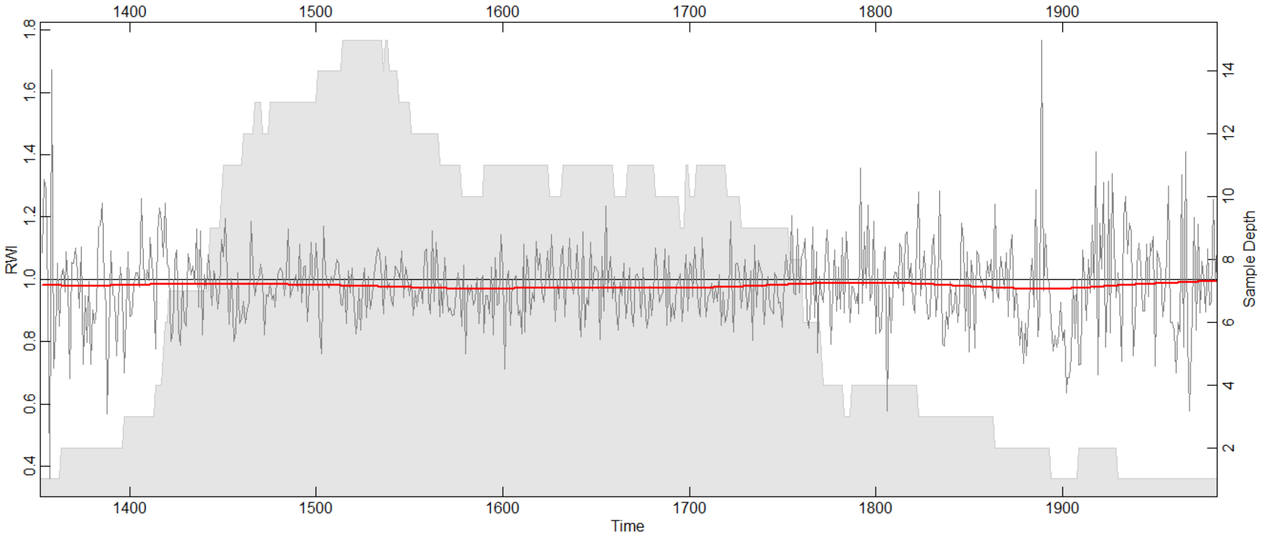

Figure 13. KYLT chronology standardized using a 50-year cubic smoothing spline, black line showing the ring width index, gray background fill showing sample depth and red line showing minimal low frequency variability (R Development Core Team, 2009 ;Bunn, 2008).

Figur 13. KYLT-kronologin standardiserad med en "50-year cubic spline", den svarta linjen visar ringbreddsindex, den gråa bakgrundsfyllnaden visar provdjup medans den röda linjen visar minimal variabilitet i den låga frekvens(R Development Core Team, 2009 ;Bunn, 2008).

7.1.1 Dated fires

Below in figure 14 the fire scar sample depth is shown where 13 different fire scars are shown. There are three different years which are previously documented fires which also shows up in the samples; 1901, 1831 and 1721 where 1901 is seen in three separate tree samples (Forsmark, F, personal communications, 26 April, 2022; Västernorrlands museum, n.d).

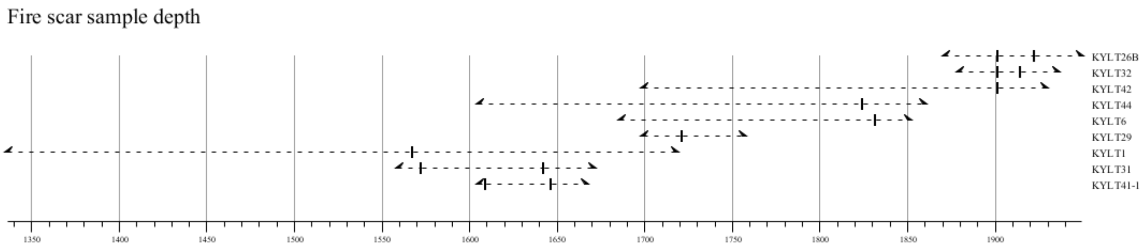

Figure 14. Fire scar sample depth, the dotted lines showing the temporal length of each tree sample with each fire scar marked on the dotted line with filled black vertical lines. (Brewer, Velásquez, Sutherland, Falk, 2022).
Figur 14. Provdjup av brandljuden, de prickade linjerna visar temporal längd av varje prov med varje brandljud markerat på linjen genom vertikala svarta linjer. (Brewer, Velásquez, Sutherland, Falk, 2022).

Figure 15 shows the final standardized chronology created from the tree samples containing fire scars. The chronology shows greater fluctuations throughout its length when compared to figure 13 with large fluctuations in ring width around the 1500s and 1800s which could be due to less samples, leading to greater variability.

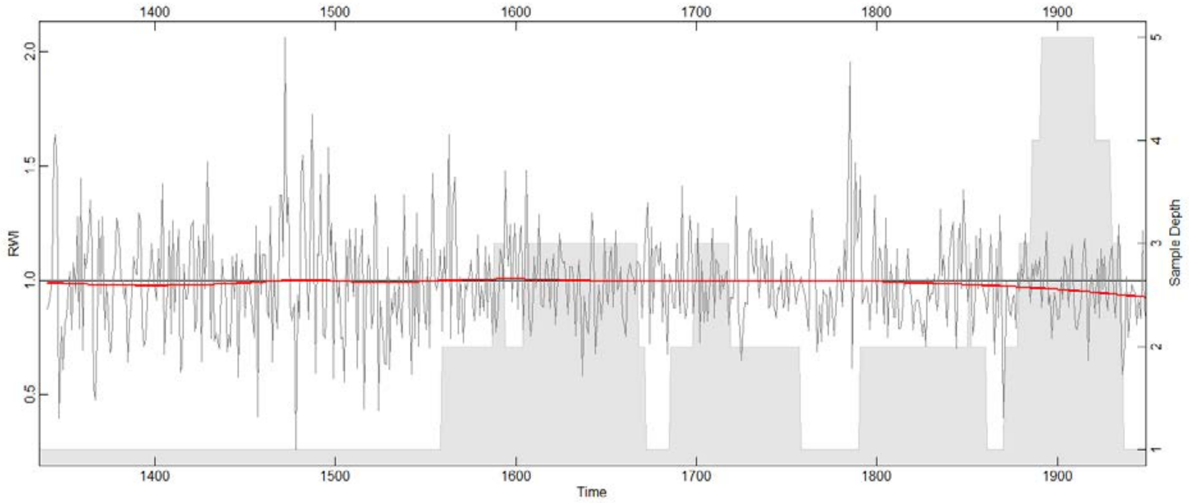

Figure 15. Chronology with fire scars present, black line showing the ring width index, gray background fill showing sample depth and red line showing low frequency variability (R Development Core Team, 2009 ;Bunn, 2008).
Figur 15. Kronologi med brandljud, den svarta linjen visar ringbreddsindex, den gråa bakgrundsfyllnaden visar provdjup medans den röda linjen visar variabilitet i den låga frekvensen (R Development Core Team, 2009 ;Bunn, 2008).

7.2 Correlation between climate and ring width

In the following chapter the statistical correlation calculations between climate and ring width in the study area will be presented.

Table 2. Showing correlation between temperature and ring width from the year 1906-1975. JJA being short for June, July and August. FD July standing for first difference estimator in July and CV being the critical value.
Tabell 2. Visar på korrelationen mellan temperatur och ringbredd mellan åren 1906-1975. JJA är en förkortning för juni, juli och augusti. FD July står för första skillnadsestimator i juli och CV står för kritiskt värde.

	JJA	July	FD July	CV
Correlation	0,19819	0,24358	0,26953	0,2242

Table 2 shows the different correlation calculations done in Excel. The correlation for June, July and August (JJA) shows a correlation of 0,198 being just under the critical correlation value of 0,224 and thus not showing any significant correlation. July correlations exceed the critical correlation being 0,244 showing a correlation between temperature and ring width in July. The highest achieved correlation was done using a first difference calculation between July and temperature, this calculation showing a correlation of 0,270. Both the normal July correlation and the first difference estimator therefore show a 95% confidence level between temperature and ring width.

Figure 16 visualizes the correlation between the temperature each year during July and ring width after a first difference has been performed on both parameters. The result shown in table 2 indicates a statistical significance which is further underlined by the graph below, the general trajectory matching in both series also indicates this.

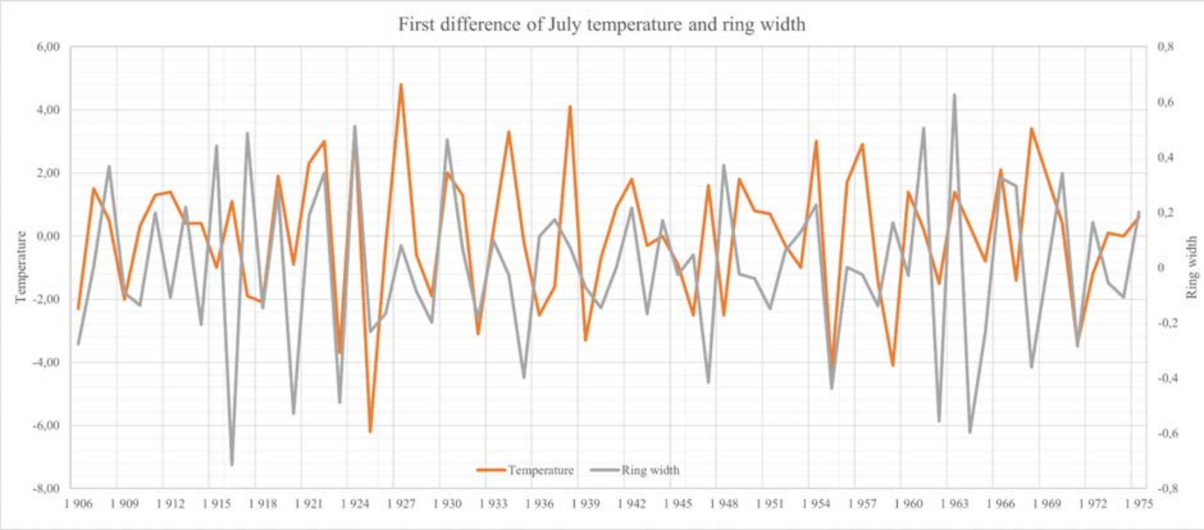

Figure 16. A visual presentation of a first difference analysis between July temperature (orange) and ring width (gray).

Figur 16. En visuell presentation av en förstaskillnadsestimator mellan Juli temperatur (orange) och ringbredd (grå)

Table 3. Showing the correlation between precipitation and ring width for all the months between the years 1901-1983. CV to the right standing for critical value.

Tabell 3. Visar korrelationen mellan temperatur och ringbredd för alla månader mellan åren 1901-1983. CV till höger är förkortning för kritiskt värde.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	CV
Correlation	-0,07971	0,109508	-0,02886	-0,02685	0,167542	0,168643	-0,04174	0,016597	-0,09491	-0,05047	-0,04743	0,047217	0.2172

Table three shows the different correlation values calculated between precipitation and ring width from the years 1901-1983. The highest correlation can be seen in the month of June with a correlation of 0,169, this is not high enough to exceed the critical value for a 95% confidence level. May showed similar results to June with a correlation of 0,168 also not being high enough to be of statistical significance.

7.3 The effect of forest fire on tree ring growth

Below, the results obtained when examining how tree growth is influenced by forest fires through a superposed epoch analysis is presented.

Table 4. Superposed epoch analysis comparing tree ring width from the KYLT chronology and fire events between the years of 1562-1927, 26 samples in the KYLT chronology, nine samples in the fire scar chronology with fires dated to 1922, 1914, 1901, 1831, 1824, 1721, 1646, 1642, 1609, 1572, 1567 (Brewer, Velásquez, Sutherland, Falk, 2022).
Tabell 4. Superposed epoch analysis som jämför ringbredden från KYLT kronologin och brandevent mellan åren 1562-1927, 26 prov i KYLT kronologin, nio prov i brandljudskronologin med daterade bränder daterade till, 1922, 1914, 1901, 1831, 1824, 1721, 1646, 1642, 1609, 1572, 1567 (Brewer, Velásquez, Sutherland, Falk, 2022).

ADJ SEG	LAGS	MEAN	STA DEV	95% CONF INT
1562 - 1927	-5	0,960	0,127	[0,712,1,208]
1562 - 1927	-4	0,930	0,178	[0,581,1,279]
1562 - 1927	-3	0,972	0,140	[0,698,1,246]
1562 - 1927	-2	0,995	0,111	[0,777,1,213]
1562 - 1927	-1	0,952	0,137	[0,684,1,220]
1562 - 1927	0	0,981	0,144	[0,698,1,264]
1562 - 1927	1	0,940	0,169	[0,610,1,270]
1562 - 1927	2	0,968	0,140	[0,694,1,243]
1562 - 1927	3	0,979	0,185	[0,616,1,342]
1562 - 1927	4	0,986	0,173	[0,647,1,326]
1562 - 1927	5	0,982	0,171	[0,648,1,316]

Table 4 shows the second analysis between tree ring width and fire events. The superposed epoch analysis was conducted in FHAES with a -5 year lag and a +5 year lag. Looking at the mean it is clear that all years from five years prior to an event to five years after an event show results close to one indicating no deviation from the normal prior or after a fire event.

8. Discussion

Examining the chronologies created, the first one in figure 11 seems to generally be following the master chronology of Torneträsk. A visual inspection comparing it to Torneträsk shows that a majority of the KYLT chronology follows the general trend previously documented. Further the results of crossdating in TSAPWin also shows satisfactory statistical correlation in several categories; Gleichläufigkeit (Glk) - 68%, Significance of Gleichläufigkeit (GSL) - ***, Correlation coefficient (CC) - 56%, T-Value (TV) - 16.8 and Crossdate index (CDI) - 81. It does however show larger fluctuations in tree ring width from the 1800s to present day and in the beginning of the chronology. An explanation could be found when examining the low sample depth. The KYLT chronology's larger fluctuations coincide with the lowest sample depth segments in the chronology providing a possible explanation. The COFECHA results show a 0.109 interseries correlation which is a less than satisfactory result for the chronology which could be due to not enough overlapping samples being dated.

It was found that a few interesting samples matched up with known fires in the area. 1721 is the earliest found that the chronology could perhaps derive from a documented fire and could relate to the fact that 1721 is the year when Russia invaded northern Sweden along the Baltic sea coast (Västernorrlands Museum, n.d). When searching for scientific literature the papers usable for this thesis were sparse. Literature focuses on other parts of "the great nordic wars" and the literature that does focus on these parts is mainly focused on Russia's burning of cities, farms and other man made structures. We found little evidence in historical literature supporting the dates of fire events identified here, nevertheless, the fires dated in 1721 could coincide with the fire ignited by the Russian army in 1721. The next documented fire seen in the samples is the fire of 1831 which is known as one of northern Sweden's largest fires (Forsmark, F, personal communications, April 26, 2022). That evidence of this fire was found was not a surprise, the bigger surprise was that no more evidence of the 1831 fire was found. Perhaps this would have been found if more samples were measured and crossdated. The next one was 1901, which is known as a not very common fire to find (Forsmark, F, personal communications, April 26, 2022), but a fire that showed up in three different analyzed samples. Perhaps the samples were taken in the center of the 1901 fire, or it was just chance which is not unlikely with the low amount of samples used in the chronology.

The next question is the relationship between tree ring width, temperature and precipitation. The chronologies created in this thesis show a correlation to temperature, the highest correlation was found during the month of July with an R-value of 0.24358 with an increase after a first difference estimator had been applied, leading to an R-value of 0.26953. Seeing as other studies in similar areas also show correlation, it is probable that this is also correct in this area. Perhaps the correlation is higher than the results show but it is likely that missing or false rings in the samples have shifted the years somewhat leading to a lower correlation. Even after the data was shifted two years this could still be the case.

Whereas the general KYLT chronology visually matches up well, these small shifts due to missing or false rings probably does influence the statistical comparison. Temperature is generally the most investigated limiting factor of trees in Sweden which further indicates that the result in this study is correct but probably has a higher correlation than shown. For example the 7400-year chronology from Torneträsk situated about 300km from the study area shows correlation between temperature and tree rings (Grudd et al., 2002). The Torneträsk chronology shows correlations of 0.58 - 0.60 (R) over the summer period of June to August (Grudd et al., 2002). This could perhaps mean that the KYLT chronology could show more of a correlation to temperature during the summer months and particularly in July.

Whether the lack of any statistically significant correlation with precipitation is accurate or not is hard to say without more studies done in the area. The resulting low correlations may prove that the northern areas of Sweden are not limited in growth by precipitation as much as it is by temperature, or it could be an error due to the difficulties presented in the discussion of methods. Errors such as missing or false rings could influence and if detected samples could be dated more correctly leading to a higher correlation. However, as shown in for example the studies done on the Torneträsk chronology, temperature is likely the most limiting factor in northern Sweden which could explain the non-significant correlation between the KYLT chronology and precipitation. The results did however show that the most influential period for precipitation was in June which correlates with the research in central Sweden that shows that *Pinus sylvestris* is mainly influenced by precipitation during May and June (Jönsson & Nilsson, 2009). It is however difficult to draw any conclusion from this as the research was done in central Sweden.

To investigate forest fires' influence on tree growth a superposed epoch analysis was performed showing no deviation from the normal before or after a fire. This could be due to several different reasons, the first and perhaps most likely is due to issues in the early stages of work, as presented in the discussion of methods subchapter. When visually inspecting the samples several instances of decreased growth after a fire event can be seen. With more samples in the analysis the likelihood for a statistical significance might increase as a lower amount of samples leaves the analysis more open to chance as one sample which does not correlate has a greater impact on the overall group of samples. If the KYLT chronology is wrongly dated this would also influence the statistical results as the fires would not be compared to the fires corresponding years. Considering forest fires' effect on tree growth in literature, such as Bär et al. (2019), indicates that there could be some effects on tree growth after experiencing a fire event, for example by showing reduced growth. The tree's physiology could also be compromised and in the end being likelier to experience delayed death. Bär et al. (2019) also shows that several different fire injuries can affect tree growth, both injuries to the stem, but also injuries to the roots and tree crown can lead to reduced growth rates. As tree growth can be affected by injuries done to parts of the tree other than the steam, it complicates the method used in this thesis where fires that do not show up in the sample might lead to changes in growth rate making the statistics hard to confirm. Our results do not confirm the hypotheses that forest fires influence tree growth in the study area, to confirm this more studies with a larger pool of samples needs to be conducted.

8.1 Discussion of method

In this chapter of the thesis possible errors in the methods will be addressed in the order they were presented previously. This chapter will also look at how the chosen methods could be used differently to produce perhaps more solid and reliable results.

Before discussing the method, the samples in themself have to be highlighted and discussed. As shown in figure 17 the samples were very difficult to work with, it is hard to say why but some explanation could possibly be found in part 4.3. As the samples were not collected by us it is hard to assess why the samples were hard to work with. The area of the samples could have had an effect, also the climate in the region could be considered extreme causing several different ring anomalies, for example caused by extremely low temperatures. Needless to say this made the task at hand far more time consuming and more of a struggle than it otherwise would have been. This could to some extent explain the results presented by the influence it had on the preparations and measuring processes. With more knowledge of this beforehand other choices, discussed further in following parts, would have been made or at least taken into more of a consideration.

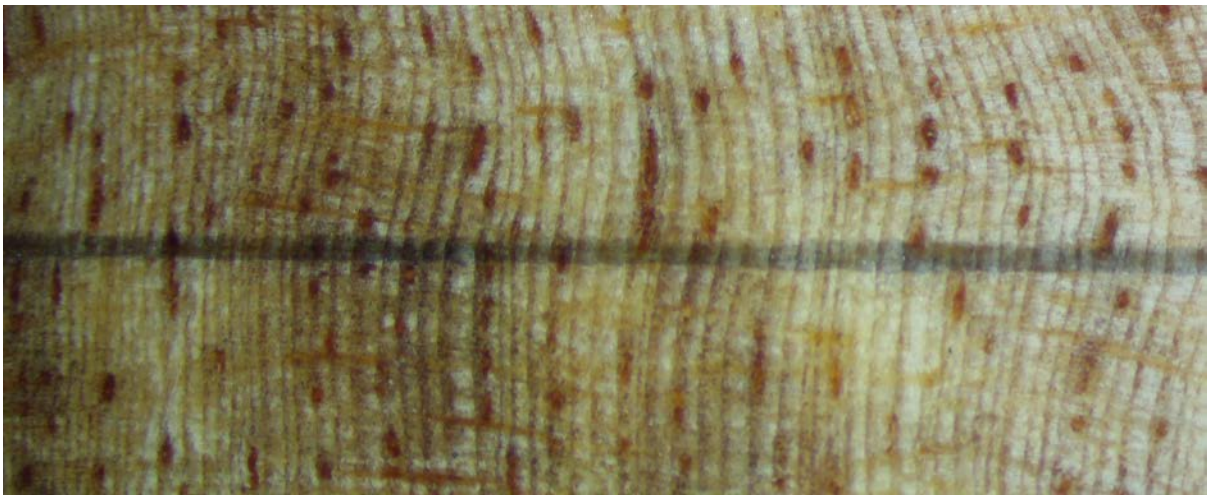

Figure 17. Showing a hard to work area of a sample of Pinus sylvestris. (Photo: Erik Janvik Kardell & Tobias Roslund).

Figur 17. Visar exempel på ett prov Pinus sylvestris som var svårt att jobba med. (Foto: Erik Janvik Kardell & Tobias Roslund).

The methodology involves a sequence of consecutive steps to prepare the samples for the measuring and crossdating. As explained in the method this was done by sanding the samples. As beginners we had difficulties to estimate the amount of time required for preparation and analysis of the samples to be able to use them in a proper way further down the line. In hindsight the smarter way to go about this part would have been not to work with as many samples as was done. By working with around half or even a third of the samples, more time could have been put into properly assessing and preparing the samples. This would have resulted in a better sanding and most likely a more accurate measuring and crossdating without compromising the validity of the results. The fact that less than half of the prepared samples ended up used further emphasizes this. With that said, using fewer samples is no guarantee of a more accurate result due to the method of dendrochronology in itself being time consuming and work heavy no matter how many samples are worked with.

When it was time to measure and crossdate it was clear that there were a lot of samples and a sparse amount of time. Despite that around 65 samples were measured and crossdated. The stressful nature of this work might have ended up affecting the measuring, at least when visually examining the samples trying to find errors in the measuring. Less samples and therefore more time would have meant that a more thorough examination would have been implemented, leading to a better crossdating procedure and probably identifying more missing, false or partial rings. The measuring of the rings themself was done to a satisfactory level and apart from more experience using the equipment and working with tree samples not much could have been changed to improve the resulting measurements. The reference chronology used to crossdate the KYLT chronology worked fine and choosing another reference would in all likelihood not lead to any significant changes in the results.

Many, if not all, of the statistical analyses was directly reliant upon the quality of the samples measurements and crossdating. Therefore not much in the tools and how the tools were used could be changed or would have altered the results if changed. With that said COFECHA lent itself to decisions that could have been done differently to perhaps produce a more tenable result. COFECHA was used to quality control the measurements and crossdating. How the program works and the data input can be altered to some degree, for example by changing the segment length to examine. A length of 50 years with 25 years overlapping was chosen, this is the default, and resulted in a low intercorrelation of 0.060, after several attempts the final intercorrelation was raised to 0.109 as seen in figure 9. This was discussed with our supervisors and it was finally decided that this was the statistics to present but to be transparent with what it actually meant. By instead using longer or shorter intervals it might have resulted in different outcomes. For example as Grissino-Mayer (2001) explains, it depends on the average length of all the samples combined, other settings might be desirable. As the samples used in the KYLT chronology averaged around 200 years, the idea that 100 year segments might have been the better option with a 50 year lag was discussed. This was tried without any improvements in the result. A lower segment length was also tried but this meant that the segments fitted into multiple places in the reference chronology making it more difficult to assess how to date it and increasing the likelihood of missdating. Finally, more samples covering the same time-span would also have improved the result in COFECHA but as discussed above this was not a viable option in this study.

To conclude, several different things would be done differently if this could be done again. Firstly a lower amount of samples would be prepared and more care in choosing the best samples before starting the work would have been taken. This does not guarantee that the samples chosen are better before the samples have been dated and analyzed, the samples chosen can still be climate insensitive and produce low correlations. Perhaps having the possibility of collecting some samples from living trees with a known date could have made the dating less complicated. Choosing a more narrow selection of questions could also have made it possible to spend more time on the samples and less time on the following analysis.

9. Conclusion

Before concluding the result in this thesis, it is important to highlight that even though the result may not have been what we expected or wanted, we are thrilled by what we in the end achieved. This was in no way an easy task with samples proving to be far more difficult to work with then was expected, this makes it even more of an accomplishment, at least in our eyes and we believe that this thesis and the results still carries value.

The KYLT chronology seems to visually correlate well with the reference chronology, it further exceeds the statistical thresholds given by TSAP. It does not however give a satisfactory correlation when entered in COFECHA. The correlation is likely mostly correct but with many errors such as missing rings or partial rings affecting COFECHA statistics and the results in the thesis. Such as; how does the created chronology correlate with temperature and precipitation? The results presented show a correlation with temperature during the month of July which correlates well with other studies done in the area. Correlations between precipitation and ring width were shown to be non-significant, most likely due to temperature being more of a factor and errors in measuring and dating. Further, the studies show no clear variance between the trees that have fire scars and the ones that do not have fire scars. This indicates no significant differences in the common signal between samples with visible scars and those with no visible scars. It most likely does however influence tree growth, the conclusion is rather that it is a complex topic that needs more research and research collaboration from many different fields such as ecology, climatology and physical geography to conclude forest fires effect on tree growth and how it might influence dendrochronological results.

Hopefully, our mistakes can highlight the difficulties of dendrochronology and be of guidance to other students trying a similar project to ours.

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Appendix

```
New_file.rwi <- detrend(rwl = your_measurments.rwl, method =
c("Spline"), nyrs = NULL, f = 0.5, pos.slope = FALSE)
```

Appendix 1. Code in R for detrending samples before creating a chronology. (R Development Core Team, 2009 ;Bunn, 2008).

Bilaga 2. Koden i R som användes för standardisering av proven innan skapandet av en kronologi. (R Development Core Team, 2009 ;Bunn, 2008).

```
New_chronology.crn <- chron(x = standardized_measurements.rwi,
prefix = "", biweight = TRUE, prewhiten = TRUE)

crn.plot(crn = New_chronology.crn[,-1], add.spline = TRUE, nyrs =
NULL, f = 0.5, crn.line.col='grey50',
         spline.line.col='red', samp.depth.col='grey90',
samp.depth.border.col='grey80',
         crn.lwd=1, spline.lwd=2.0, abline.pos=1,
abline.col='black', abline.lty=1,abline.lwd=1,
         xlab="Time", ylab="RWI")
```

Appendix 2. Code in R for building and plotting a tree ring chronology. (R Development Core Team, 2009 ;Bunn, 2008)

Bilaga 2. Koden i R som användes för konstruktionen och visualiseringen av en trädringskronologi. (R Development Core Team, 2009 ;Bunn, 2008).