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# A Dendrochronological Investigation of the Effects of Climate on Latewood Growth in Bohuslän, Sweden

**Sara Camén**

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Department of Earth Sciences
University of Gothenburg
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UNIVERSITY OF GOTHENBURG

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**Geovetarcentrum/Earth Science Centre**

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**Mailing address**
Geovetarcentrum
S 405 30 Göteborg

**Address**
Geovetarcentrum
Guldhedsgatan 5A

**Telephone**
031-786 19 56

Geovetarcentrum
Göteborg University
S-405 30 Göteborg
SWEDEN

# Abstract

As climate change becomes a more important issue all over the world, information about past climate is of high relevance to better understand what is changing and different from the past. Tree rings can provide information about past climates and has been of value for paleoclimate research and the study of ongoing climate change. This study focuses on using the section of a tree ring that form at the end of the growing season, known as latewood. Rather than only using the whole ring width, the study of the different sections of a tree ring can provide further information. While dendrochronology has a long history in Fennoscandia and Sweden, southwestern Sweden has not been studied to a large extent. This study aims to be a beginning step to explore if tree rings from Bohuslän can be used as a climate proxy to reconstruct past climate in this region. The climate parameter affecting latewood and the differences between the climate parameter affecting latewood and the whole ring is investigated in this study. Whether a difference before and after 1950 can be found is also explored. Tree ring samples from Scots pine (*Pinus sylvestris*) was collected in the nature reserve of Halle-Vagnaren in Bohuslän (Sweden). A correlation analysis between latewood and normalised monthly precipitation as well as temperature data was conducted. The same correlation analysis was conducted for the whole ring width as well. A statistically significant correlation was found between the latewood and the same year's precipitation in July before 1950 was found as well as for the same year's precipitation in June after 1950. A statistically significant correlation for the whole ring was only found for the same year's precipitation in May before 1950, but an indication can be seen for a shift toward the same year's precipitation in June after 1950. The shift of the statistically significant correlation for the latewood could be due to an earlier start of the growing season or due to changed precipitation patterns. The results show a stable relationship between latewood and summer precipitation over time and latewood from the study area could therefore possibly be used as a climate proxy in the future.

# Table of Contents

# 1. Introduction

Climate and climate change has become an important topic all over the world in recent years. To better understand what is changing now, information about past climate is needed (Masson-Delmotte et al., 2013). Tree rings can be used as a proxy that provide information about past climate, since their growth is largely affected by the climate (Fritts, 1976; Lamarche Jr, 1978). Dendrochronology, the study and dating of tree rings, is therefore of great importance to better understand the climate change that is happening now (Hughes, 2002). While many studies use the whole ring width (RW) to study climate, investigating the different parts of the ring, latewood (LW) and earlywood (EW), can reveal more information. One example of this is from the North American monsoon region, where LW and EW has been used to better study precipitation (e.g Meko & Baisan, 2001; Griffin et al., 2013). Another example is by Lebourgeois (2000), where climatic signals in EW and LW using Corsican pine in France were studied. Lebourgeois (2000) suggested that EW and LW width can be used to gain subseasonal climatic information. Kalela-Brundin (1999) studied the RW, EW and LW in Norway and found that the climatic responses of the RW and EW are similar and the LW differ in that region.

In this report, LW from Scots pine (*Pinus sylvestris*) from the nature reserve Halle-Vagnaren, in Bohuslän in southwestern Sweden, will be investigated. Southwestern Sweden has a long coastline, and a large portion of Sweden's total population lives along this coast (SCB, 2022). With rising greenhouse gas emissions, the climate is expected to change during the next 80 years and Sweden will be affected (IPCC, 2021; Eklund et al., 2015). It is therefore of great importance to investigate past climates in southwestern Sweden to better understand current and future climate in the area. Fennoscandia, that Sweden is a part of, has a long history of dendrochronology (Linderholm et al., 2009). Despite this have very few studies been conducted in southwestern Sweden and Bohuslän. Seftigen et al. (2015a) and Seftigen et al. (2015b) have investigated hydroclimate in Fennoscandia using tree rings. The studies have included samples from sites southwestern Sweden, but the number of studies in this area is still limited and it can be further explored.

## 1.1 Aim

This study aims to be a beginning step to explore if tree rings from Bohuslän can be used as a climate proxy to reconstruct past climate in this region, as very few studies have been conducted there. Leveraging the knowledge found in previous studies (see above), an investigation of LW will be conducted to possibly reveal more information about the climate parameter that affects the trees in the study area. Because a prerequisite for a tree-ring proxy is a stable relationship between the tree ring growth and the limiting climatic factor (National Research Council, 2006), this study will investigate if changes in the climate parameter that most strongly affect the LW growth can be seen before and after 1950. In addition will this study compare LW and RW to investigate if different information can be revealed.

The research questions that this study aims to answer:

- Which climate parameter (temperature or precipitation) most strongly affects the latewood width in Scots pine (*Pinus Sylvestris*) in Halle-vagnaren nature reserve in Bohuslän, Sweden?
- In what way does the climate parameter affecting the latewood width in Scots pine (*Pinus Sylvestris*) in the chosen study area change before and after 1950?

- What differences can be seen between the climate parameter most affecting the latewood width compared to the whole ring width in Scots pine (*Pinus Sylvestris*) in the chosen study area?

## 1.2 Climate Change

The concentration of greenhouse gases in the atmosphere has been increasing since around 1750-1800, leading to heating of the planet (Steffen et al., 2015; Leichenko & O'Brien, 2019). However, the increase accelerated significantly around 1950, consequently leading to further global warming (Steffen et al., 2015; NOAA, 2023). Global temperatures have risen with an average of 0.08°C per decade since 1880, however, the average rate of increase have grown to 0.18°C per decade since 1980 (NOAA, 2023). In Sweden has the mean temperature risen with 1.9°C from the reference period 1861-1890 to the latest reference period 1991-2020 (Schimanke et al., 2022). Since 1980 has the mean temperature in Sweden risen with 0.5°C per decade (Schimanke et al., 2022). IPCC's sixth assessment report present that evidence has been found that there has been an increase of precipitation in mid and high latitudes since 1950, likely due to human influence (Eyring et al., 2021). In line with IPCC sixth assessment report has the precipitation in Sweden increased as well. In Bohuslän has the annual precipitation increased with 140 mm during the reference period 1991-2020 compared to 1961–1990 (Schimanke et al., 2022).

## 1.3 Dendrochronology

Dendrochronology is the study of the chronological sequence of which trees in temperate climates grow, creating one tree ring annually (Fritts, 1976; Stokes & Smiley, 1968). A tree's growth is often affected by variations in climate, resulting in wider rings during years with more favourable climatic conditions, and years with less favourable conditions will often result in a narrower ring (Fritts, 1976). The growth rate of a tree does not only vary annually but also diurnally, seasonally as well as throughout the tree's life with a generally higher growth rate in the beginning (Fritts, 1976). There are two distinct sections of each annual ring known as earlywood (EW) and latewood (LW) (Domec & Gartner, 2002) (figure 1). The EW form in the beginning of the growing season and the cells are often less dense, larger and with thin cell walls (Domec & Gartner, 2002; Fritts 1976). The EW account for 40-80% of the whole ring width (Domec & Gartner, 2002). Toward the end of the growing season, during autumn, the growth rate slows and denser cells with thick walls and darker colouration form. This is known as latewood (LW) (Domec & Gartner, 2002; Fritts 1976). During a year of extremer climate and adverse conditions, the tree's growth might cease, and no ring will form. This is known as a missing ring (Fritts, 1976). However, if the climatic conditions become less optimal during the growing season when a ring already has begun to form, the new cells forming will be smaller with thicker walls, making it appear as if the growing season has come to an end (Fritts, 1976). When better conditions return, the growth will continue with bigger cells. This results in a darker band in the EW, which is known as a false ring (Fritts, 1976).

A subfield of dendrochronology is known as dendroclimatology, where the dendrochronological method is used to study past climates (Fritts, 1976). Tree rings can serve as a high resolution, natural archive of past climates and has been of value for paleoclimate research and the study of ongoing climate change (Hughes, 2002). Temperature, precipitation and drought indices can be reconstructed using tree rings (Speer, 2010). Trees used for dendroclimatology are generally from climate sensitive sites, such as rocky slopes or at the northern treeline (Speer, 2010). A method often used to find which climate parameter that affects the sampled trees, is to correlate the chronology created from the samples with weather data (Speer, 2010; Blasing et al., 1984). Dendrochronology and its subfields such as dendroclimatology rely on the "Uniformitarian Principle" (Wilmking et al., 2017). The principle implies that the link between today's climate and today's variations in tree growth must have been present in the past (Wilmking et al., 2017). And as mentioned, a prerequisite for a tree-ring proxy is a stable relationship between the tree ring growth and the limiting climatic factor over time (National Research Council, 2006).

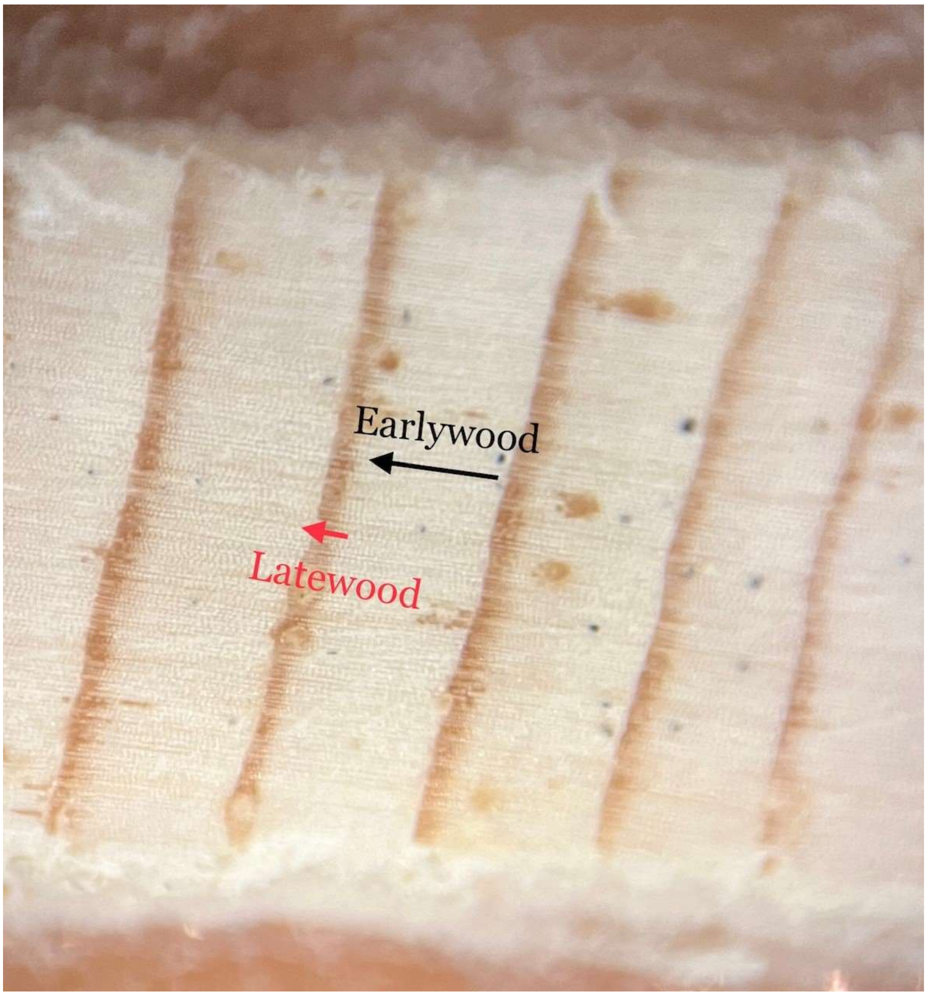

*Figure 1. Sample of Scots pine showing the annual tree rings with latewood and earlywood.*

## 1.4 Scots pine (*Pinus Sylvestris*)

Scots pine (*Pinus Sylvestris*) can be found throughout all of Sweden and can be up to 900 years old (Ne.se, n.d-a). The genera *Pinus* is known to be utilized successfully in the field of dendrochronology (Fritts, 1976). Scots pine, specifically, has been used in many studies conducted in Europe to study climate (e.g, McCarroll et al., 2003; Linderholm et al., 2014; Bogino et al., 2009).

# 2. Method

## 2.1 Site Description

This study focuses on an area in southwestern Sweden, north of the city of Strömstad and close to the Norwegian border. The samples were collected in the nature reserve Halle-Vagnaren (N 59°39’65" E 11°35’50") with permission from Länsstyrelsen. The nature reserve is located by Skagerrak with most of its area on a rock outcrop 120 m above sea level (figure 2 & 6). The area’s tree population has a few examples of birch trees but is mainly dominated by Scots pine. The low growing vegetation mainly consists of heather, blueberry and different species of moss. In the area of the nature reserve where the trees were sampled, there are signs of difficult growing conditions and many of the Scots pines has grown in crooked and twisted ways (figure 3).

Halle-Vagnaren is located in the northern part of the province Bohuslän in western Sweden (figure 2). Bohuslän covers the western part of Sweden between the city of Gothenburg and the border of Norway and is known for its archipelago with 3000 islands and 4500 islets (Ne.se, n.d-b). The vegetation is very diverse with both different species of trees such as oak and pine, but also many low growing plants and shrubs like crowberry and liverwort (Ne.se, n.d-b). The climate in Bohuslän is known to be varied and is classified as Dfb according to the updated version of the Köppen-Geiger climate classification by Peel et al. (2007). Dfb climate type is distinguished by humid winters and cold climate with cool summers (Ne.se, n.d-c). The area generally reaches its highest temperatures in July and August and lowest temperatures in January, February and March (figure 4). Highest amount of precipitation generally falls in September and October and lowest amount in falls in February, March, April and May (figure 4).

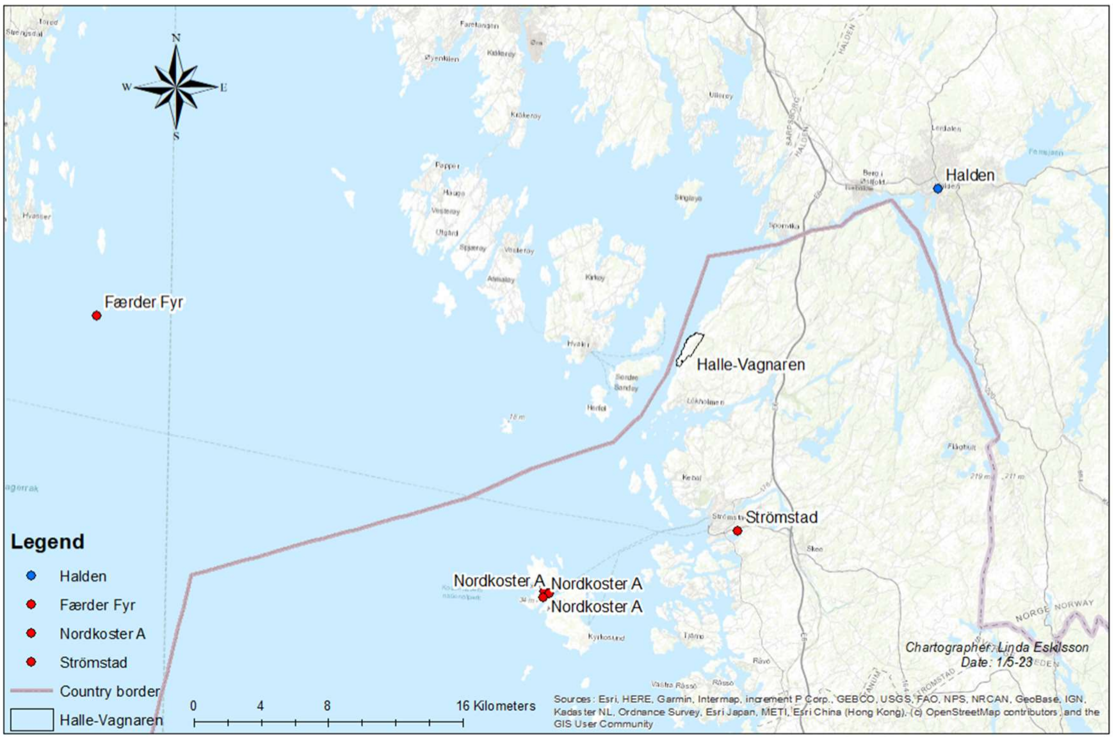

*Figure 2. Figure through the courtesy of Linda Eskilsson. A Map showing the nature reserve of Halle-Vagnaren and the weather stations Nordkoster A, Strömstad, Færder Fyr and Halden, as well as the country border between Sweden and Norway.*

*Figure 3. Scots pine that has grown sideways and twisted at the sample site in Halle-Vagnaren nature reserve (Sweden).*

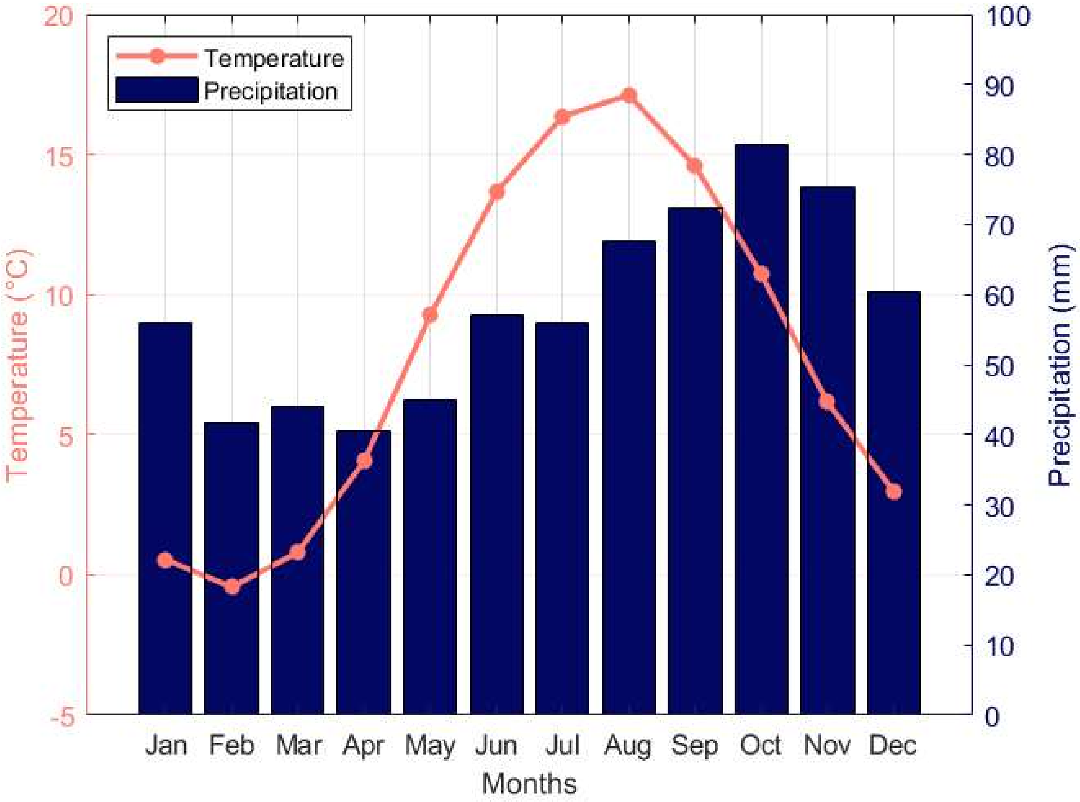

*Figure 4. Climograph to visualise general weather patterns in the study area. The figure shows mean temperature and precipitation for the area between the years 1968-2022. Weather data is taken from the Weather station Nordkoster A (Sweden).*

## 2.2 Fieldwork

A 5 mm increment bore was used to sample 25 Scots pine (*Pinus sylvestris*) trees in the nature reserve of Halle-Vagnaren. Since the area is a virgin forest that is also exposed to harsh winds, many trees have not grown straight (figure 3). The trees that were chosen for sampling were therefore chosen based on how straight they had grown. Only trees that had grown straight were chosen with the intention of getting samples with clear visibility of the growth of the tree rings. The trees were also chosen based on the slope of the area, trees growing in slopes were not chosen. Since the samples were taken in early April, there were some limitations to which trees that were possible to sample. Some trees were frozen and could therefore not be sampled. The samples were taken at chest hight, around 120 – 150 cm above ground level, at least 10 cm from any branches or damages and the intention was to drill to the pith (centre) of the tree for each sample (figure 5). The angle between the bore and the tree was aimed to be 90°. For each tree, two samples were taken with a distance of 90°-180° between each bore hole. The first sample for each tree was labelled A and the second was labelled B. One tree was only sampled once since it was small enough to drill straight through. GPS coordinates for each tree was taken using the app "SW Maps" on a smartphone. In addition, a picture of each tree sampled was taken. The placement of the trees can be seen in figure 6 and 7.

*Figure 5. Sampling of Scots pine using 5 mm increment bore at chest height in Halle-Vagnaren nature reserve (Sweden).*

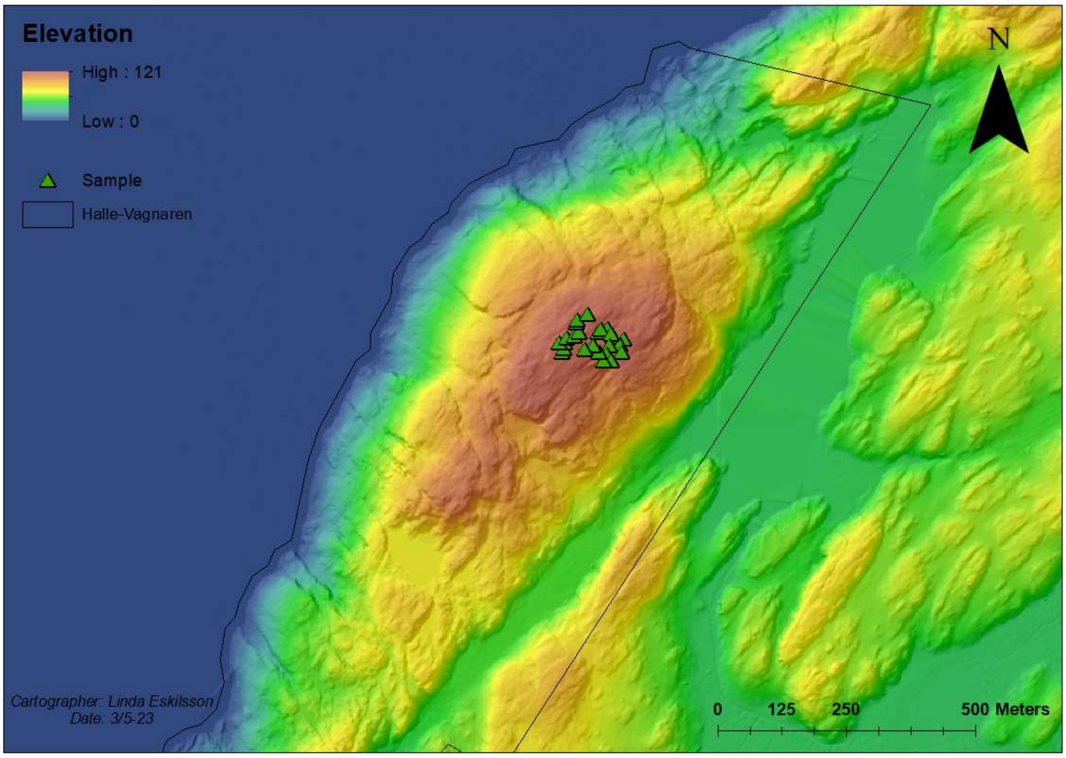

*Figure 6. Figure through the courtesy of Linda Eskilsson. Elevation map of Halle-vagnaren nature reserve (Sweden) and the sample site.*

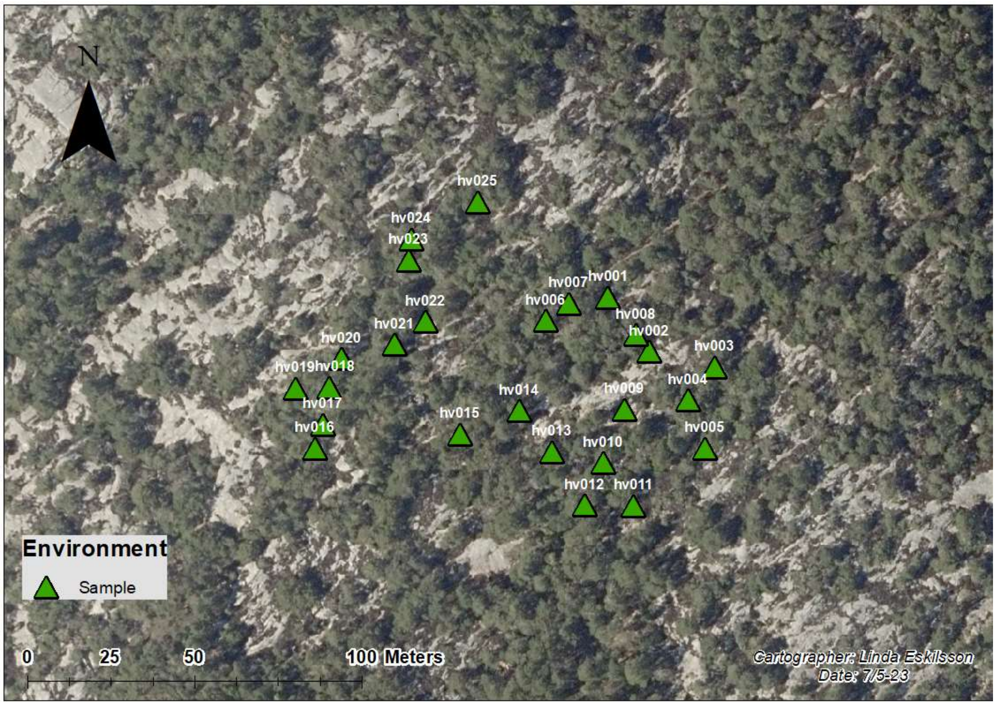

*Figure 7. Figure through the courtesy of Linda Eskilsson. Map showing the locations of where the samples were taken in Halle-Vagnaren nature reserve (Sweden). HV followed by three numbers are the name given to each tree sampled.*

## 2.3 Sample Preparation

Each sample was glued with to a small wooden plank with the cell structure in a vertical direction. The samples rested for about 24 hours with clamps holding them in place so that the glue could solidify. One sample could not be used due to severe rot. Each sample was thereafter sanded by a belt grinder with a sandpaper of lower grit size and then by hand with finer grit sizes of 120, 240, 320, 400, 500, 600 and lastly 800 to better see the tree rings and growth direction of the cells.

## 2.4 Sample Dating

The samples were dated using the naked eye and a microscope. Each sample was dated from the last growing year by the bark to the last visible ring close to the pith. Since the samples were collected in early April of 2023, right before the growing season had properly begun, the ring closest to the bark was 2022. The year for the ring closest to the pith of each sample was noted in a Microsoft Excel spreadsheet along with other notes of interest, such as years with very thin or thick tree rings, years with possible false rings and years with very thick or thin LW or EW. The samples were then scanned into a computer using a scan. The images had a resolution of 1600 pixels per inch (PPI) and were saved as TIFF files. The images were then used in the software CooRecorder (version 9.3.1) (Cybis Elektronik & Data AB; http://www.cybis.se/forfun/dendro/) where the width of the LW and EW of each sample was measured following the cell structure. The samples were also dated in CooRecorder. The measurements and dating were then saved as a POS file with the option “Remove distance to pith” selected. The method for how to measure ring width in CooRecorder was taken from Maxwell and Larsson (2021) and accompanying videos.

## 2.5 Tree-Ring Analysis

The POS files were imported into Cdendro version 9.4 to convert the LW, EW and RW into RWL files. The RW was made by the combination of the width of LW and EW. The new RWL files were imported into CofechaXP2007 (Holmes, 1983). The settings were set to default and then information about possible missing rings or mistakes in the dating for each sample was received. The samples with possible missing rings or other mistakes were inspected in CooRecorder and the measurements or dating was adjusted if needed.

The adjusted RWL files were added separately to Cdendro again. Each A and B sample were compared to each other by making one of them a reference using “Create mean value sample” and then visually comparing the other sample to the created reference. The feature “Show cross correlation” was also used to compare the two samples. “Create mean value sample” was used again with both samples and saved as a RWL file. The purpose of this was to create a mean value from the two samples for each tree. The RWL file was then added to a target collection. The samples in the target collection were compared by using the intercorrelation between in the whole collection as well the T-value for each sample. Four mean value samples from the collection for the RW was sorted out due to low T-values and low intercorrelation. Both A and B sample from the mean value samples that were eventually sorted out were tested against the target collection individually to investigate if one of the samples were faulty and one was better, but no adequate results were found. All samples for the LW were used. The new RWL files were imported to CofechaXP2007 to get statistics. The RWL files was then imported into the software Arstan (ARSTAN_49v1b_MRWE) (Cook & Holmes, 1999). The output was a standardised chronology for LW and RW, as well as different figures.

Monthly precipitation data from Halden in Norway between the years 1895-1991 (figure 2 & table 1) was retrieved from Climate Explorer provided by the Royal Dutch Meteorological Institute (KNMI) (https://climexp.knmi.nl/selectstation.cgi?id=someone@somewhere ). Due to the length of the timeseries from Halden, additional data was retrieved from the Swedish Meteorological and Hydrological Institute (SMHI) (https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=precipitation24HourSum,stations=core,stationid=81540). The data from SMHI was daily precipitation data from the weather station Nordkoster A between 1967 and today (2023) (figure 2 & table 1). Monthly temperature data from Færder Fyr in Norway between the years 1886-1955 (figure 2 & table 1) was also collected from KNMI's Climate explorer. The length of the timeseries from Færder Fyr was only from 1886-1955, additional temperature data from SMHI was therefore downloaded as well (https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=airtemperatureInstant,stations=core). The temperature data from SMHI was hourly data and from two different stations, Nordkoster A and Strömstad (figure 2 & table 1). The temperature data from the three different stations were all different lengths and overlapped with one of the other series (table 1).

The data from Strömstad and Nordkoster A was imported into MATLAB (version R2021b) in sections, due to them having different measuring times during different time periods. Each section was made into a monthly average and then added together into the full series from each station. The data from Færder Fyr had no values in 1928 and this gap was filled with an average from the monthly values from 1927 and 1929. The daily precipitation data from Nordkoster A was also imported into MATLAB. The daily precipitation data from each month was added together to a total monthly value. All weather data was normalised using the following equation: normalisation = (dataset – mean (dataset)) / standard deviation (dataset). The normalised temperature data from Nordkoster A and Færder Fyr were correlated with the normalised data from Strömstad to test if the data was similar enough to add together as one series. Only the overlapping time periods were correlated. Strömstad and Nordkoster A had a correlation of 0.9983 and Strömstad and Færder Fyr had a correlation of 0.9934. The three time series were then added together to make a longer time series, 1886-2022. The overlapping period between Nordkoster A and Halden was also correlated and a r-value of 0.8796 was found. The two series were then added together to make a time series from 1895-2022.

The standardised LW and RW from Arstan was imported into MATLAB and cut to the same time period as the temperature data and precipitation data. The LW and RW for each year was correlated with the temperature and precipitation data for the corresponding year as well as with the previous year. The whole time period for each of the weather dataset was cut into two parts, before and after 1950, to investigate a possible change in the correlation between the climate parameter and ring width before and after 1950. The two chronologies were also cut accordingly. The same correlation analysis as mentioned above was conducted again for each of the two new sections. The results from the correlation analyses were then plotted. The RW and the LW were plotted with the normalised precipitation data for May, June and July based on the results from the previous correlation analysis to better see the shift in correlation between the monthly precipitation and both chronologies.

*Table 1. Type of data retrieved from different weather stations and their operating periods.*

| Station | Type of Data | Operating period |
|---|---|---|
| Færder fyr | Temperature, °C (Monthly mean) | 1886 - 1955 |
| Strömstad | Temperature, °C (hourly) | 1949 - 1973 |
| Nordkoster A | Temperature, °C (hourly)<br>Precipitation, mm/day | 1967- today |
| Halden | Precipitation, mm/month | 1895 - 1991 |

# 3. Result

## 3.1 Statistics Chronology

Statistics from CofechaXP2007 regarding the chronology and the series for both RW and the LW width are presented in table 2 and 3. The number of series are different for the RW because four samples had to be removed due to low t-values and low intercorrelation to the rest of the series.

The chronologies for both RW and LW starts year 1827. The RW chronology has a maximum sample depth of 21 and the LW chronology has a sample depth of 25. The sample depth is 20 series by 1940 and then decreases to 10 series by 1900 for both chronologies (figure 8 & 9). Both standardised chronologies show years with thinner and wider rings (figure 8 & 9). Some more prominent fluctuations can be seen in both the standardised LW chronology and the raw LW chronology (figure 9).

Table 2. Statistics from CofechaXP2007 regarding the chronology and series for the whole ring width (RW). The intercorrelation refers to how well the samples correlate with each other.

| **Whole ring** | |
|---|---|
| Number of trees | 21 |
| Total length of chronology (years) | 196 |
| Intercorrelation | 0.609 |
| Mean length series (years) | 127.8 |

Table 3. Statistics from CofechaXP2007 regarding the chronology and series for the latewood width (LW). The intercorrelation refers to how well the samples correlate with each other.

| **Latewood** | |
|---|---|
| Number of trees | 25 |
| Total length of chronology (years) | 196 |
| Intercorrelation | 0.632 |
| Mean length series (years) | 128.5 |

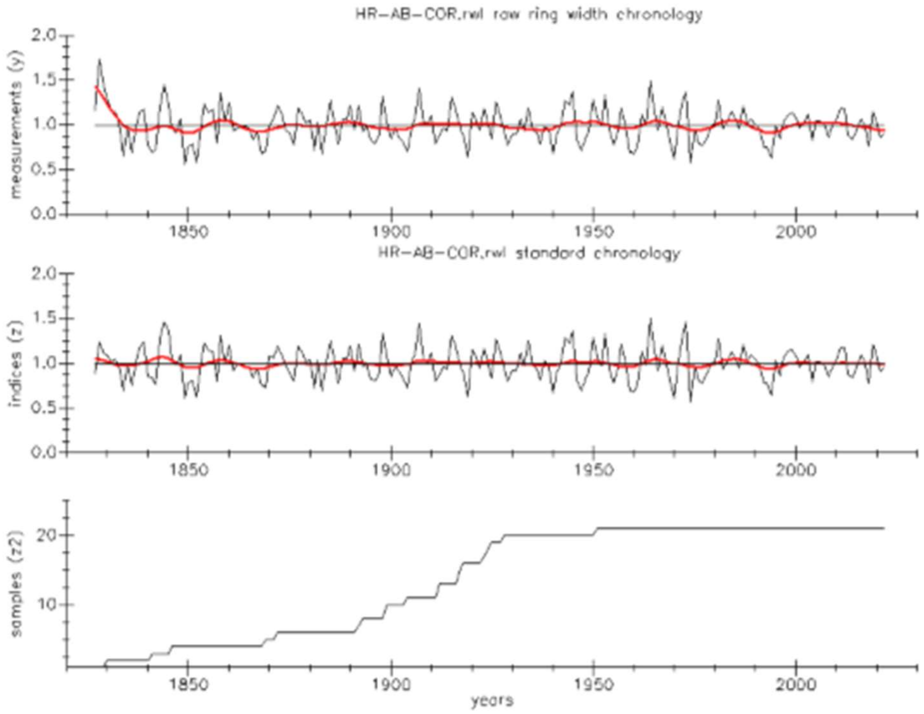

*Figure 8. Produced by Artstan. The top graph shows the raw measurements ring width chronology from the year 1827-2022. The middle graph shows the standardised ring width chronology from the year 1827-2022. The bottom graph shows the sample depth for the chronology.*

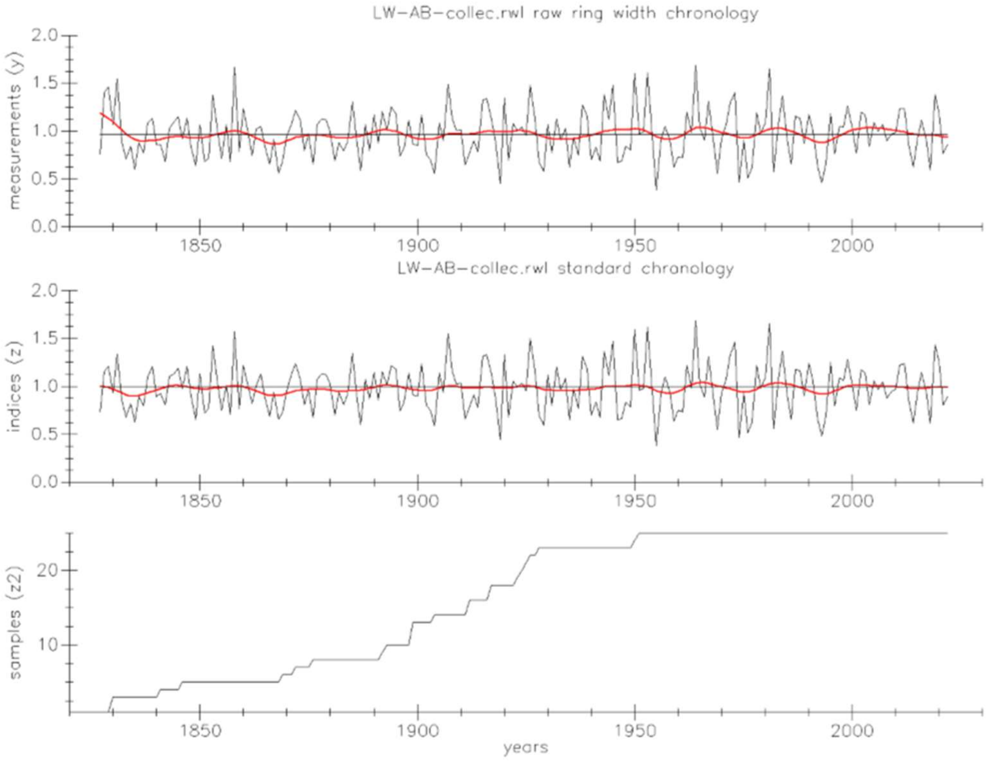

*Figure 9. Produced by Arstan. The top graph shows the raw measurements for the latewood chronology from the year 1827-2022. The middle graph shows the standardised latewood chronology from the year 1827-2022. The bottom graph shows the sample depth for the chronology.*

## 3.2 Climate Correlation Analysis

The results from the correlation analysis between the standardised LW width and normalised monthly precipitation, between the years 1895-2022 (figure 10A), 1895-1949 (figure 10B) and 1950-2022 (figure 10C) can be seen in figure 10. R-values ≥0.396 are statistically significant with a p-value <0.05, according to Person’s correlation coefficient. A Statistically significant correlation between the same year’s normalised monthly precipitation in June and the standardised LW width can be seen for the period 1895-2022 (figure 10A). A statistically significant r-value have also been found for the same year’s normalised monthly precipitation in July and the standardised LW width during the period 1895-1949 (figure 10B) as well as for June during the period 1950-2022 (figure 10C). A tendency for June’s precipitation to affect the LW during the period 1895-1949 can also be seen, but it is not statistically significant. The results from the correlation analysis between the standardised LW width and monthly mean temperature, between the years 1886-2022 (figure 11A), 1886-1949 (figure 11B) and 1950-2022 (figure 11C) can be seen in figure 11. R-values ≥0.396 are statistically significant with a p-value <0.05, according to Person’s correlation coefficient. No statistically significant correlation has been found for any of the time periods.

The results from the correlation analysis between the standardised RW and normalised monthly precipitation, between the years 1895-2022 (figure 10D), 1895-1949 (figure 10E) and 1950-2022 (figure 10F) can be seen in figure 10. R-values ≥0.433 are statistically significant with a p-value <0.05. No statistically significant r-values have been found for the whole period (figure 10D), but a statistically significant correlation between the same year's normalised monthly precipitation in May and the standardised RW can be seen for the period between 1895-1949 (figure 10E). The r-value for the correlation between the same year’s normalised monthly precipitation in June and standardised RW for the period between 1950-2022 is 0.430 and the threshold for a statistically significant value is 0.433, meaning that this correlation is almost statistically significant (figure 10F). The results from the correlation analysis between the standardised RW and monthly mean temperature, between the years 1886-2022 (figure 11D), 1886-1949 (figure 11E) and 1950-2022 (figure 11F) can be seen in figure 11. R-values ≥0.433 are statistically significant with a p-value <0.05, according to Person’s correlation coefficient. No statistically significant correlation has been found for any of the time periods.

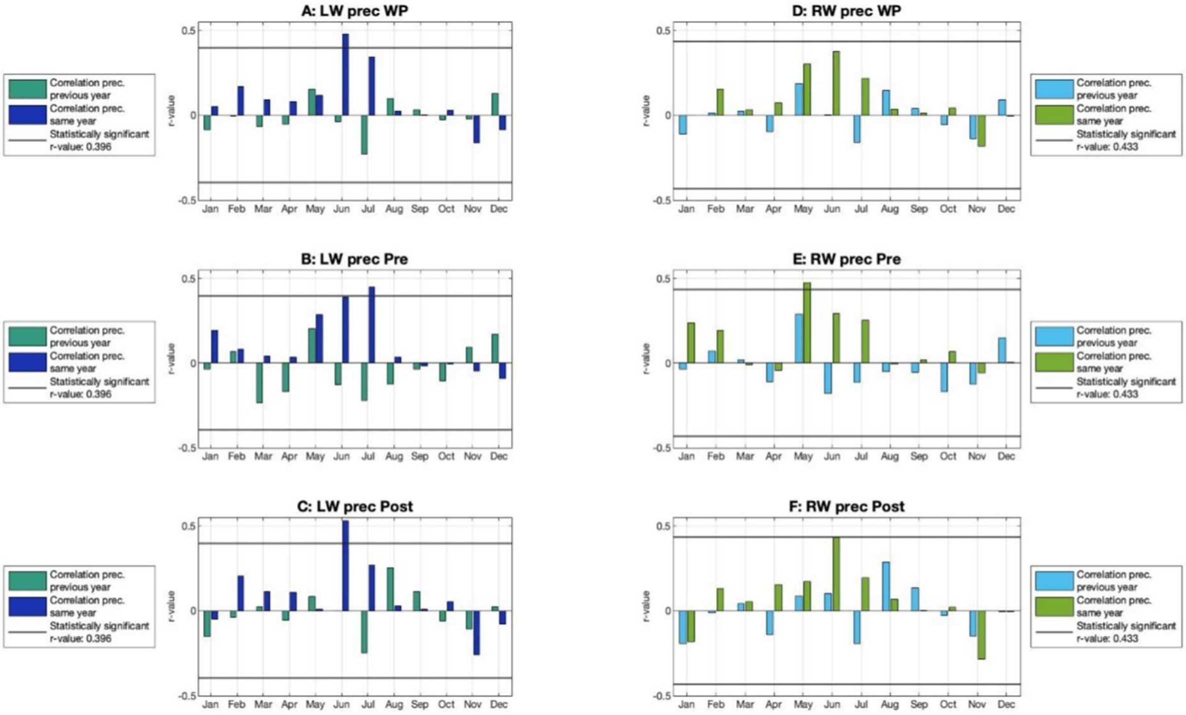

*Figure 10. Correlation between the standardised LW and normalised and averaged monthly precipitation from Halden (Norway) and Nordkoster A (Sweden) as well as the correlation between the standardised RW and normalised monthly precipitation from the same weather stations. A and D show the period 1895-2022, B and E show 1895-1949, and C and F show 1950-2022. R-values ≥0.396 for LW and r-values ≥0.433 for RW have a p-value <0.05 and are statistically significant (Based on Pearson's Correlation Coefficient). Teal bars represent the correlation between the standardised LW width and previous year's monthly precipitation. Dark blue bars represent the correlation between the standardised LW width and the same year's monthly precipitation. Light blue bars represent the correlation between the standardised RW and previous year's monthly precipitation. Light green bars represent the correlation between the standardised RW and the same year's monthly precipitation.*

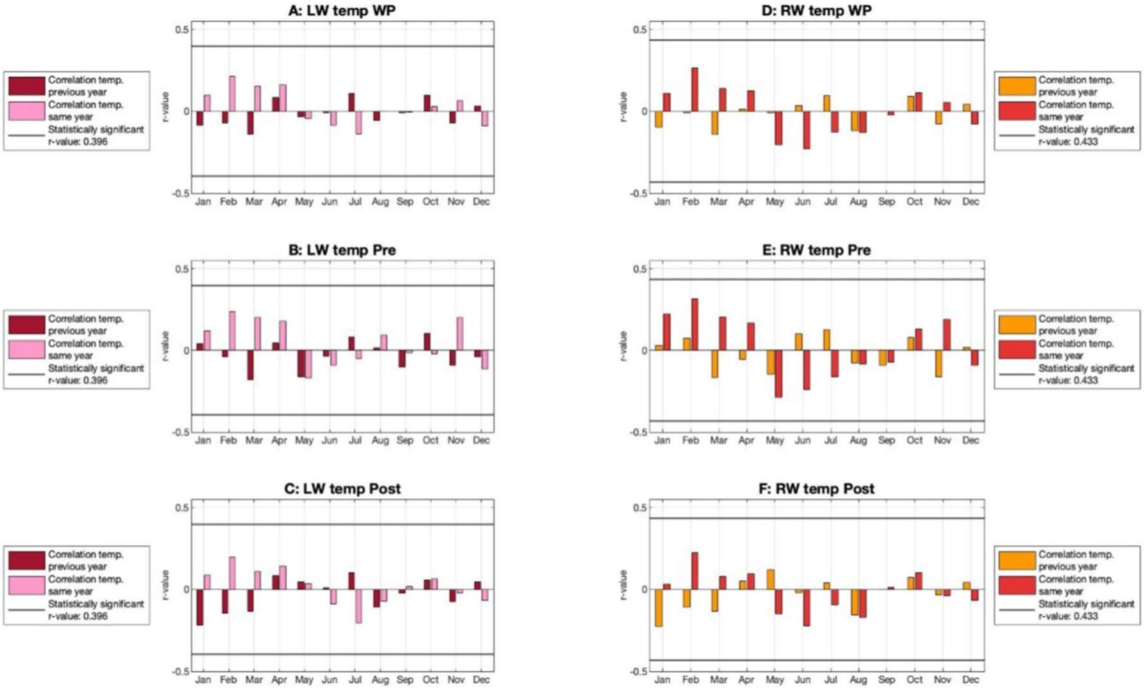

*Figure 11. Correlation between the standardised LW and normalised monthly mean temperature (°C) from Færder Fyr (Norway), Strömstad (Sweden) and Nordkoster A (Sweden) as well as Correlation between the standardised RW and normalised monthly mean temperature (°C) from the same weather stations. A and D show 1886-2022, B and E show 1886-1949, and C and F show 1950-2022. R-values ≥0.396 for LW and R-values ≥0.433 for RW have a p-value <0.05 and are statistically significant (Based on Pearson's Correlation Coefficient). Dark red bars represent the correlation between the standardised LW width and previous year's monthly mean temperature. Pink bars represent the correlation between the standardised LW width and the same year's monthly mean temperature. Orange bars represent the correlation between the standardised RW and previous year's monthly mean temperature. Red bars represent the correlation between the standardised RW and the same year's monthly mean temperature.*

The result in figures 12 show that there is shift from the precipitation in July to the precipitation in June to have the statistically significant correlation to the LW. Figure 13 show the precipitation for June and July for the time period 1895-2022 plotted with the LW to visualise when after 1950 the shift in statistically significant correlation from July to June could have happened in time. The shift seems to start happening around 1960 and becomes more prominent after 1980 (figure 12).

The result in figure 13 show that there is shift from the precipitation in May to the precipitation in June to have the highest correlation to the RW. Figure 12 show the precipitation for May and June for the time period 1895-2022 plotted with the RW to visualise when after 1950 the shift in the highest correlation from May to June could have happened in time. The shift seems to happen around 1980.

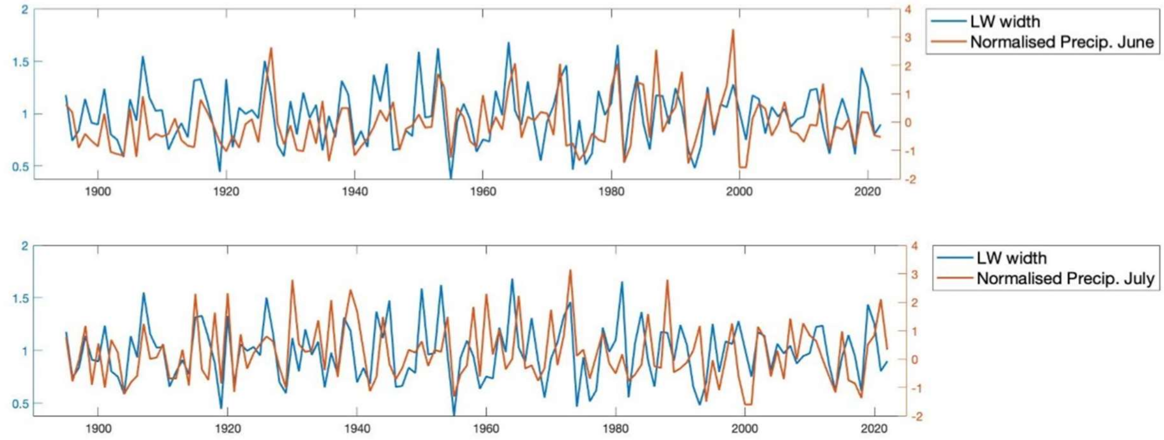

*Figure 12. Standardised LW and normalised and averaged precipitation for June and July. The figure is visualising the correlation during different years over the time period 1895-2022.*

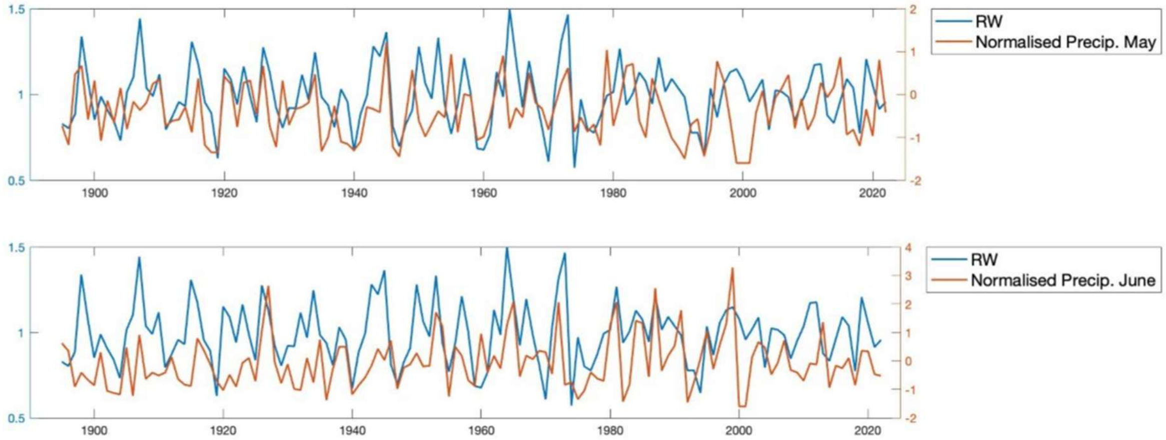

*Figure 13. Standardised RW and normalised and averaged precipitation for May and June. The figure is visualising the correlation during different years over the time period 1895-2022.*

# 4. Discussion

## 4.1 Chronology

The LW chronology has 25 trees, a total length of 196 years and an intercorrelation of 0.632. The intercorrelation show that they are likely affected by the same environmental or climatic parameter. The sample depth remained fairly high, with 20 trees, until 1940 and then decreases rather quickly to 10 trees by 1900. This shows that the sampled trees were fairly similar in age, with few young trees. Higher sample depth means that more samples represent a period of time. Since the sample depth has decreased by 1900, the reliability is not as strong during the time before that.

The chronology for the whole ring has 21 trees, a total length of 196 years and an intercorrelation of 0.609. The intercorrelation is slightly lower than for the LW, yet still high.

The sample depth is also fairly high until 1940 and then decreases. Similar to the LW, the reliability before 1900 is not as strong due to the low sample depth.

## 4.2 Climate parameter affecting latewood

The results indicate that precipitation during the summer the same year of growth affects the growth of LW in the chosen study area in southwestern Sweden, meaning that more precipitation result in wider LW. The results show a statistically significant correlation between LW and precipitation in July before 1950 and in June after 1950. The results show therefore a stable relationship between summer precipitation and the tree ring growth over time, meeting a prerequisite for a tree ring proxy (National Research Council, 2006). A study conducted in south-eastern Sweden by Seftigen et al. (2020) using Scots pine and blue intensity also found a correlation between precipitation and LW during June and July.

A shift from the precipitation in July to the precipitation in June to have the highest correlation can however be seen in the results, indicating a change. The shift seems to start around 1960 and becomes more prominent after 1980 (figure 12). The monthly precipitation for July has a statistically significant correlation before 1950 but June has an almost statistically significant correlation before 1950 as well. After 1950 is the correlation strongest in June and not statistically significant in July. There is a stable relationship between the LW and summer precipitation through the whole period, but the month with the strongest correlation changes. The results shows that there is potential for using LW to reconstruct past hydroclimate in areas that is rather humid, such as southwestern Sweden.

The cause for the shift after 1950 could be due to many reasons, one being an earlier start of the growing season. With an earlier start to the growing season, the conditions that used to be common in July could have shifted to be common in June instead. Studies have shown that the growing season has become longer, in part because of an earlier start, in northern Europe in recent decades (e.g., Aalto et al., 2021; Linderholm et al., 2008; Menzel & Fabian, 1999). It does however seem unlikely that this would be the reason for the shift since the RW is not indicating an earlier start of the growing season. Another reason for the shift could be because of a change of precipitation patterns. There is evidence for changes toward higher amounts of precipitation in the mid and high latitudes after 1950 (Eyring et al., 2021). That would, however, possibly lead to a decrease in sensitivity to precipitation, which cannot be seen in the results of this study. SMHI’s report from 2022 show that there has been an overall increase in precipitation in Bohuslän during the reference period 1991-2020 compared to 1961–1990 (Schimanke et al., 2022). Bengtsson & Rana (2013) suggest that the increases in precipitation on the west coast of Sweden are mainly happening during the winter months and not during summer, however. The possible changes in precipitation in the area in this study might not be in amount, but rather in how the precipitation falls i.e., whether it falls in larger amounts at once or is more spread out. Heavier rainfall at once in combination with a generally warmer climate could lead to the conditions for growth of LW being more favourable in June rather than July. Specific precipitation patterns for this area are, however, out of the scope of this study and could be studied further.

## 4.2 Comparison

A difference in the results from the correlation analysis between the weather data and the LW and the correlation analysis for the whole ring and the weather data can be seen. A tendency for a shift from the precipitation in May to the precipitation in June to have the strongest correlation to RW can be seen in the results. Worth noting is that only the correlation for May in the period 1895-1949 (Figure 10E) is statistically significant, but the r-value in June during the period 1950-2022 is close to statistically significant, showing that there is a tendency. As mentioned above, a shift can be seen in the results for the LW as well, from July to June.

According to Domec & Gartner (2002), does the earlywood (EW) account for 40-80% of the whole ring width. This could mean that the climate parameter affecting the RW could fall more in line with the climate parameter affecting the EW rather than the LW. Seftigen et al. (2020) found a clear correlation between tree rings from southeastern Sweden and summer precipitation. The study by Seftigen et al. (2020) show that EW had the strongest correlation to precipitation May and June and the RW had the strongest correlation in May and June as well. This indicate that the RW fall more in line with the climate parameter affecting EW in sites in south-eastern Sweden. Since the correlation between RW and precipitation in this study is strongest in May and then June, that indicates that there is likely a higher correlation between EW and RW rather than LW and RW. There is a statistically significant correlation for precipitation for both the LW and RW before 1950 and after 1950 is the correlation still statistically significant for the LW but not quite for the RW. This could be an indication of a change in the EW and the climate parameter affecting it. LW could have better potential to be used as a proxy for hydroclimate in this area since the correlation between LW and precipitation is strong through the whole period and not quite as strong for RW.

## 4.3 Improvements and Uncertainties

The weather data was taken from several stations and was combined after being normalised. A correlation analysis was conducted to confirm if the data was similar enough to be combined. The correlation analysis between the precipitation data from Halden and from Nordkoster A had an r-value of 0.8796 which is not as high as the r-value from the correlation analysis between the different temperature data. This could lead to some uncertainties in the results regarding correlation analysis between the precipitation and the chronologies, specifically regarding the results after 1950. There is a possibility that the shift in correlation from July to June could be due to the change of station. However, it should be noted that the data from Halden reached to 1991, meaning that 42 years after 1950 still was from the same station. There is no visible shift in the results after 1991 (Figure 12 & 13), indicating that the change of station might not have affected the results too much. This should nevertheless be considered when interpreting the results of this study.

The whole ring and the LW was measured based on interpretation. A portion of the samples had LW that was more unclear where it started. This led to a decision based on opinion and knowledge was made. To remove some subjectivity, the samples could have been measured by several people and then been compared. Due to time restrictions, this was not possible.

The sample depth decreases around 1940 and is significantly lower by 1900. This could lead to more uncertainty regarding the results before 1950. This could be improved by sampling more trees and increasing the possibility of having more samples reaching back further in time. This was not possible in this study due to a limit in number of trees allowed to sample by Länsstyrelsen and time.

# 5. Conclusion

A statistically significant correlation between LW and precipitation has been found in Halle-Vagnaren nature reserve in Bohuslän, Sweden. The correlation before 1950 is statistically significant in July and statistically significant in June after 1950. A tendency can be seen in June before 1950 as well. The statistically significant correlation for the whole studied period is found in June. The shift from July to June could be due to a change in the growing season or due to changes in precipitation patterns. Specific precipitation patterns for this area have not been investigated in this study and could be studied further.

This study has showed that more information can be found when studying LW specifically, as a difference between the RW and LW can be seen in the results. The results show a stable relationship between summer precipitation and LW growth over time, indicating potential for LW being used as a climate proxy for hydroclimate in the studied area. It should be noted that the month with strongest correlation between precipitation and LW shifts from July to June. This study has also showed that it can be of value to divide the studied period into sections to study changes in the climate parameter affecting the growth of Scots pine. A further step could be to investigate whether LW density show a similar or different correlation to precipitation in the area.

A difference between the LW and RW can be seen. A statistically significant correlation between precipitation and RW has been found, but only in May before 1950. The correlation in June after 1950 is almost statistically significant, indicating a shift. Since there is a statistically significant correlation for the LW after 1950 but not quite for RW, it could be an indication of a change in the EW and the climate parameter affecting it.

This study is a sister project to a study made by Linda Eskilsson. Eskilsson conducted an investigation with focus on EW and the whole ring width in the same area. See "*A Dendrochronological Study of Climate Parameters' influence on Earlywood growth in Scots Pine in the Nature Reserve Halle-Vagnaren in Bohuslän, Sweden* ".

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# 7. Bibliography

Aalto, J., Pirinen, P., Kauppi, P.E., Rantanen, M., Lussana, C., Lyytikäinen-Saarenmaa, P., & Gregow, H. (2021). High-resolution analysis of observed thermal growing season variability over northern Europe. Climate Dynamics, 58, 1477–1493.

Bengtsson, L., & Rana, A. (2013). Long-term change of daily and multi-daily precipitation in southern Sweden. Hydrological processes, 28 (6), 2897-2911. DOI: https://doi.org/10.1002/hyp.9774 .

Blasing, T.J., Solomon, A.M., & Duvick, D.N. (1984). *Response functions revisited*. Tree Ring Bulletin, 44, 1-15.

Bogino, S., Fernández Nieto, M.J. & Bravo, F. 2009. *Climate effect on radial growth of Pinus sylvestris at its southern and western distribution limits*. Silva Fennica, 43(4), 609–623.

Briffa, K.R., Schweingruber, F.H., Jones, PD., Osborn, T.J., Shiyatov, S.G., & Vaganov, E.A. (1998). Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. Nature, 391.

Büntgen, U., Frank, D.C., Schmidhalter, M., Newwirth, B., Seifert, M., & Esper, J. (2006). Growth/climate response shift in a long subalpine spruce chronology Trees, 20. DOI: 10.1007/s00468-005-0017-3.

Cook, E.R & Holmes, R.L. (1999). *Users Manual for Program ARSTAN.* Laboratory of Tree-Ring Research, University of Arizona. https://www.ltrr.arizona.edu/~sheppard/DISC2019/arstan.txt

Domec J.C & Gartner B.L. (2002). *How do water transport and water storage differ in coniferous earlywood and latewood?* Journal of Experimental Botany, 53 (379), 2369–2379.

Eklund, A., Axén Mårtensson, J., Bergström, S., Björck, E., Dahné, J., Lindström, L., Nordborg, D., Olsson, J., Simonsson, L., & Elin Sjökvist, E. (2015). *Sveriges framtida klimat Underlag till Dricksvattenutredningen.* Klimatologi, 14.

Eyring, V., N.P. Gillett, K.M. Achuta Rao, R. Barimalala, M. Barreiro Parrillo, N. Bellouin, C. Cassou, P.J. Durack, Y. Kosaka, S. McGregor, S. Min, O. Morgenstern, and Y. Sun. (2021). *Human Influence on the Climate System*. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. DOI: 10.1017/9781009157896.005.

Fritts, H. C. (1976). *Tree rings and Climate.* Academic Press.

Griffin, D., Woodhouse, C.A., Meko, D.M., Stahle, D.W., Faulstich, H.L., Carrillo, C., Touchan, R., Castro, C.L., & Leavitt, S.W. (2013). *North American monsoon precipitation reconstructed from tree-ring latewood.* Geophysical research letters, 40. DOI:10.1002/grl.50184.

Holmes, R.L. (1983). Computer-assisted quality control in tree-ring dating and measurment. Tree-ring bulletin, 43.

Hughes, M.K. (2002). *Dendrochronology in climatology - the state of the art.* Dendrochronologia , 20 (1–2), 95-116. DOI: https://doi.org/10.1078/1125-7865-00011 .

IPCC. (2021). *Summary for Policymakers.* Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. DOI: 10.1017/9781009157896.001.

Kalela-Brundin, M. (1999). *Climatic information from tree-rings of Pinnus sylvestris L. and a reconstruction of summer temperatures back to AD1500 in Femundsmarka, eastern Norway, using partial least squares regression (PLS) analysis*. The Holocene, 9 (1).

LaMarche, V.C. Jr., (1978). *Tree-ring evidence of past climatic variability.* Nature, 276.

Lebourgeois, F. (2000). *Climatic signals in earlywood, latewood and total ring width of Corsican pine from western France*. Annals of forest science, 57.

Leichenko, R., & O'brien, K. (2019). Climate and Society. Polity press.

Linderholm, H.W., Bjorklund, J.A., Seftigen, K., Gunnarson, B.E., Drobyshev, I., Jeong, J.H., Stridbeck, P., & Liu, Y. (2009). Dendroclimatology in Fennoscandia – from past accomplishments to future potentials. Climate of the Past Discussions, 5, 1415–1461.

Linderholm, H.W., Peng Zhang, P., Gunnarson, B.E., Björklund, J., Farahat, E., Fuentes, M., Rocha, E., Salo, R., Seftigen, K., Stridbeck, P., & Liu, Y. (2014). *Growth dynamics of tree-line and lake-shore Scots pine (Pinus sylvestris L.) in the central Scandinavian Mountains during the Medieval Climate Anomaly and the early Little Ice Age.* Frontiers in Ecology and Evolution, 2. DOI: https://doi.org/10.3389/fevo.2014.00020.

Linderholm, H.W., Walther, A., & Chen, D. (2008). *Twentieth-century trends in the thermal growing season in the Greater Baltic Area*. Climatic Change, 87, 405–419. DOI: 10.1007/s10584-007-9327-3.

Masson-Delmotte, V., M. Schulz, A. Abe-Ouchi, J. Beer, A. Ganopolski, J.F. González Rouco, E. Jansen, K. Lambeck, J. Luterbacher, T. Naish, T. Osborn, B. Otto-Bliesner, T. Quinn, R. Ramesh, M. Rojas, X. Shao and A. Timmermann. (2013). *Information from Paleoclimate Archives*. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Maxwell, S., & Lars-Ake Larsson, L.Å. (2021). Measuring tree-ring widths using the CooRecorder software application. Dendrochronologia, 67. DOI: https://doi.org/10.1016/j.dendro.2021.125841.

McCarroll. D., Jalkanen, R., Hicks, S., Tuovinen M., Gagen, M., Pawellek, F., Eckstein, D., Schmitt, U., Autio, J., & Heikkinen, O. (2003). *Multiproxy dendroclimatology: a pilot study* *in northern Finland.* The Holocene, 13 (6), 829–838. DOI: https://doi.org/10.1191/0959683603hl668rp

Meko, D.M., & Baisan, C.H. (2001). Pilot study of latewood-width of conifers as an indicator of variability of summer rainfall in the North American monsoon region. International Journal of Climatology, 21. DOI: 10.1002/joc.6461.

Menzel, A., & Fabian, P. (1999). *Growing season extended in Europe*. Nature, 379.

Nationalencyklopedin. N.d-a. *Tall*. Ne.se. https://www-ne-se.ezproxy.ub.gu.se/uppslagsverk/encyklopedi/l%C3%A5ng/tall

Nationalencyklopedin. N.d-b. *Bohuslän*. Ne.se. http://www-ne-se.ezproxy.ub.gu.se/uppslagsverk/encyklopedi/lång/bohuslän.

Nationalencyklopedin. N.d-c. *Köppens klimatklassificering*. Ne.se. https://www-ne-se.ezproxy.ub.gu.se/uppslagsverk/encyklopedi/l%C3%A5ng/k%C3%B6ppens-klimatklassificering .

National Research Council. (2006). *Surface Temperature Reconstructions for the Last 2,000 Years.* The National Academies press.

NOAA. (January 12, 2023). *Climate Change: Global Temperature.* Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). *Updated world map of the Köppen-Geiger climate classification.* Hydrol. Earth System Science, 11, 1633–1644. DOI: https://doi.org/10.5194/hess-11-1633-2007 .

Schimanke, S., Joelsson, M., Andersson, S., Carlund, T., Wern, L., Hellström, S., & Kjellström, E. (2022). *Observerad klimatförändring i Sverige 1860–2021.* Klimatologi, 69.

Seftigen, K., Cook, E.R., Linderholm, H.W., Fuentes, M., & Björklund, J. (2015a) *The Potential of Deriving Tree-Ring-Based Field Reconstructions of Droughts and Pluvials over Fennoscandia.* Journal of Climate, 28 (9), 3453–3471. DOI: https://doi.org/10.1175/JCLI-D-13-00734.1 .

Seftigen, K., Björklund, J., Cook, E. R., & Linderholm, H. W. (2015b). *A tree-ring field reconstruction of Fennoscandian summer hydroclimate variability for the last millennium.* Climate Dynamics, 44, 3141-3154. DOI: 10.1007/s00382-014-2191-8 .

Speer, J.H. (2010). *Fundamentals of tree-ring research.* The University of Arizona Press.

Statistiska centralbyrån (SCB). (2022). *Folkmängd i landskapen den 31 december 2021.* SCB.se. https://www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/folkmangd-och-befolkningsforandringar---helarsstatistik/folkmangd-i-landskapen-den-31-december-2021/

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015). *The trajectory of the Anthropocene: The Great Acceleration.* The Anthropocene Review, 2(1), 81–98. DOI: https://doi.org/10.1177/2053019614564785 .

Stokes, M. A., & Smiley, T. L. (1968). *An introduction to tree-ring dating.* University of Chicago.

Wilmking, M., Scharnweber, T., van der Maaten-Theunissen, M., & van der Maaten, E. (2017). *Reconciling the community with a concept—The uniformitarian principle in the dendro-sciences*. Dendrochronologia, 44, 211-214. DOI: https://doi.org/10.1016/j.dendro.2017.06.005