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A Dendrochronological Study of Climate Influence on Earlywood growth in Scots Pine in the Nature Reserve Halle-Vagnaren in Bohuslän, Sweden

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Abstract

There has been a great acceleration of global mean surface temperature increase since the 1950s, where changes in different spheres and more frequent weather and climate extremes have been observed. To be able to better understand the past, and thereby prepare for the future, climate proxies are used to reconstruct the climate. Tree rings are one of them and is considered to be one of the best proxies, with its high resolution and availability. Each year, an annual tree ring is formed, which consist of earlywood, produced in the early part of the growing season, and latewood, produced on the late part of the growing season. There are both internal and external factors that affect the tree ring growth. Two of the external factors are temperature and precipitation. This report investigates the correlation between the two climate parameters and earlywood width, as well as the tree ring width. It is also investigated if the correlation differs between the period before and after the Great Acceleration in 1950. Lastly it is also investigated if earlywood and tree ring width can be used for climate reconstructions. A total of 25 Scots pine trees (Pinus Sylvestris) were sampled upon with a 5 mm tree ring bore from the nature reserve Halle-Vagnaren located in Bohuslän, Sweden. Standardized chronologies were created and compared to normalized mean temperature and precipitation data. No statistically significant correlation was found between temperature and earlywood width and ring width, which indicates that temperature is not the limiting factor. A statistically significant correlation was found in precipitation in May the same year for both earlywood and ring width for the early period. The similarities can be explained by the high proportion of earlywood in an annual ring. In the late period, no statistically significant correlation was found for earlywood, which indicates that the climate parameter influencing the earlywood have changed. There was almost a statistically significant correlation found for precipitation in June the same year for ring width during the late period. This raises the question regarding the influence of latewood in the ring width, where potential changes in climate only affect the formation of latewood. What is interesting to see is that there are differences during the studied periods, indicating that there has been a shift regarding what climate parameters affect the tree ring growth. Earlywood has the potential to be used for a precipitation reconstruction, but only before 1950. Further investigation is needed to see if the correlation remains further back in time, as well as extended research in the area, to see if the climate parameters have the same influence in a wider area. The tree ring width has also a potential with reconstructing precipitation, however, the shift in correlating months needs to be further investigated.

Sammanfattning

Det har skett en kraftig ökning av den globala medeltemperaturen sedan 1950-talet, där förändringar i olika sfärer och mer frekventa väder- och klimatextremer har observerats. För att bättre kunna förstå det förflutna, och med det förbereda för framtiden, används proxydata för att rekonstruera klimatet. Årsringar från träd är en av dessa och anses som en av de bästa källorna till proxydata, tack vare dess höga resolution och tillgänglighet. Varje år produceras en årsring, vilket består av vårved, som bildas under den tidiga delen av växtsäsongen, och sommarved, som bildas under den senare delen av växtsäsongen. Det finns både interna och externa faktorer som påverkar trädets tillväxt. Två av de externa faktorerna är temperatur och nederbörd. Den här rapporten undersöker korrelationen mellan de två klimatparametrarna och vårvedens vidd, samt hela ringens vidd. Det undersöks även om det finns en skillnad i korrelation mellan perioden innan och efter ”the Great Acceleration” vid 1950. Sist undersöks även om vårved och hela ringen kan användas för klimatrekonstruktioner. Totalt togs prov från 25 tallar (Pinus Sylvestris) med en 5 mm borr från naturreservatet Halle-Vagnaren i Bohuslän, Sverige. Standardiserade kronologier framställdes och jämfördes med normaliserade medelvärden för temperatur och nederbörd. Ingen statistisk signifikant korrelation hittades mellan temperatur, vårved och hela ringen, vilket indikerar att temperatur inte är den begränsade faktorn. En statistisk signifikant korrelation hittades för nederbörd i maj samma år, för både vårved och hela ringen under den tidiga perioden. Likheten kan förklaras av den höga andelen vårved i en årlig ring. I den sena perioden hittades ingen statistisk signifikant korrelation för vårved, vilket indikerar att det har skett en förändring i den begränsande faktorn för vårveden. En statistisk signifikant hittades nästan för nederbörd i juni samma år för hela ringen under sen sena perioden. Detta väcker frågan angående inflytandet av sommarved i hela ringen, där potentiella förändringar i klimatet bara påverkat formationen av sommarveden. Vad som är intressant att se är att det finns skillnader under de studerade perioderna, vilket indikerar på en förändring angående vilken klimatparameter som påverkar trädets tillväxt. Vårved har potentialen att användas för rekonstruktion av nederbörd, dock bara innan 1950. Vidare forskning behövs för att se om korrelationen fortsätter längre tillbaka i tiden, samt utökad forskning i området för att se om klimatparametrarna har samma inverkan i en större area. Hela ringen har också potential för att göra en rekonstruktion av nederbörd, dock behöver förändringen i korrelation mellan månaderna undersökas vidare.

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1. Introduction

It is important to study past climate to see how the climate system has responded to changes in climate forcings in the past. This can then be used in assessments on how the climate system might respond to changes in climate forcings in the future (Jansen et al., 2007). One important climate variability that have been observed when studying past climate is the abrupt increase in global mean surface temperature, with an increase of 1.1°C between 1850 and 2020 (IPCC, 2023). Tree rings can be used as proxy data and have an exceptional value when reconstructing past climate variability (Fritts, 1976; Jansen et al., 2007; Linderholm, 2001). They have both a wide geographical availability, are easy to replicate (National Research Council, 2006) and the production and dating of annual rings gives the possibility to precisely calibrate the tree ring width each year with climate data (Fritts, 1976).

There are limiting factors that affect the trees growth, such as, temperature, precipitation, and access to sunlight (Fritts, 1976). A variation in tree ring width, that is how much the tree grew one year, is an indicator that there is an external factor that affects the tree. Björklund et al. (2017) points out that tree ring width (RW), is one of the most frequently used parameters, whereas earlywood width (EW) is one of the more rarely used. There are however a few exemptions, such as the work from Kalela-Brundin (1999), Tuovinen (2005), Jönsson and Nilsson (2009) and Seftigen et al. (2020).

Variations in tree growth that is happening today, as well as weather variations and climate patterns, have also happened in the past (Fritts, 1976). Reconstruction of different climate parameters are needed to be able to make predictions of future climates (Linderholm et al., 2004). There have been more temperature reconstructions made in Fennoscandia (which Sweden is a part of) compared to reconstructions of precipitation (Linderholm et al., 2010). The dry conditions that is needed for trees to be precipitation dependent is not generally associated with the geographical location of Fennoscandia, and the information given from the precipitation reconstructions might not be as strong as those of temperature in higher latitudes (Linderholm et al., 2010). Seftigen (2014) demonstrates however that there are areas in Sweden that have the potential to provide a good proxy for moisture variability.

Trees growing in higher latitudes or elevation are more affected by temperature, where trees growing in arid forests are more affected by drought (Fritts, 1976). There have also been more studies made in the northern and middle part of Fennoscandia (e.g. Jönsson & Nilsson, 2009; Kalela-Brundin, 1999; Linderholm et al., 2010), compared to the southern part. Those that have been made have also been more centred on the central and southeastern part of Sweden (e.g. Jönsson & Nilsson, 2009; Seftigen et al., 2020). With a few exceptions, such as the work from Seftigen et al. (2015a) and Seftigen et al. (2015b), not many studies have been carried out in southwestern Sweden.

There are considerably more people living in the southern part of Sweden, compared to the northern part (Statistics Sweden, 2022). There are also, for example, few places with old and untouched forest by the coast of the province Bohuslän (Länsstyrelsen Västra Götaland, n.d.). To be able to make longer reconstructions, forests that are untouched by humans are prioritized to get as old trees as possible. It is therefore of interest to find and study trees in virgin forest in previously unexplored areas to gain a broader insight into the climate in the past.

1.1 Aim

The aim of this work is to broaden the information of dendrochronological studies in southwestern Sweden regarding earlywood (EW), as well as further information about tree ring width (RW). It is also investigated if EW could be used for climate reconstructions. This is done by investigating the influence of climate parameters (temperature and precipitation) on EW in Scots pine (*Pinus sylvestris* L.) taken from the nature reserve Halle-Vagnaren in Bohuslän, Sweden. It will also be investigated if the climate parameters affecting the EW have changed after the Great Acceleration in year 1950 (Steffen et al., 2015), compared to what it was before. The same analysis will be done for RW and compared with the analysis made on EW.

1.2 Research Questions

The research will be carried out with the following questions in mind:

- To what extent does earlywood width, as well as the tree ring width of Scots pine (*Pinus sylvestris* L.) from the nature reserve Halle-Vagnaren (Bohuslän, Sweden) and temperature/precipitation correlate?
- What differences can be seen between the climate parameter affecting the earlywood width compared to the climate parameter affecting the tree ring width in Scots pine (*Pinus sylvestris* L.) from the nature reserve Halle-Vagnaren (Bohuslän, Sweden)?
- In what way have the climate parameter affecting earlywood width along with the tree ring width changed after the Great Acceleration in 1950 (Steffen et al., 2015), compared to what it was before?
- How well can earlywood width, as well as the tree ring width, be used to make a climate reconstruction for temperature/precipitation?

1.3 Dendrochronology

By counting the annual rings throughout the sample, the age of the tree can be determined. An annual ring consist of a section of earlywood (EW) and latewood (LW) (Fritts, 1976; Stokes & Smiley, 1996). Earlywood is produced in the beginning of the growing season and is characterized by having large and thin-walled cells (Fritts, 1976; Stokes & Smiley, 1996), and accounts for 40-80% of the annual ring (Domec & Gartner, 2002). Latewood is produced at the end of the growing season and is characterized by having small and thick-walled cells (Fritts, 1976; Stokes & Smiley, 1996). The boundary between two rings is seen by an abrupt change in cell size, from the smaller latewood from one year, to the larger earlywood for the next year (Fritts, 1976; Stokes & Smiley, 1996). See figure 1 for visualization.

There are both internal and external factors that affect how much the tree grows (Fritts, 1976). Fritts (1976) points out some of the most important external factors, which are temperature, water, soil minerals, light and carbon dioxide. To be able to find a clear climate signal in the tree, a variation in the width of the tree rings is needed (Fritts, 1976; Stokes & Smiley, 1996). This gives the sample a pattern, that can be used to compare samples with each other (Fritts, 1976; Stokes & Smiley, 1996). The trees must however be affected by the same environmental factor (Fritts, 1976). This technique, i.e. dating samples through comparison of growth patterns between dated and undated samples, is called crossdating (Fritts, 1976; Stokes & Smiley, 1996), and is in itself evidence that there is something that is affecting the tree ring growth (Fritts, 1976). In years with extreme events, when the external factor is highly limiting, there is a possibility that the growth of the ring is discontinuous, leading to a potential absence in some part of the ring. This is called a missing or locally absent ring (Fritts, 1976; Stokes & Smiley, 1996). Stress periods during the growing season can cause the formation of false rings, which are latewood like rings formed in the earlywood section (figure 1). Both of these rings can be detected with the help of crossdating (Fritts, 1976; Stokes & Smiley, 1996). The limiting factor can change from year to year, as well as its correlation to the tree ring growth (Fritts, 1976). Higher temperature can for example be beneficial during the early part of the growing season, whereas it during the later growing season instead becomes the most limiting factor for growth (Fritts, 1976).

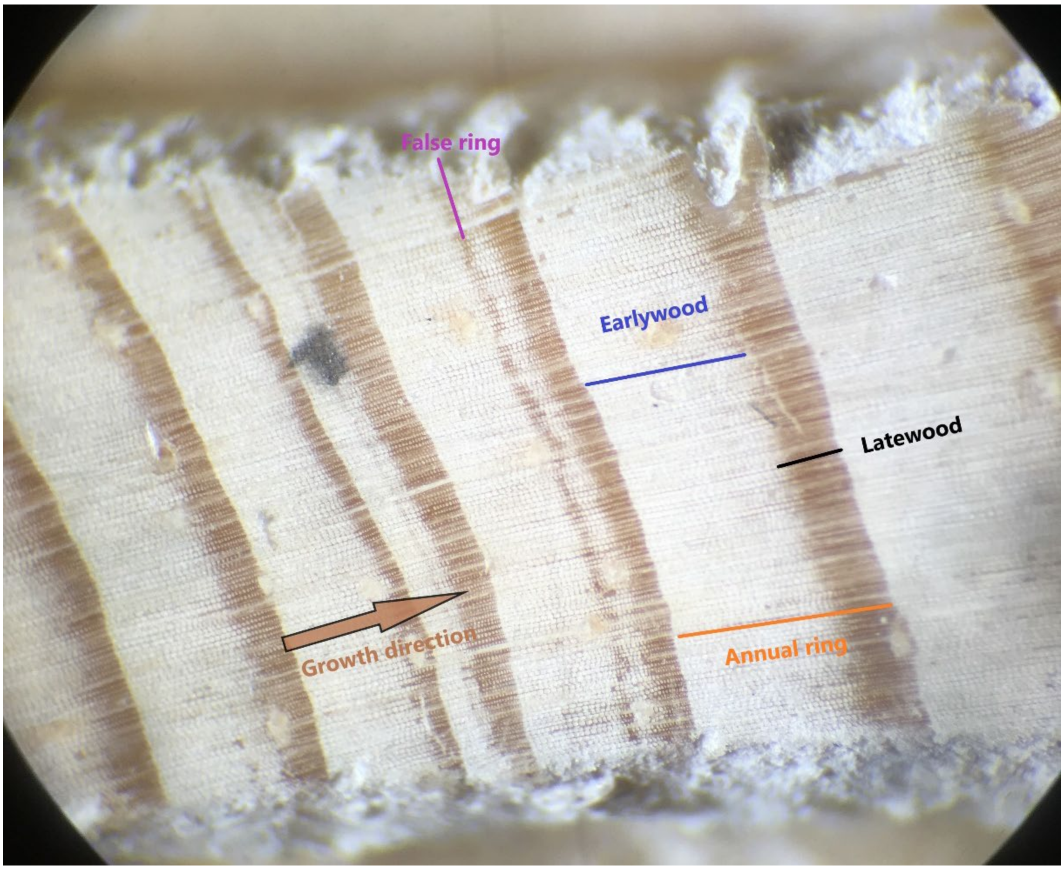

Figure 1. Picture of a sample and its tree rings from Halle-Vagnaren (Bohuslän, Sweden) through the lens of a microscope. The growth direction of the cells goes from the left to the right in the picture. Earlywood is produced in the beginning of the growing season and is the part of the tree ring where the colour of the cells are lighter, shown in blue. Latewood is produced at the end of the growing season, where the cells have a darker colour, shown in black. An annual tree ring consists of earlywood and latewood, shown in orange. False rings, shown in purple, can be produced during stress periods under the growing season and are characterized by bands of darker cells which gradually returns to lighter coloured cells, compared to the abrupt shift from latewood previous year and earlywood the next year.

1.4 The Great Acceleration and Climate Change

There is a high confidence that human activities have caused global warming, where the greatest influence have been through greenhouse gas emissions (IPCC, 2023). A greater increase in global surface temperatures have not been seen over the last 2000 years, as have been observed since the 1970s (IPCC, 2023). In a comparison made between the periods 1861-1890 and 1991-2020, an increase of 1.9°C was found for annual mean temperature in Sweden (Schimanke et al., 2022). Since the 1980s the mean increase in temperature has been around 0.5°C/decennium in Sweden (Schimanke et al., 2022).

There have been observations of rapid changes in different spheres, such as the biosphere, hydrosphere and atmosphere, to name a few (IPCC, 2023). More frequent weather and climate extremes have also been observed since the 1950s (IPCC, 2023). The term "Great Acceleration" have been used to describe the abrupt change in the Earth System, regarding the socio-economic and biophysical sphere (Steffen et al., 2015). The associated graphs shown in the work from Steffen et al. (2015), shows an acceleration after the 1950s in both these sectors, which have become a symbol for the Anthropocene (Steffen et al., 2015).

The hydrological climate in Sweden have changed during the latest millennia, where the current climate is relatively wet when especially comparing the period from around 1000-1200 CE (Chen et al., 2021). For the past 100 years (1902-2018) there have been an overall wetting trend, in particular from the period 1950-2014 and is caused by an increase in winter precipitation (Chen et al., 2021). There is however a difference in the trend depending on the geographical location in Sweden, where in the north, the most significant increase in precipitation was found and a smaller increase or a decreasing trend was found for the middle and southern part of Sweden (Chen et al., 2021). Since the 1930s, there have been an increase in amount of annual precipitation, where it has gone from 600 mm/year to almost 700 mm/year (Schimanke et al., 2022). The amount of precipitation fallen each year has however varied from year to year, where there can be periods where the precipitation is consistent and some periods where there is a great difference between years (Schimanke et al., 2022).

2. Method

2.1 Site Description

There are over 5000 nature reserves in Sweden (Naturvårdsverket, n.d.), where Halle-Vagnaren (N 59°39'65" E 11°35'50") is one of them and is located around 15 km north of Strömstad in the province Bohuslän (Länsstyrelsen Västra Götaland, n.d.), close to the border of Norway (figure 2). The vegetation consists mostly of pine trees, with exposed bedrock in the area (Länsstyrelsen Västra Götaland, n.d.). The forest surrounding Halle-Vagnaren is described to have the characteristics of a pine virgin forest, which have adapted to the salt and wind effect of the coastal climate (Länsstyrelsen Västra Götaland, n.d.). It is also one of the few remaining untouched forest in the coast of the province Bohuslän (Länsstyrelsen Västra Götaland, n.d.). According to the updated Köppen-Geiger classification, the climate in Bohuslän is classified as Dfc, which is described as cold, without a dry season and with warm summers (Peel et al., 2007). The coldest month is February, with a mean temperature around -1°C (SMHI, 2009) and the warmest month is August, with a mean temperature around 17°C (figure 3). The yearly precipitation varies from around 600 mm to 1000 mm (SMHI, 2009), with the highest volume fallen in October (figure 3). The lowest volume falls during February and April (figure 3).

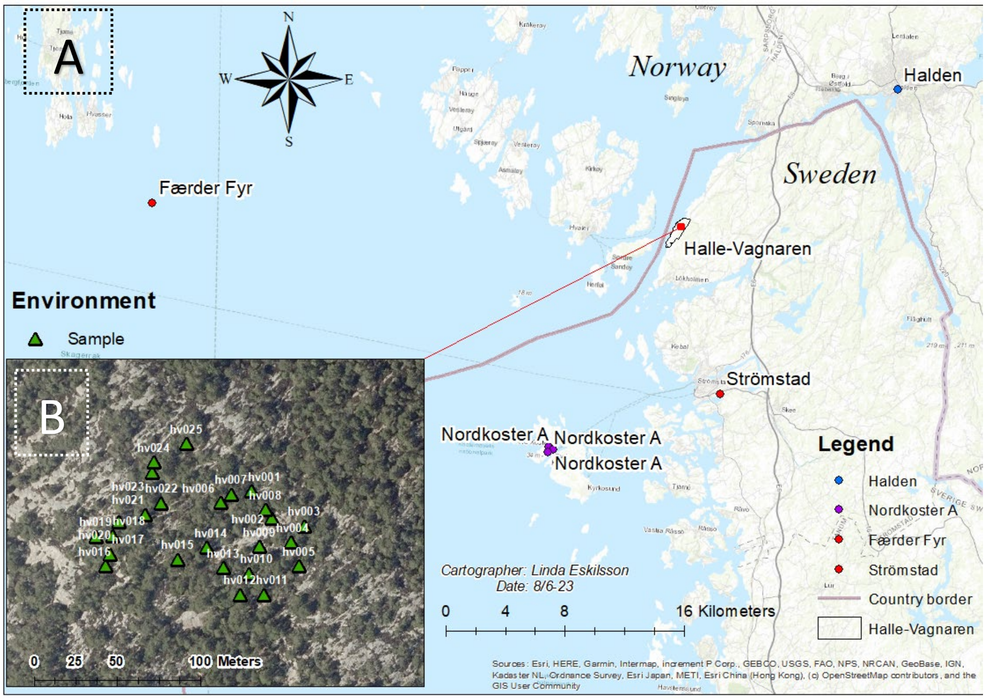

Figure 2. A) Location of the study area, Halle-Vagnaren (Bohuslän, Sweden), as well as the location of the stations where the weather data was taken from. Where temperature data was taken from is marked with red colour, and precipitation data is marked with blue colour. Station where both precipitation and temperature data was taken from is marked with a purple colour. Halden and Færder Fyr is located in Norway. Nordkoster A and Strömstad is located in Sweden. B) An enlargement of the area where the samples were taken and their location, as well as an overview of what the environment looked like.

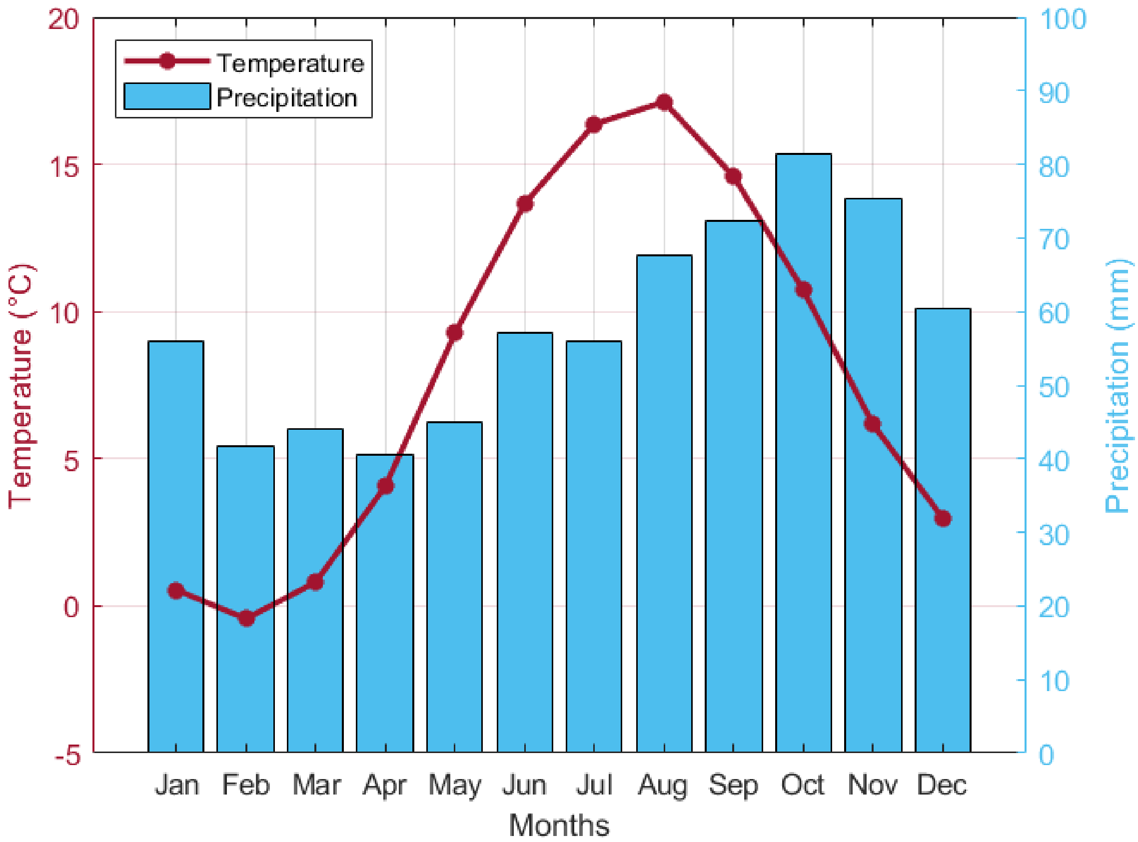

Figure 3. Climograph over Halle-Vagnaren located in Bohuslän (Sweden), representing mean temperature and precipitation for each month from the time period 1968-2022. Both datasets were taken from the weather station Nordkoster A (Sweden), 17 km from the study site. See table 1 for further information regarding the datasets.

When arriving at Halle-Vagnaren for the field work, snow had accumulated on the ground and some of the trees were frozen in some parts, which was noticed when taking the samples. The thickness of the bark varied from roughly 0.5 - 2 cm. The trees in the study area consisted mainly of pine trees, with only a few birch trees present. There were a variety of ways the pine trees grew; some grew straight up and some in a twisted way (figure 4). Areas with exposed rock was also present (figure 2B). Heather, blueberries, lingonberries and moss were also present. The samples were taken on a hill with an elevation of 120 meters above sea level (figure 5A), with the ocean located northwest of the area (figure 2A). The slope where the samples were taken were low (figure 5B).

Figure 4. Pictures taken from field work in Halle-Vagnaren (Bohuslän, Sweden), representing different varieties of how Scots pine grew in the study area.

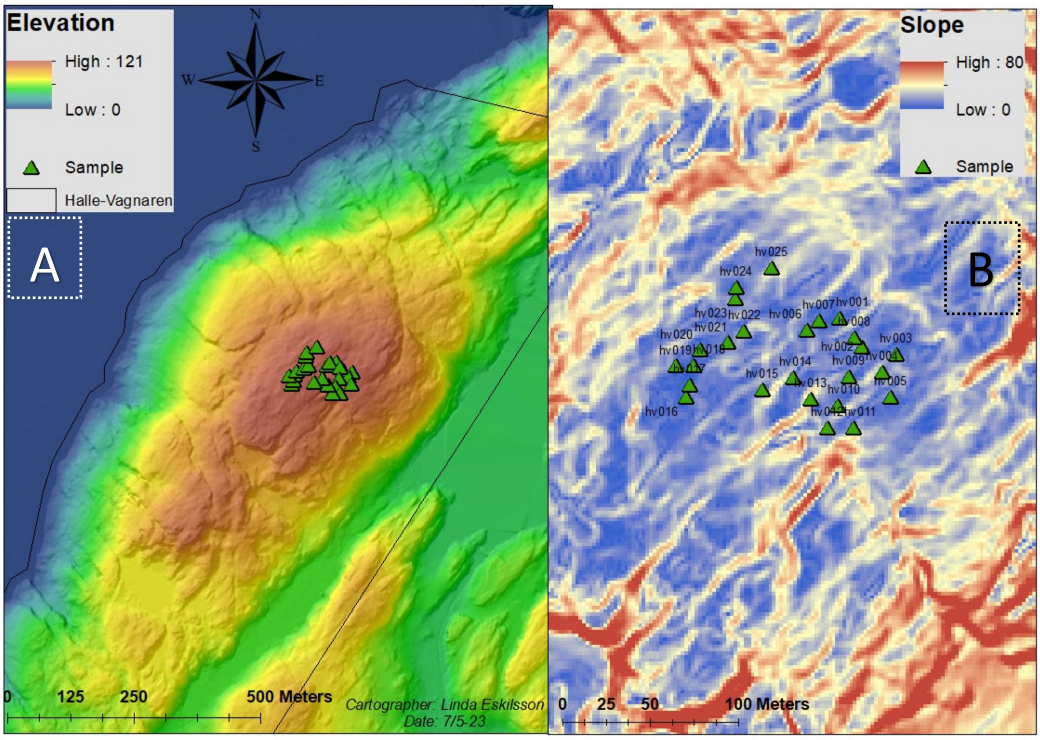

Figure 5. A) shows the elevation (meters above sea level) and B) shows the slope (°) of the study area, Halle-Vagnaren (Bohuslän, Sweden). The location of where the samples were taken is shown in both maps, represented by green triangles. Elevation data from SLU (2019).

2.2 Sampling and Sample Preparation

With permission from Länsstyrelsen, a total of 25 trees were sampled upon from the study area Halle-Vagnaren. Both young and old looking trees were targeted and chosen randomly in the area. To avoid complications in further steps, only trees growing at a straight angle were selected. Two samples for each tree were taken (labelled A and B) from all but one tree, where the last tree was bored straight through. This was done using a tree ring bore with a bore size of 5 mm. The samples were taken in chest hight, around 110-130 cm from the ground and around 10 cm from branches, creases or other variations on the tree. The tip of the bore was aimed at the centre of the tree (pith) and the angle between the bore and the tree was 90° (figure 6). The bore was bored so that it had passed the centre of the tree. The second sample was taken in the same way, but 90°-180° from the first sample. The samples were kept in straws, which were marked with the tree number and if it was the first or second sample (A or B). The coordinates of the trees were taken with a phone application, called “SW Maps”. Pictures of each tree were also taken, as a compliment to how the environment and the slope were where the tree grew, as well as potential damages on the tree.

Figure 6. A) shows the angle when taking a tree sample from chest hight. B) shows how the bore is aimed for the centre of the tree (pith).

In the lab, the samples were then glued to wooden borders with the help of clamps, then labelled and left to dry one night. The samples were glued so that the centre was in the direction of how the tree grew from the ground. The day after, the samples were separated with a band saw. After that, they were sanded with a sandpaper machine with lower grain size, and then sanded by hand with graine sizes of 240, 320, 400, 500, 600 and then 800 (figure 7A).

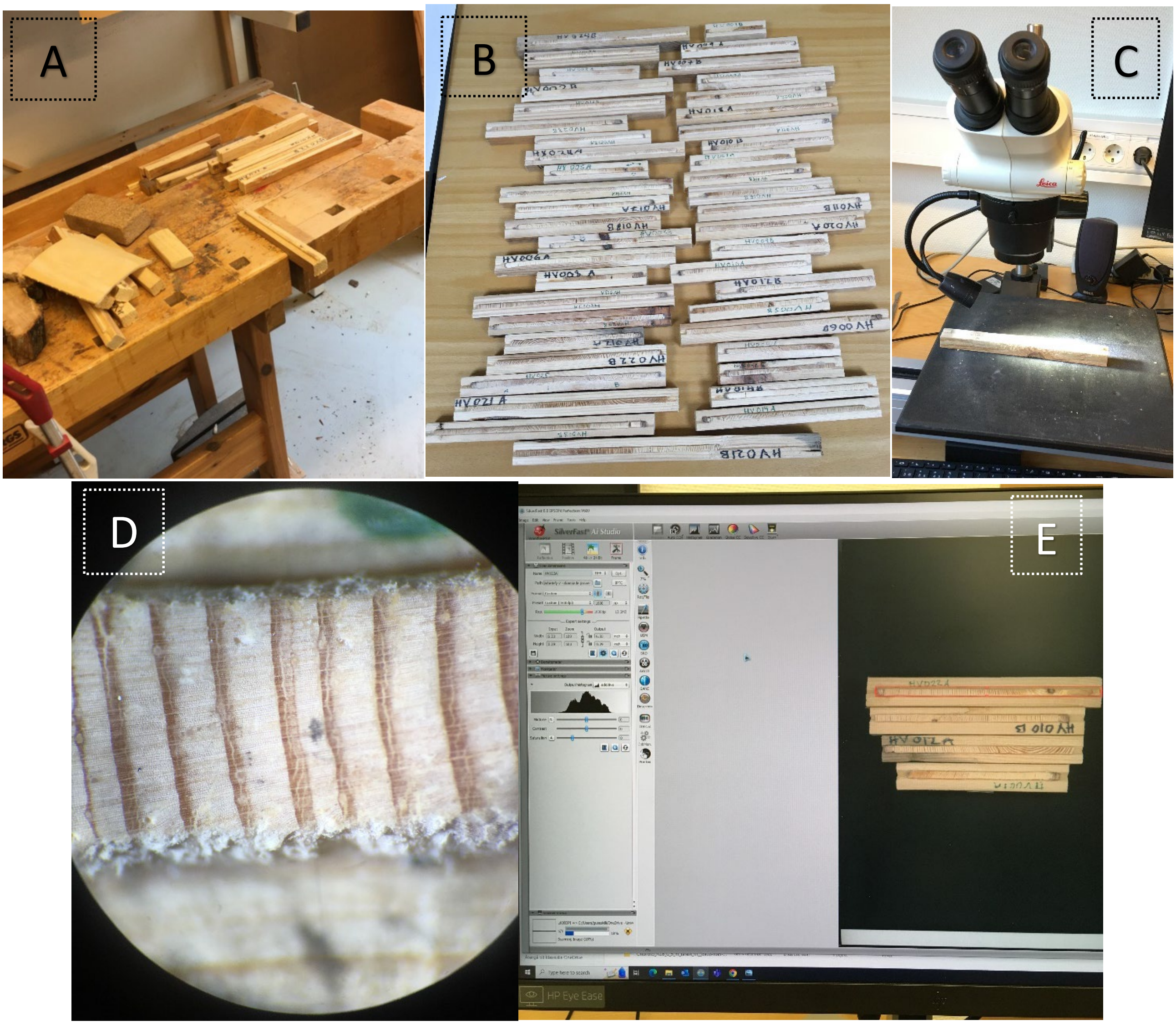

Figure 7. Pictures of some of the steps in the preparation and measuring of the samples taken from Halle-Vagnaren (Bohuslän, Sweden). A) shows a station where the samples were sanded by hand in the lab. B) shows all samples used in the analysis. C) and D) show a setup where the rings are counted for a sample, where a dot shown in D represents a decennium. E) shows the step when the samples were scanned into a computer.

2.3 Dating and Measuring the Samples

The samples were dated by counting the rings from the bark to the centre of the sample (figure 7C-D). The first ring represented year 2022, because the samples were collected in April 2023, which means that the growing season just had started and no whole ring had been formed yet. Thin and thick years, latewood (LW) and earlywood (EW), as well as false rings and other notes were noted down in Microsoft Excel.

An EPSON scanner was used to scan the samples into a computer, with the resolution set to 1600 pixels per inch (figure 7E). The pictures were then used in the software CooRecorder (version 9.3.1), to be able to measure the width of the latewood and earlywood for each ring. The method on how to do this was followed by Maxwell and Larsson (2021) report and by the included videos. When the length of both LW and EW for each ring of a sample was measured, it was saved as a *.pos* file and the option "Remove distance to pith" was selected.

2.4 Chronology Construction

The *.pos* files were then used in CDendro (version 9.4) (Maxwell & Larsson, 2021) to convert the width of the latewood (LW), earlywood (EW) and the tree ring (RW) (earlywood plus latewood) into *.rwl* files, which then were used in CofechaXP2007 (short Cofecha) (Holmes et al., 1986). Each file was used separately in the program. The different information in the parts given by the program were used to determine where potential missing rings could be found. Those samples were then looked at again in CooRecorder to see if any mistakes were made, and fixed if one was found.

The new *.rwl* files for EW, LW and the RW were then added to CDendro again, separately. Each A and B sample for the same tree were compared, by making one of them a reference by using "Create Mean Value Sample" and then clicking on the other sample. The comparison was done both visually and with the help of "Show cross correlation" by selecting both samples. A separate collection was created and set to be the target collection. "Create Mean Value Sample" were then used again with both samples selected and saved as a *.rwl* file and loaded into the target collection. The trees with only one sample were made as a reference and saved the same way. This was done for all trees for the RW, LW and EW. The complete target collection for RW, LW and EW was then used to create a chronology, one for each parameter. This was done by again choosing "Show cross correlation" to see *ttest* values and intercorrelation for each individual tree compared to the rest. Trees with low values were removed and its responding A and B sample were correlated with the target collection separately, to see if one on its own were better correlated. The samples that showed a better correlation were added to the target collection and the ones that did not were removed. The chronologies for LW, EW and RW were then saved as new *.rwl* files and loaded separately into Cofecha to get statistics. The same files were then loaded into Arstan (ARSTAN_49v1b_MRWE) (Holmes et al., 1986) to get the standardized ring width index (RWI) for the whole chronology, as well as different figures. The standardized RWI takes away different parameters that affect the tree when it grows, such as the growth trend for trees, so that only the influence of climate parameters remain (Holmes et al., 1986).

2.5 Correlation Analysis between Chronologies and Climate Parameters

Temperature data was retrieved from 3 different stations; Færder Fyr (1886-1955), Strömstad (1949-1973) and Nordkoster A (1967-still operating (2023)) (table 1). The precipitation data was retrieved from 2 different stations; Halden (1895-1991) and Nordkoster A (1967-still operating (2023)) (table 1). The datasets from Færder Fyr and Halden was retrieved from KNMI's Climate Explorer (https://climexp.knmi.nl/selectstation.cgi?id=someone@somewhere) and had a monthly resolution (table 1). The datasets from Strömstad and Nordkoster A was retrieved from the Swedish Meteorological and Hydrological Institute (SMHI) (https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=airtemperatureInstant,stations=core), where the temperature had an hourly resolution and the precipitation a daily resolution (table 1).

Table 1. List of the stations where the climate data used in the analysis came from. Færder Fyr and Halden are stations from Norway. Strömstad and Nordkoster A are stations from Sweden.

Station	Resolution	Operating period	Used period
Temperature (°C)			
Færder Fyr	Monthly	1886 - 1955	1886 - 1955
Strömstad	Hourly	1949 - 1973	1956 - 1967
Nordkoster A	Hourly	1967 - still operating	1968 - 2022
Precipitation (mm)			
Halden	Monthly	1895 - 1991	1895 - 1991
Nordkoster A	Daily	1967 - still operating	1992 - 2022

All datasets were loaded into MATLAB (version R2021b) (table 1). Due to the different measuring times for Nordkoster A (temperature) and Strömstad (Appendix A), these datasets were loaded in sections into MATLAB. The datasets that did not have a monthly resolution (see table 1) were converted to monthly averages for each of the stations. There were no values for the year 1928 for Færder Fyr, and mean values between 1927 and 1929 were calculated and replaced the missing values.

The following equation was used to normalize all weather data: *normalization = (dataset – mean (dataset)) / standard deviation (dataset)*. Where there was an overlap in the normalized temperature data between the stations, a correlation analysis was made for that period. The same was done for the normalized precipitation data and its stations. The correlation between Strömstad and Nordkoster A (temperature) was 0.9983 (r-value) and the correlation between Strömstad and Færder Fyr was 0.9934 (r-value). The r-value for the correlation between Nordkoster A (precipitation) and Halden was 0.8796. The normalized temperature data from the tree stations were added together into one longer time series, 1886-2022, which represents the whole study period. The data was then cut into two shorter periods; the early period between 1886-1949 and the late period between 1950-2022. The normalized precipitation data from the two stations were also added together into one longer time series, 1895-2022. The data was also cut into two periods; the early period between 1895-1949 and the late period between 1950-2022.

The standardized RWI for EW and the RW from Arstan was imported into MATLAB and cut to the same length as the normalised temperature and precipitation data for each studied period (whole, early, late). The standardized data was then correlated with the temperature and precipitation data from the months previous year, as well as the months the same year for each studied period. The values were then plotted together with the correlation value from Person's correlation coefficient.

2.6 Climograph and Maps

The temperature and precipitation dataset from Nordkoster A (table 1) was loaded into MATLAB. One value for each month was calculated from the time period 1968-2022 for both datasets. The values were then plotted to create a climograph.

The layers from table 2 was used in ArcMap (version 10.8.1). All polygons except the one representing Halle-Vagnaren was removed from the nature reserve dataset and made hollow, so that the boundary for the area would be shown. A hillshade layer was used behind the elevation layer for better visualization and was created with the tool "Hillshade", with the elevation data as the input layer. The elevation data was used again as an input layer when creating a slope layer with the tool "Slope". New *.shp* files were created in ArcCatalog (version 10.8.1), one for each station (figure 2). A point was added, and the coordinates were set for the station by right clicking and selecting "Absolute X, Y..." and "Decimal Degrees" were chosen.

Table 2. Layers used when creating maps in ArcMap.

Type of data	File type	Source	Link to data
Orthophoto	Tif	SLU (2018)	https://www.slu.se/site/bibliotek/soka-och-lana/soka/digitala-kartor/
Elevation data	Raster	SLU (2019)	
Nature reserves	Shape	Länsstyrelserna (2022)	https://ext-geodatakatalog.lansstyrelsen.se/GeodataKatalogen/?query=784386983_GeodataKatalogen_AdvancedUser_resultset&loc=sv
Country bounder	Shape	Lantmäteriet (2022)	https://www.geodata.se/geodataportalen/srv/swe/catalog.search;jsessionid=A53B7F318B9CE4E86E8A08DEB82DF94D#/metadata/442facf2-d8a0-4d79-b48b-271da01cd490
Sample point	Shape	Field work	-
Basemap	Basemap	ArcMap	-

3. Results

3.1 Statistics and Standardized Chronology

There were one more dated tree for RW compared to the number for EW, and the mean length of the series were slightly longer for RW than for EW (table 3). The length of the chronologies was the same for both RW and EW and the intercorrelation was higher for RW compared to that of EW (table 3). Before 1951, there is a decrease in the number of trees representing each year when going further back in time (figure 8C and 9C). There are 8-20 trees for both the EW and RW representing the time period (1895-2022) for the precipitation data (figure 8C and 9C). There are 5-22 trees for both the EW and RW representing the time period (1885-2022) for the temperature data (figure 8C and 9C). A fluctuation in width can be seen for both EW and RW, shown in part A and B for the graphs in figure 8-9.

Table 3. Statistics from the program Cofecha. The samples were taken from the nature reserve Halle-Vagnaren (Bohuslän, Sweden). The length of the chronology goes from 1827-2022. The "number of dated series" represents the number of trees for each chronology.

	Earlywood	Ring width
Number of dated series (trees)	20	21
Length of chronology (years)	196	196
Mean length of series (years)	126	128
Intercorrelation	0.562	0.609

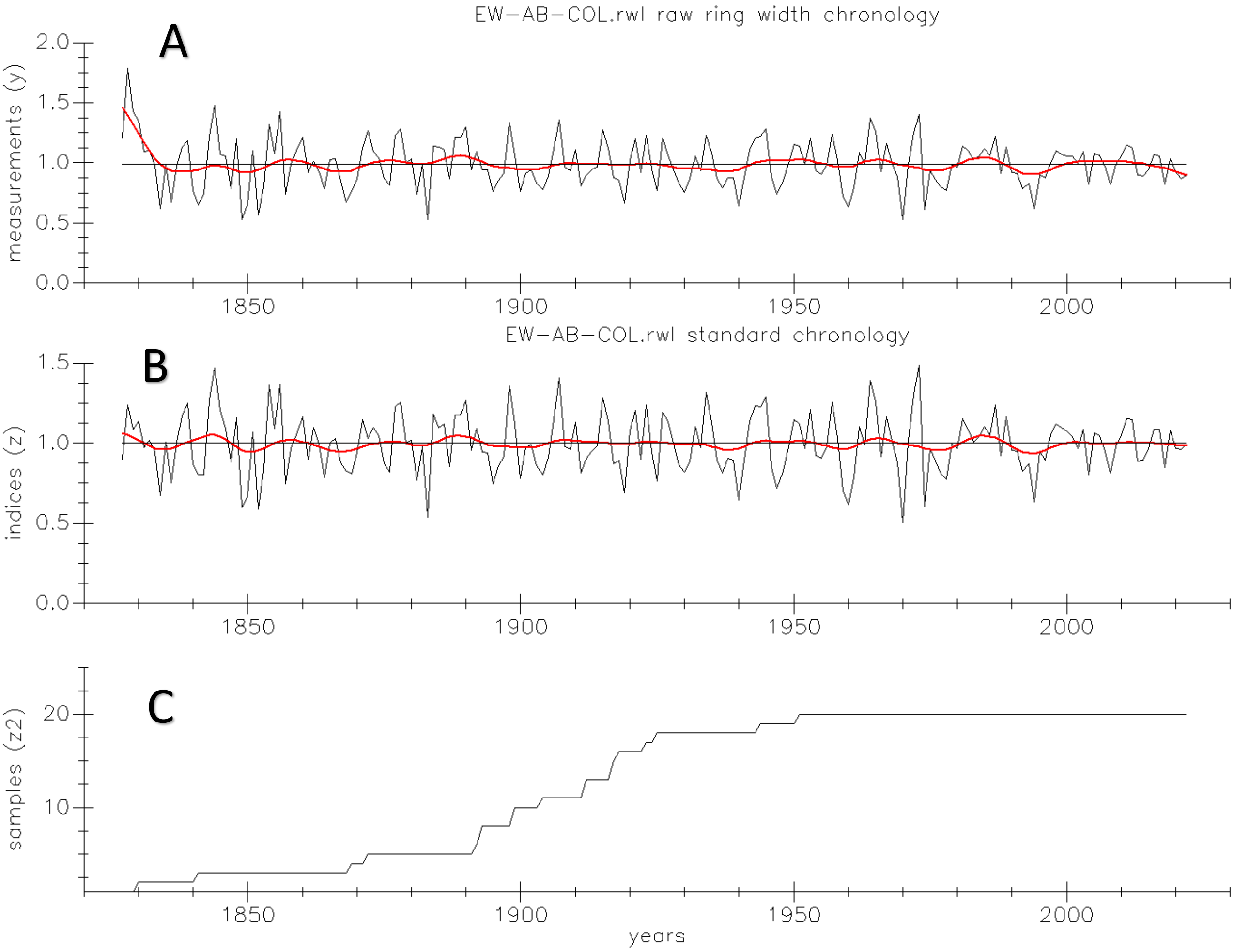

Figure 8. A) and B) represents a chronology for the earlywood width, A) based on the raw ring width data and B) based on the standardized ring width data for the time period 1827-2022. C) represents the sample depth, that is how many samples that are covering each year. The graph was produced with the Arstan program.

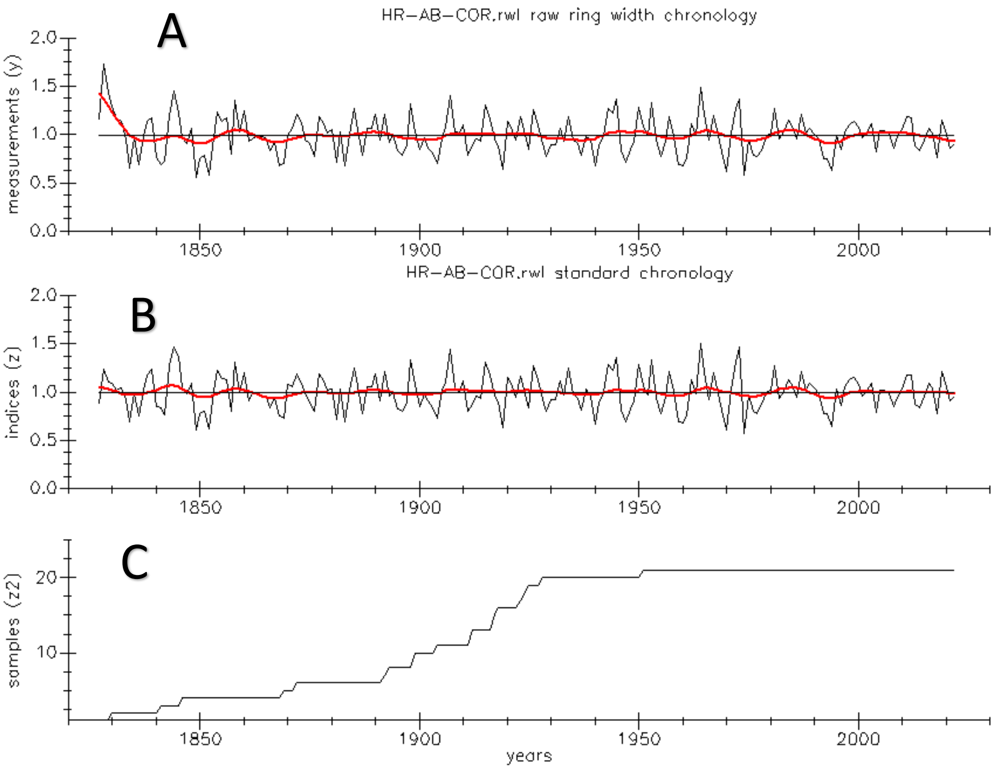

Figure 9. A) and B) represents a chronology for the tree ring width, A) based on the raw ring width data and B) based on the standardized ring width data for the time period 1827-2022. C) represents the sample depth, that is how many samples that are covering each year. The graph was produced with the Arstan program.

3.2 Correlation Analysis with Precipitation

A statistically significant correlation (SSC) can be found the same year in May, when correlating precipitation and EW for the early period (figure 10B). For the whole study period and late period, no SSC was found for neither precipitation the same year nor the year before (figure 10A and 10C).

When looking at the whole study period for the correlation analysis between RW and precipitation, no SSC could be found, neither when comparing the precipitation previous year nor the same year for each month (figure 10D). A SSC can be found for the early period for May the same year (figure 10E). There is almost a SSC for June the same year (difference of 0.003) for the late period (figure 10F).

3.3 Correlation Analysis with Temperature

No SSC can be found for either study periods (whole, early, late), when comparing temperature and EW, as well as temperature and RW (figure 11). This is true for the temperature previous year and the same year for each month.

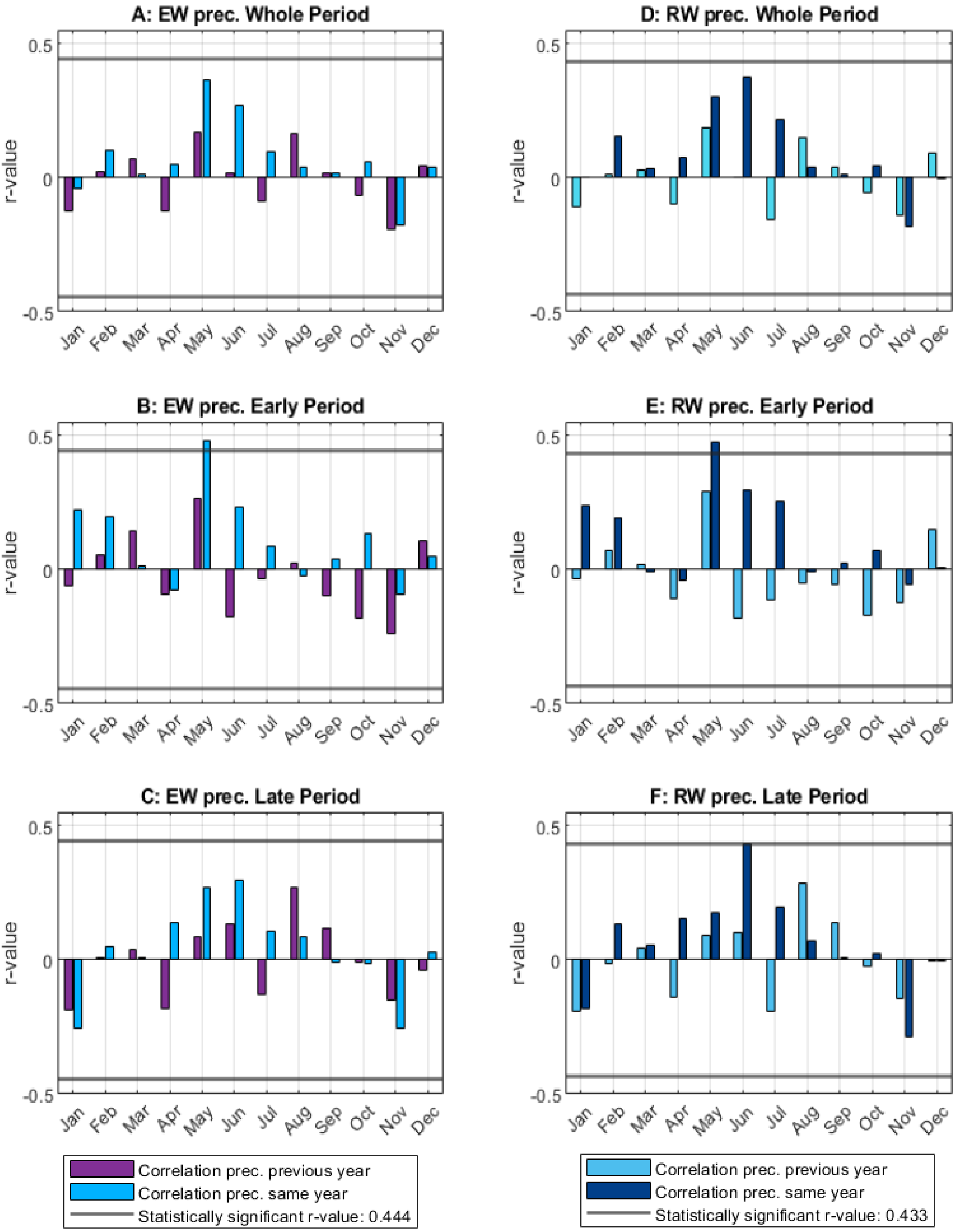

Figure 10. Correlation analysis between precipitation and both earlywood (EW) (A-C) and the tree ring width (D-F). The analysis was done for the whole study period (A and D, 1895-2022), the early period (B and E, 1895-1950) and for the late period (C and F, 1951-2022). The statistically significant r-value was 0.444 for EW and 0.433 for RW, with a p-value of 0.05, based on Person's correlation coefficient. The turquoise and purple bars represent correlation with precipitation from the previous year. The light and dark blue bars represent correlation with precipitation from the same year.

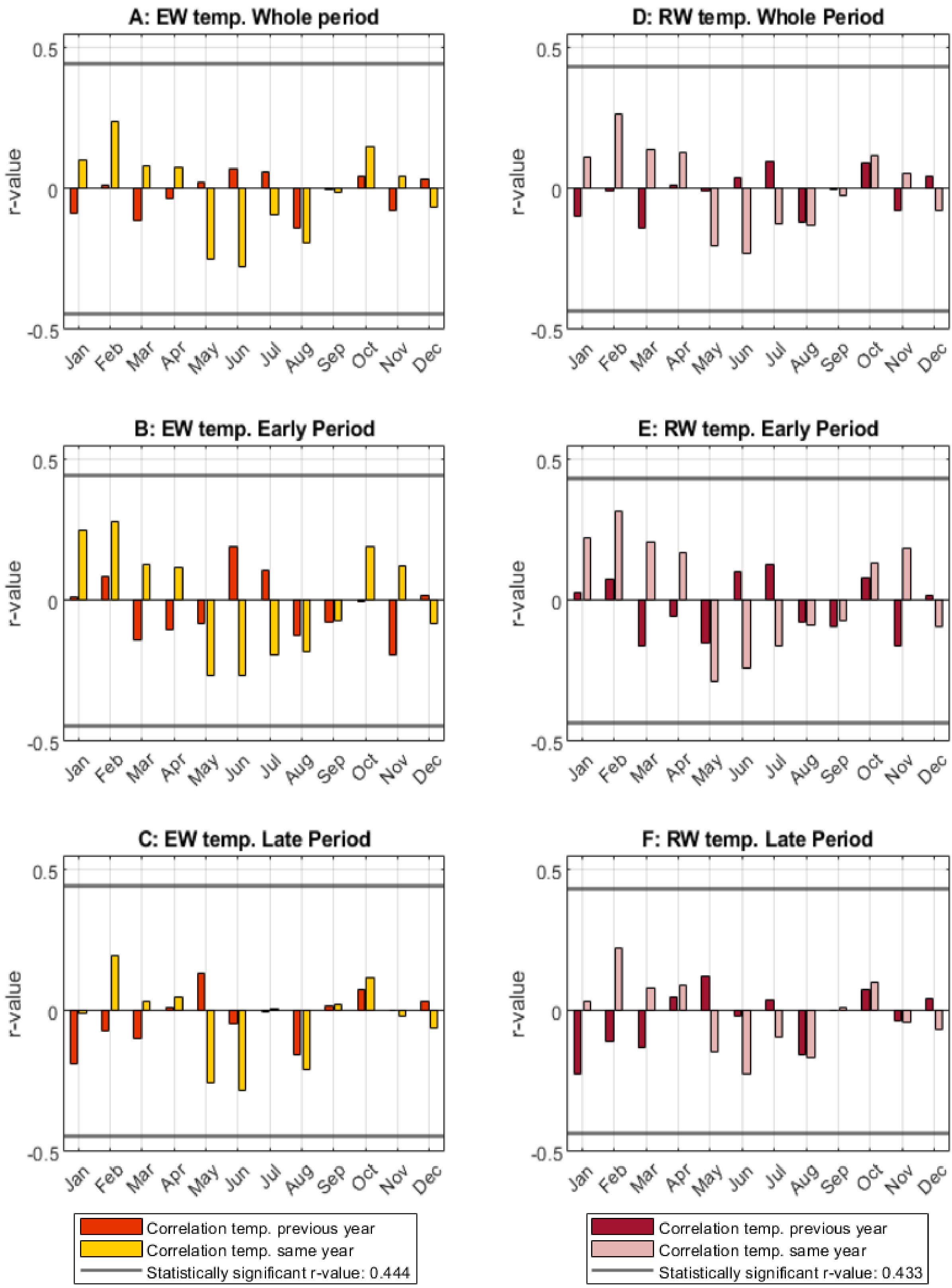

Figure 11. Correlation analysis between temperature and both earlywood (EW) (A-C) and the tree ring width (RW) (D-F). The analysis was done for the whole study period (A and D, 1886-2022), the early period (B and E, 1886-1950) and for the late period (C and F, 1951-2022). The statistically significant r-value was 0.444 for EW and 0.433 for RW, with a p-value of 0.05, based on Person's

correlation coefficient. The orange and red bars represent correlation with precipitation from the previous year. The yellow and pink bars represent correlation with precipitation from the same year.

4. Discussion

4.1 Comparison between Earlywood and Ring Width

A SSC can be found regarding the correlation between precipitation and both EW and RW (figure 10), which indicates that it might be the external limiting factor for tree ring growth. No SSC can be found regarding the correlation between temperature and both EW and RW in any of the studied periods (figure 11), even though an increase in temperature has been found (Schimanke et al., 2022). This indicates that temperature is not the external limiting factor for tree ring growth.

A SSC for precipitation the same year in May for the early period can be found for both EW and RW (figure 10B and 10E). The production of EW accounts for 40-80% of the total width of a tree ring for a year (Domec & Gartner, 2002), which can explain why they have the same correlation at the same time. On the other hand does RW almost have a SSC for precipitation the same year in June for the late period (figure 10F), which cannot be seen for EW (figure 10C). The SSC found in May is not shown for RW in the late period, which indicates that there has been a shift in when this factor influences the RW, from precipitation the same year in May to June, but not for EW. The SSC in May cannot be seen in the late period for EW either, which indicates that this climate parameter no longer influences the tree ring growth in the same way. As mentioned in the study from Schimanke et al. (2022), the amount of annual precipitation has increased from 600 mm/year to almost 700 mm/year since the 1930s. An overall wetting trend has also been found for the period 1902-2018 (Chen et al., 2021). Due to this increase in precipitation and wetter climate, the EW might not be dependent on precipitation in the same way over the years, which can explain the absence of a SSC in the late period (figure 10C). The lower correlation in the late period can also explain why no SSC was found for the whole study period (figure 10A). A change in precipitation pattern can also be a factor that can have had an influence on both the shift for RW and the absence of a SSC for EW. Other conditions might also have changed so that the precipitation no longer is the most limiting factor, such as the availability to sunlight or nutrients (Fritts, 1976).

A more in-depth investigation on how the climate have changed during the different studied periods in Bohuslän would have been interesting to analyse, as well as if the samples would have a correlation with other parameters, such as a drought index, but these aspects are outside the scope of this project. Due to the drier climate in the past (Chen et al., 2021), EW has the potential to be used for precipitation reconstructions for older time periods (before 1950) for the area, where the correlation might remain further back in time. This potential connection needs however to be studied further. RW has also the potential to be used for reconstructing precipitation, but further research needs to be done regarding the shift in correlation. Neither EW nor RW has the potential to reconstruct temperature, due to the absence of a SSC.

4.2 Comparison with Previous Studies

Jönsson and Nilsson (2009) made an investigation in the east of Sweden (62°36'N, 18°02'E) and found that EW and RW from Scots pine had the strongest correlation with precipitation the same year in May and June and the time period studied was 1890–2001. Another study made in the eastern and southeastern part of Sweden (57–62° N/14–19° E) from Seftigen et al. (2020) found a SSC for both EW and RW and precipitation in May and June during the studied period 1901–2010. It is interesting to see that the result from this work shows that no SSC was found for the longer time period studied (figure 10A and D). However, both a SSC was found for the same months, only in this study during different time periods. A possible explanation to the absence of a SSC for the late period for EW can be the "divergence problem", where studies have found a reduction in sensitivity after the 20th century (D'Arrigo et al., 2008). Chen et al. (2021) found that there is a small positive trend for precipitation in the southwestern part of Sweden, where a decrease in precipitation was found in the southeastern part. With higher precipitation, the limiting factor for EW might change and the signal might decrease, whereas it can still be seen for the eastern part of Sweden. It can be seen in figure 8A-B and figure 9A-B that the variability in growth pattern decreases for both EW and RW after the 1980s. It needs to be further investigated if this is caused by a reduction in sensitivity. The divergence problem has however mostly been studied regarding temperature and needs to be further studied (D'Arrigo et al., 2008).

Kalela-Brundin (1999) found that July temperature is the most limiting factor for both EW and RW and that precipitation did not seem to be the limiting factor. Kalela-Brundin (1999) study area was in south-eastern Norway close to the Swedish border (62°00'N, 12°11'E), whereas this study area was located in the southwest of Sweden. A possible explanation to why the results differ is the difference in latitude, where trees growing in higher latitudes are more affected by temperature (Fritts, 1976). However, result from Tuovinen (2005) found that EW correlated most with precipitation in June and temperatures in mid-winter and March. This study took place even further north, by the border line of Finland (69°40'N, 27°05'E). A possible explanation to why the correlation is one month after the results from this report can be because of a later growing season in higher latitudes (SMHI, 2011), which can explain why precipitation is more important for the tree ring growth in June and not as much in March for Tuovinen (2005) results.

4.3 Potential Influence of Latewood

What would have been interesting to investigate is the ratio between EW and LW and how it might have changed during the studied periods. There might have been changes in the climate that only affected the LW during the different studied periods. This might have given an explanation to why there is a difference between the SSC for EW and RW, where with a larger part consisting of LW, RW would be influenced more by the conditions set for LW. The analysis if there is a correlation between climate parameters (temperature and precipitation) and LW and RW during the same periods for the same study area (Halle-Vagnaren) is carried out by Camén (2023).

4.4 Improvements and Uncertainties

Between 1925-1930, there is a drop in the number of dated series (figure 8-9), which means that the years before this period are not represented by as many samples. This raises the question on the reliability of the correlation analyses for the earlier period. With a higher number of samples representing a period, the smaller the influence of individual changes for individual trees, where for example a tree can get more sunlight if a tree in front of it fell down, and therefore can grow more. The intercorrelation between the trees are however quite high, 0.562 for EW and 0.609 for RW (table 3), which indicates that the trees in the area are mostly affected by the same parameter. The temperature data only goes back to 1889 and the precipitation data to 1895, where there are still 5 and 8 trees representing this time period, respectively, which eases the influence of individual trees. To get a better representation further back in time, more samples can be taken. This was however not possible for this study, due to both limitation in time and permission.

The results from the precipitation during the late period (figure 10C and 10F) can be misleading, due to the lower correlation (0.8796) between the two precipitation stations (Halden and Nordkoster A). The changes that can be seen in the result can be influenced by the difference between the values of the two stations, not due to a change in the correlation between the parameters and the precipitation data. The dataset from Halden covers 42 years, and the dataset for Nordkoster A covers 30 year of the late period, where both cover as many years as what usually is used when looking at changes in the climate (World Meteorological Organization, 2021). Due to the long period for both datasets, this could then however cover potential changes in the climate system, which would not have been detected if only Halden would have been used. It is not known either which of the datasets correlates best with the tree data, which would be interesting to investigate in future studies.

5. Conclusion

There is a SSC found for both EW and RW and precipitation, however, the correlation differs between the parameters. Both of them have a SSC in May for precipitation the same year during the early period (before 1950), which can be explained by the higher proportion of EW in an annual ring. RW have almost a SSC for June precipitation the same year during the late period (after 1950), where no SSC was found for EW during the same time. This indicates that precipitation can be the limiting factor for the tree's growth, but only during the early period for EW and during the early and late period separately for RW. This suggest that there might be another limiting factor that influences the EW more during the late period. No SSC was found between EW and RW and temperature in any of the studied time periods, which indicates that temperature is not the limiting factor for growth in Scots pine in the nature reserve Halle-Vagnaren.

The results indicate that both EW and RW can be used when studying different climate parameters. There is however a difference between studying a longer period of time (whole period), compared to shorter periods (early and late period). This suggest that there has been a shift in the climate between these periods. Further investigations regarding this would be interesting to research, to investigate if these variations only are local or if this shift can be seen in other areas as well.

EW has the potential to be used for a precipitation reconstruction, but only before 1950. The climate has been dryer in the past, which gives a potential for there to be a SSC further back in time as well. RW has also the potential to reconstruct precipitation. This needs however to be studied further, as well as other investigations in the area to confirm that the correlation with the climate parameter is seen in a wider area.

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Appendix

Table A. Time of temperature (°C) measurement from the two weather stations from Sweden.

Operating time	**Time of measurement**
Nordkoster A	
1967 - 1972	06:00, 12:00, 18:00
1973 - 2000	03:00, 06:00, 09:00, 12:00, 15:00, 18:00
2000 - Still operating	Hourly
Strömstad	
1949 - 1972	00:00, 06:00, 12:00, 18:00
1973	00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, 21:00