Comparison of annual response to weather for Norway spruce *(Picea abies)* and Scots pine *(Pinus sylvestris)*

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Master Thesis no. 302

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Abstract

Different tree species react differently to variation in climate. This relationship can be found by measuring how annual ring width correlates to different climate variables. This information may be important as a basis for understanding how future forests may be altered by climate change. This study aims to investigate how radial growth of Norway spruce and Scots pine in Kronoberg and Kalmar county responds to precipitation and temperature by dendrochronological methods. The chosen stands had similar fertility and was stratified based on three age categories, >30, >50 and >80 years. Tree ring chronologies were detrended with a spline function and correlation analysis against monthly precipitation and monthly mean temperature was performed. The results showed significant positive correlation between radial growth in Norway spruce and monthly precipitation in May to July and a negative correlation with mean monthly temperature in May to August. A significant positive correlation between radial growth in Scots pine and monthly mean temperature in October to December previous year was found. Concerning the current trend of "sprucification" in Southern Sweden and the predicted increase of drought events in the future, these results can rise further concerns regarding the suitability of Norway spruce in this area. Hopefully, this study can shed further light on what challenges awaits Norway spruce and Scots pine forests of Southern Sweden in a changing climate.

Keywords*: Norway spruce, Scots pine, tree-ring width, climatic response, Southern Sweden.*

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Introduction

Because of human induced climate change, growing conditions for our forests have changed and are expected to continue to change *(Pachauri et al., 2014)*. Swedish forests have in recent time experienced an increased growth, probably due to several different factors such as improved forest management, improved plant material, an extended growth period, increased atmospheric CO_2 and the fertilizing effect of nitrogen deposition *(Spiecker, Mielikäinen, Köhl, & Skovsgaard, 2012)*. However, there are also potential negative effects of a changing climate. The risk for extreme weather such as storms, droughts or heavy precipitation will likely increase *(Lagergren & Jönsson, 2017)*. This will not only affect forest growth but also presumably increase the stress on forests and trees, making them susceptible to damage from secondary agents such as pests and pathogens *(Lagergren & Jönsson, 2017)*. Therefore, the need for resilient forestry are likely to increase in the future. In this context, the understanding of how different tree species may react to a changing climate is crucial for taking elaborated forest management decisions in the future.

The Intergovernmental Panel on Climate Change (IPCC) has developed four scenarios on how the greenhouse gas effect will increase in the future, the Representative Concentration Pathways (RCP), which can be used for climate modeling. The RCP scenarios are referred to as the level of radiative forcing achieved in 2100 relative to pre-industrial levels; 2.6, 4.5, 6.0 or 8.5 W / m^2 (Pachauri et al., 2014). RCP8.5 represents a continued increase of greenhouse gas emission up till year 2100, RCP6.0-, 4.5 and 2.6 represents continued increase of emissions up till year 2060, 2040 and 2020 respectively. From these global scenarios, RCP4.5 and RCP8.5 have been recalculated with a higher resolution for northern Europe by the Swedish Meteorological and Hydrological Institute (SMHI). Both scenarios show an increase in the annual average temperature in the whole of Sweden, with the most profound increase occurring with RCP8.5, showing an increase of 4 °C in the south of Sweden and 6 °C in the north. RCP4.5 showing an increase of 2 °C in the south and 4 °C in the north *(Claesson et al., 2015)*. Most of the temperature increase will occur during the winter.

The annual precipitation is also expected to increase, RCP4.5 shows 10-30 % increase and RCP8.5 15-40 % increase. The increase is greatest in northern Sweden during the winter and spring months and less during the summer and autumn, especially in southern Sweden. The risk for dry soils during the summer months will increase in southern Sweden, particularly in the southeastern parts. These climate changes will have a great impact on forest growth in Sweden. By using the Heureka Regwise model, a forest impact assessment was conducted by *Claesson et al, (2015)* which concluded that, compared to no climate change effect, RCP8.5 would increase forest growth with 56,8 % after 100 years. This increase is 18,9 % due to an increased forest stock and the remaining 37,9 % is due to a changed climate. However, this assessment has insecurities regarding the potential damage a changed climate might inflict on the forest in form of windthrow, fires, severe drought, flooding or outbreaks of insects and other pests which are all likely to increase. By using a 3PG-Heureka hybrid model, the cumulative effect of these risk factors could be better parameterized *(Subramanian, 2016)*. If Swedish forestry is to take advantage of the potential increased forest growth, it requires that the negative effects of a changed climate can be managed simultaneously.

Norway spruce (*Picea abies)* and Scots pine (*Pinus sylvestris)* are the two dominant tree species in Sweden. Respectively accounting for 41 % and 39 % of the standing volume (*Swedish statistical yearbook of forestry, 2014).* Lately, there has been talk about a "sprucification" of southern Sweden where Norway spruce, who traditionally is planted on mesic and fertile sites, more frequently also has been planted on drier and less fertile sites *(Claesson et al, 2015)*. Often this occurs at the expense of Scots pine, which usually is the chosen plant material for drier and less fertile sites *(Lodin, Brukas, & Wallin, 2017).* There may be several reasons why a forest owner may favor Norway spruce when choosing regeneration material. In comparison with Scots pine, Norway spruce is less susceptible to browsing damage. This circumstance in combination with high experiential knowledge regarding the management of spruce forests among forest owners makes Norway spruce an attractive species for regeneration *(Lodin, Brukas & Wallin, 2017).* The implications of this shift have not been thoroughly examined but it is likely to yield poor results due to an increased risk of drought, windthrow, spruce bark beetle outbreak and root rot *(Eriksson et al, 2015)*

It is well known that exogenous factors such as temperature and water availability will affect a tree's ability to grow. These climate factors influence the cambial activity within a tree. Favorable climate and growing conditions is often reflected in a well-developed annual ring while unfavorable conditions often result in a thinner annual ring. By using dendrochronology to study the development of annual rings, a lot of information about a tree's past growing conditions can be acquired *(Speer, 2009)*. By comparing annual ring width with climate data, the relationship between different climate variables and annual ring widths can be measured *(Suvanto et al., 2016; Zang, Pretzsch, & Rothe, 2012; Aakala & Kuuluvainen, 2011).* Past research indicates that the growth of the northern boundary of the boreal forest is limited by temperature while the southern boundary is mostly limited water availability *(Cook & Peters, 1997)*, but it can be problematic to describe climate-growth relationship in such general terms. The impact of climate variables on radial growth can vary greatly between tree species and site conditions *(Pichler & Oberhuber, 2007)*. A study conducted by *Ols et al, (2018)* showed a relationship between North Atlantic Ocean dynamics and growth responses in annual rings of boreal forests in Sweden and Canada. Although a lot of effort have been put on studying tree-growths relationship with climate variables, there is still a lack of understanding how this relationship is expressed across different ecosystems, tree species, age classes and edaphic conditions.

The aim of this study was to assess the influence precipitation and temperature may have on annual ring width of Norway spruce and Scots pine of different age classes in Kronoberg and Kalmar county by the means of dendrochronological methods. Under predicted climate change scenarios, where Sweden is expected to be exposed to more extreme weather events, this knowledge could be highly valuable.

Material and methods

Study area

This study was performed as part of a Ph.D. study by Oscar Nilsson where the overall goal is to investigate growth differences between Norway spruce and Scots pine on sites where regeneration with either species could be feasible. A total of 110 monoculture stands from production forests of Norway spruce and Scots pine was extracted from land owner databases of Sveaskog (a state-owned forest company) and Södra (a private forest owner's association). The position of study area and extracted stands can be seen in figure 1 and 2. The extracted sample was stratified based on age in to three categories, more than 30, 55 and 80 years respectively. In this study however, only 43 stands were included for further ring-width analysis. These stands were distributed between tree species and age category as seen in table 1. Hereafter the age categories will be referred to as young stands, middle-aged stands and old stands.

Table 1:Number of stands with Norway spruce or Scots pine as dominant tree species. Stands included in this study was distributed over the age categories, 30 ,50 and 80 years as presented in this table.

Stand age	Norway spruce	Scots pine
30	7	9
55	6	8
80	6	7

Stands were evaluated based on their site index. By using NFI data, the largest overlap between Norway spruce and Scots pine was assessed to be between a site index (SI) of 24 to 28. Site index for the Scots pine was converted to the corresponding value for Norway spruce according to Hägglund & Lundmark, 1981.

The standing volume in each stand had to consist of at least 80 % of either Norway spruce or Scots pine, according the land owner data base.

The first inventory was made during the autumn 2016. Four sample plots with a radius of 10 m were randomly distributed in each stand. All trees above 4 cm diameter at breast height 1.3 m (dbh) was calipered. Heights was measured on the two trees with largest diameter and on one random selected tree within the sample plot.

Figure 1*: The study areas position in South-east Sweden (approximately latitude 57, longitude 16).*

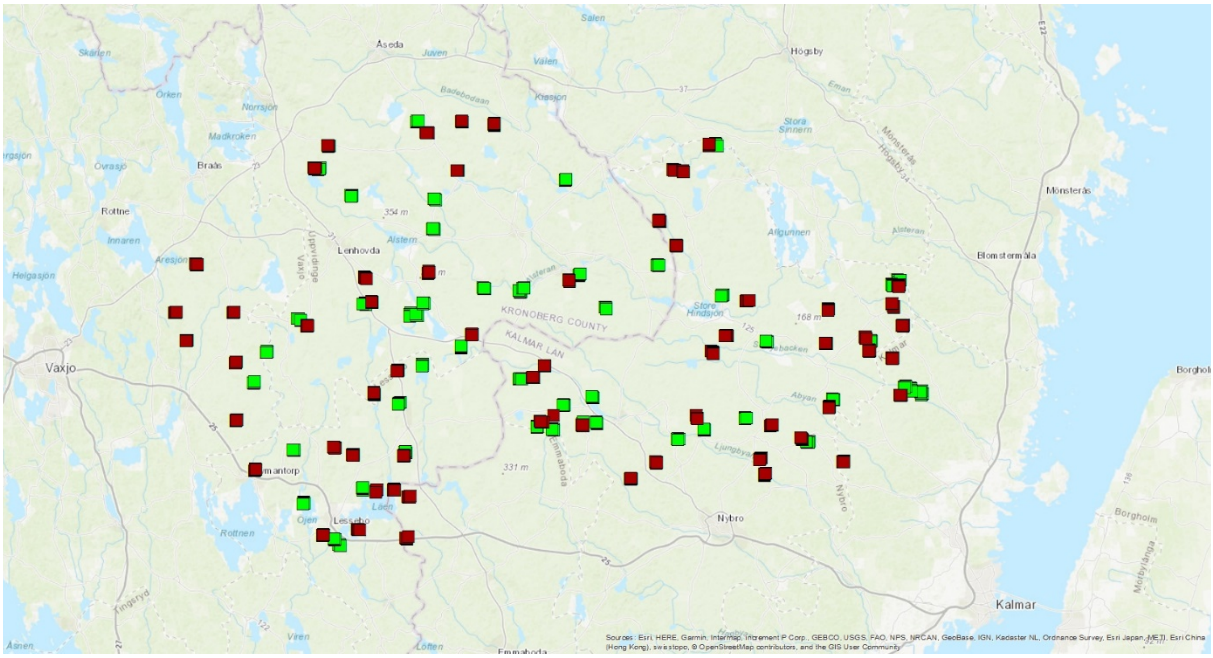


Figure 2*: The positions of the selected stands of Norway spruce (green squares) and Scots pine (red squares) shown in dark red colour.*

Tree-ring width chronologies

A second inventory of the selected stands was performed during the summer and autumn of 2017. An increment borer was used to sample cores at breast height (1.3 m) from three trees at every sample plot, in total 12 samples per stand. The two trees with the highest diameter at breast-height (dbh) within the plot was selected and one tree was randomly selected. The number of stumps within the sample plot and their approximate age was assessed in order to estimate time since last thinning. The stands were categorized as recently thinned, thinned within the last 5 years, thinned more than 5 years ago and never thinned.

The cores collected during the inventory were analyzed at dendrochronology lab at Southern Swedish Forest Research Centre, Alnarp. After the cores had dried they were glued with a water soluble white glue onto a prefabricated wooden core mount to facilitate further process of the cores. To avoid distortion and missing rings when measuring annual ring widths, the cores were glued in a cross-sectional view facing up (Speer, 2013). An electric sander with a 120-grit sandpaper was then used to polish the cores.

All cores were scanned to high resolution images using a flat-bed scanner. The pictures were then imported into software CooRecorder for tree-ring width measurement (http://www.cybis.se). The cores were measured starting at the outermost part, closest to the bark, making it easy to determine the year of each tree-ring. Coorecorder offers an automated tree ring identifier, although close attention was necessary to make sure the annual rings were accurately measured and that no rings were missed (Figure 3). The rings were measured perpendicular to each ring boundary. In order to keep the measurement perpendicular, the angle of measurement had to be adjusted when approaching the pith.

When approaching the pith of the core, the curvature of the rings increased and the angle of measurement had to be adjusted to keep it perpendicular. If the core did not include the pith, Coorecorder offers a tool to estimate the number of rings and the distance to the pith based on the curvature on the last rings (Figure 4).

After measuring all cores, a total number of 345 tree-ring width series was imported into Rstudio, a software environment for statistical computing (*R core team 2015).*

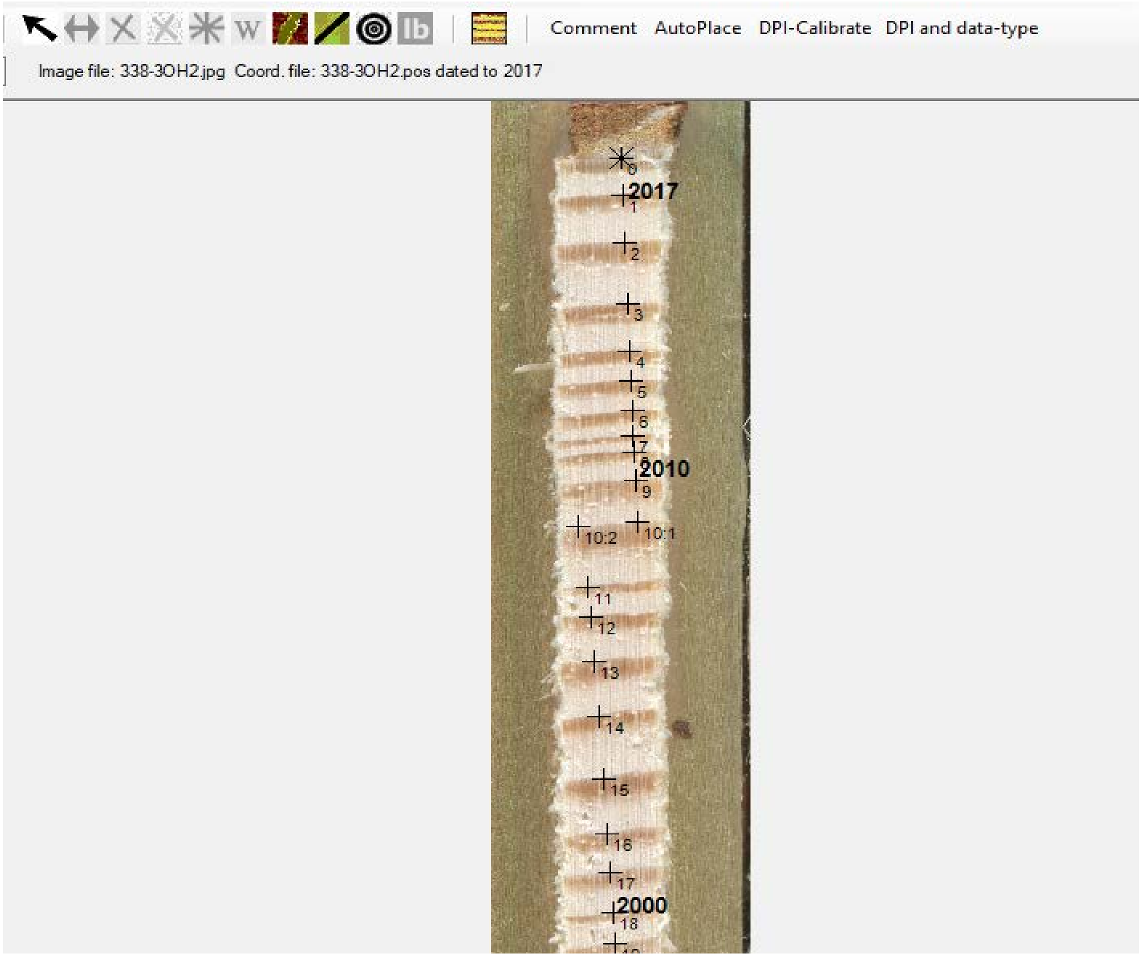


Figure 3:*Example of identification of tree-ring borders with CooRecorder.*

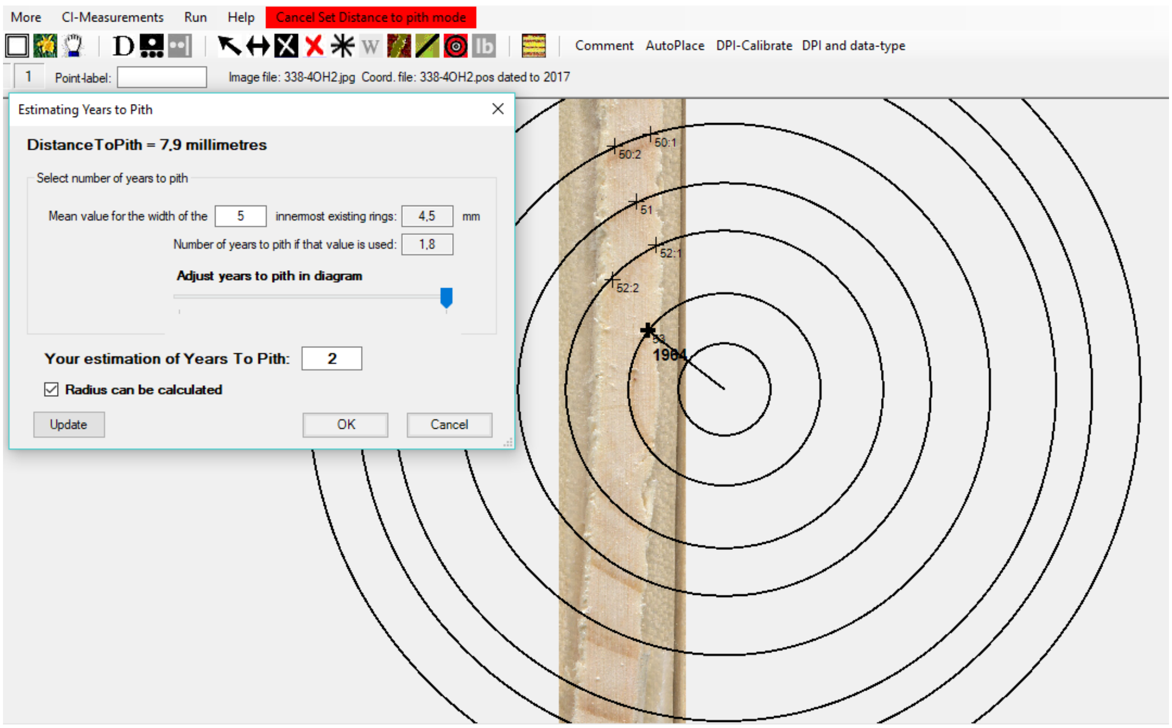


Figure 4*: Example of how Coorecorder allows you to estimate the number of rings to the pit.*

Approximately 150 cores had to be excluded from further analysis due to different forms of damage, leading them to impractical to date the year each annual ring had originated or leading to unreliable measurement of their annual ring widths. Such damages would usually be, loss of the outermost part of the core or the core being in too many pieces. The annual ring of 2017 could not be measured on those cores that were collected during the summer of 2017 as it was not yet fully developed. Therefore, the year 2017 was excluded from the tree-ring analysis.

Further on, in order to keep the sample size high and thereby increase the reliability of the observed growth trends, the years included in the analysis was limited to 1980-2016 (Figure 5). The core sample size increased in more present years because it included all age categories. By using a bigger sample size, potential effects from non-representative trees was minimized.

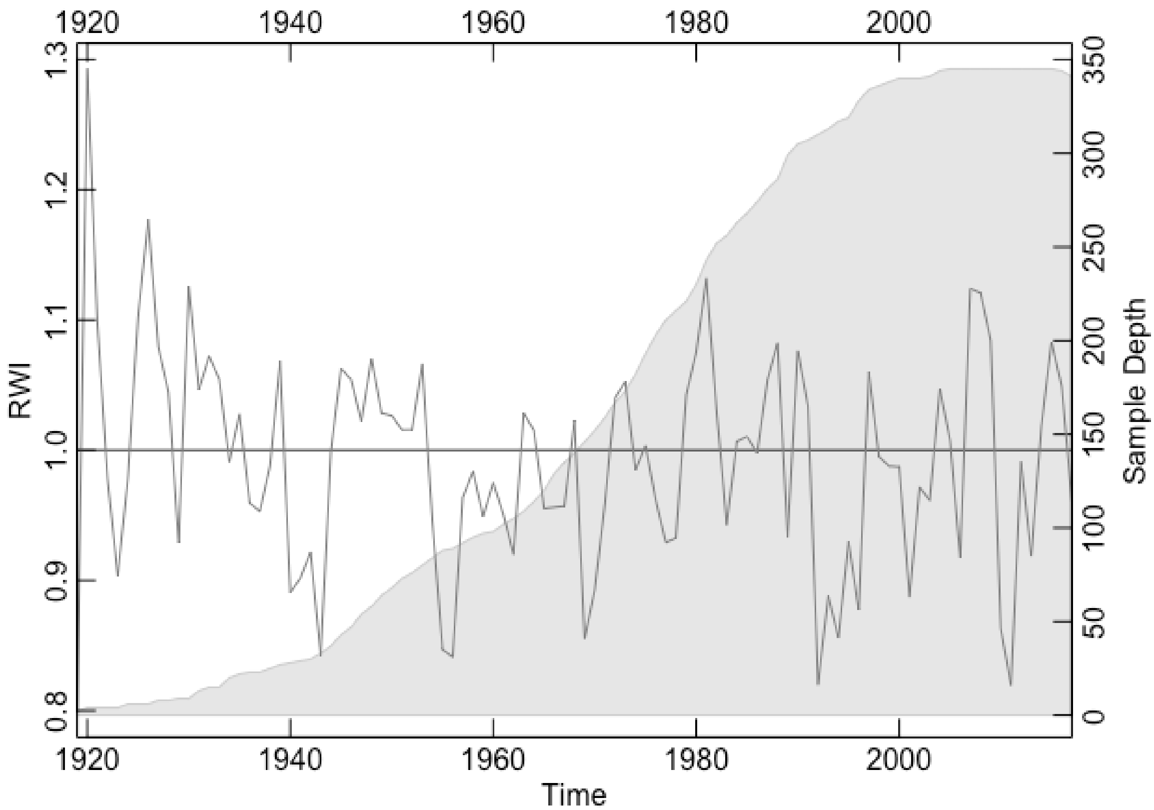


Figure 5*: Sample size (grey-shaded area) in each year for both Norway spruce and Scots pine. RWI =1.0 indicates the predicted annual ring growth for that year and the grey trend line corresponds to the annual growth in ring width index, indicating higher or lower than predicted.*

The dplR library package was used to process the raw tree-ring series within R in accordance with *Bunn, 2008*. The dplR package contains functions for carrying out some standard tree-ring analyses such as detrending, chronology building and cross dating *(Suvanto et al., 2017)*. Detrending was performed in order to remove growth trends related to age, size and non-climatic disturbances. By including many stands in the analysis, the potential effect from thinning operations on radial growth should be smoothened out and was therefore not considered as a confounding factor.

After visually reviewing the results from different detrending alternatives *(Bunn, 2008)*, a linear regression spline was chosen and species specific ring-width indices (RWI) was constructed, representing the annual fluctuations of the ring-widths with the age related trends taken out, where RWI=1.0 is the predicted growth, RWI>1.0 indicates higher and RWI<1.0 indicates lower growth than predicted.
RWI was constructed for Norway spruce and Scots pine respectively. In addition, the species samples were further divided between young, middle-aged and old stands in order to detect anomalies related to stand age.

The treeclim library package was used for the numerical calibration of proxy-climate relationships in accordance with *Zang & Biondi, 2015*. The package offered bootstrapcorrelation functions for seasonal correlations. The primary climatic variable, in this case monthly precipitation sum, was computed as the simple (Pearson) correlation coefficient and the secondary climatic variable, in this case monthly mean temperature, was computed with the influence of the primary variable on tree-growth removed. The functions evaluate both single month, average three month and average six month correlations with annual RWI in a moving window starting from September the year before and ending in August the current year.

Climate data

Climate data for the study area and the selected years was obtained from SMHI using a global climate model, JRA 55 *(Harad et al., 2016).* The Japanese meteorological agency conducted the second Japanese global atmospheric reanalysis, named the Japanese 55-year Reanalysis or JRA-55. It offers comprehensive climate data in a gridded format with high spatial resolution, from year 1958 and onwards by reanalysing weather observations from multiple sources such as weather stations, satellites and radiosondes. Climate data used in this study included monthly precipitation sum and monthly mean temperature.

Age classes and Dominate/Random trees

When the ring-width indices for Norway spruce and Scots pine were divided based on age category, the same trends could be observed between the age categories for both species (Figure 6).

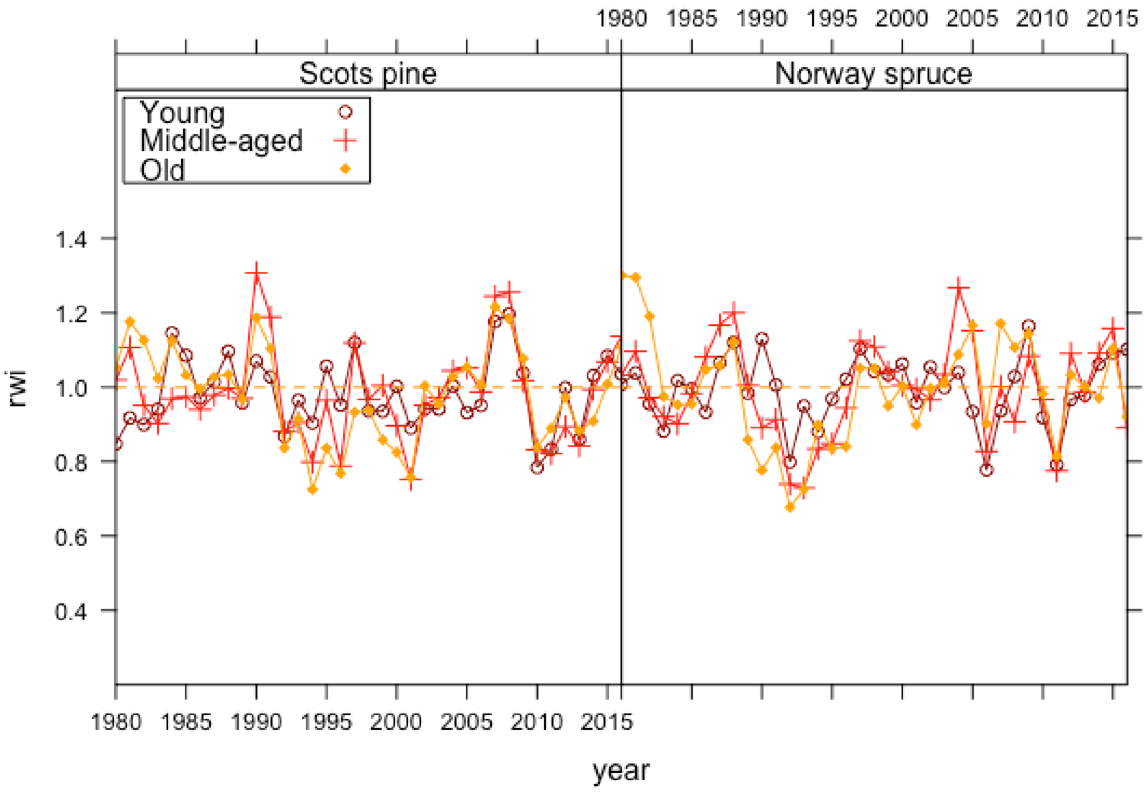


***Figure 6**: Ring-width indices for Norway spruce and Scots pine divided based on age category from 1980 to 2016. RWI of young stands showed in dark-red, middle-aged stands in red and old stands in orange. Scots pine to the left and Norway spruce to the right.*

After having compared ring-width indices for dominate and randomly sampled trees, no clear difference could be seen (Figure 7). Based on this fact, dominate and randomly sampled trees was merged together and no distinction was made in the correlation analysis.

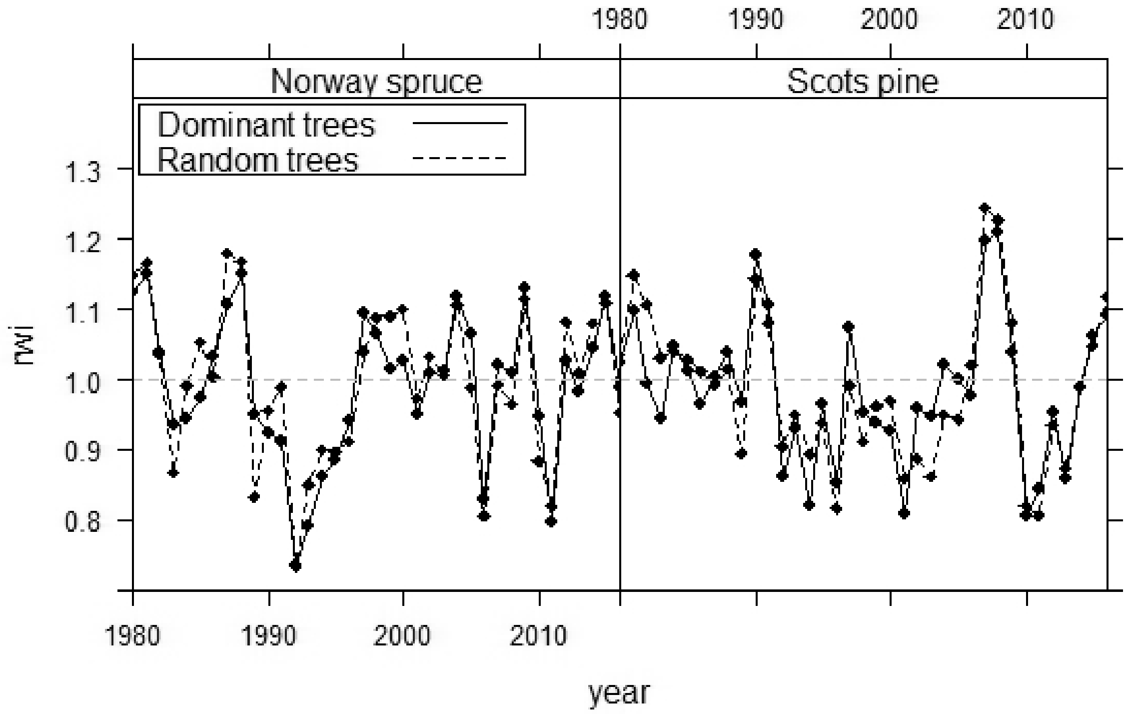


Figure 7*: Ring-width indices for dominant (solid line) and random trees of all age categories (dotted line) for Norway spruce and Scots pine.*

Comparison of RWI and indexed climate

Based on the results from the correlation analysis, the climate variables that showed high correlation was selected for visual interpretations of the tree growth response. The annual fluctuations of the climate variables were rescaled to indices where the mean between 1980-2016 had the value 1 and years below mean had lower index while years above mean had values above.

Results

Ring width indices for spruce and pine

After visually examining RWI for Norway spruce and Scots pine, several years with either spikes or drops in radial growth was identified for both tree species. The selection of Norway spruce stands, showed poor growth in year 1992-1996, 2006, and 2011, while the stands peaked in radial growth 1981, 1988, 2004, 2009 and 2015 (Figure 8).

After the growth decline in 1992 the four years following also showed modest growth and did not fully recover until 1997. Scots pine also showed a drop in radial growth in 1992 with the four following years showing a modest growth. Other drops in growth could be seen 2001, 2010 and 2011. Substantial peaks in growth could be seen in 1990, 2007 and 2008 (Figure 9). Both species indicated decreased growth in 1992 and the four years to follow, also 2010 and 2011 represented decreased growth for both species. However, the peaks in growth did not coincide in the same manner. While Norway spruce experience a peak in 1988, Scots pine instead showed an ample growth in 1990, 2007 and 2008 (Figure 10).

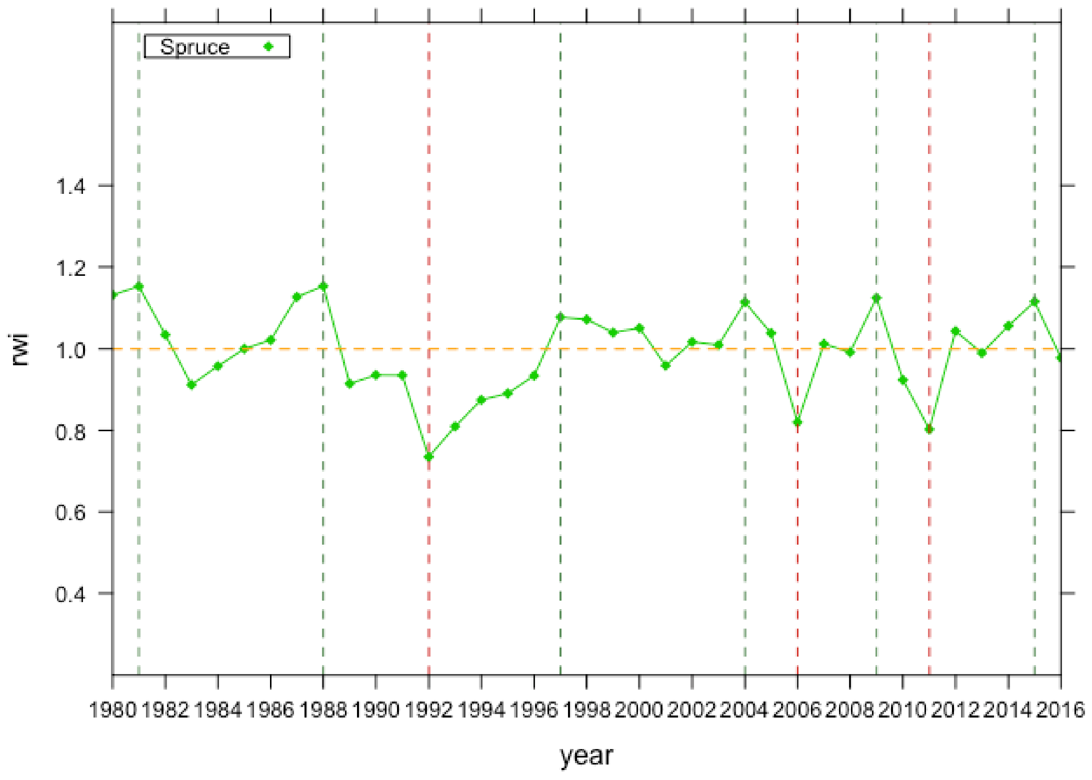
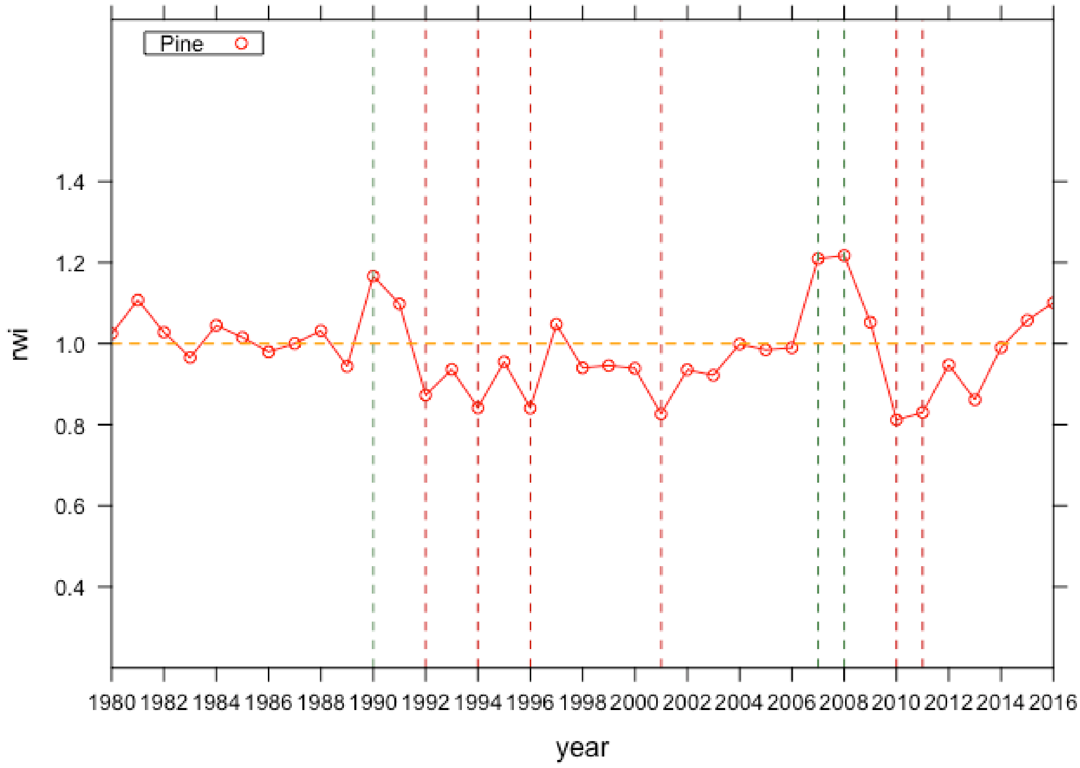


***Figure 8**: Ring-width index of Norway spruce (green curve) from 1980 to 2016. Years with favorable growth are marked with dark-green dotted lines while years with unfavorable years are marked with brown dotted lines.*



Figur 9*: Ring-width index of Scots pine (red curve) from 1980 to 2016. Years with favorable growth are marked with darkgreen dotted lines while years with unfavorable years are marked with brown dotted lines.*

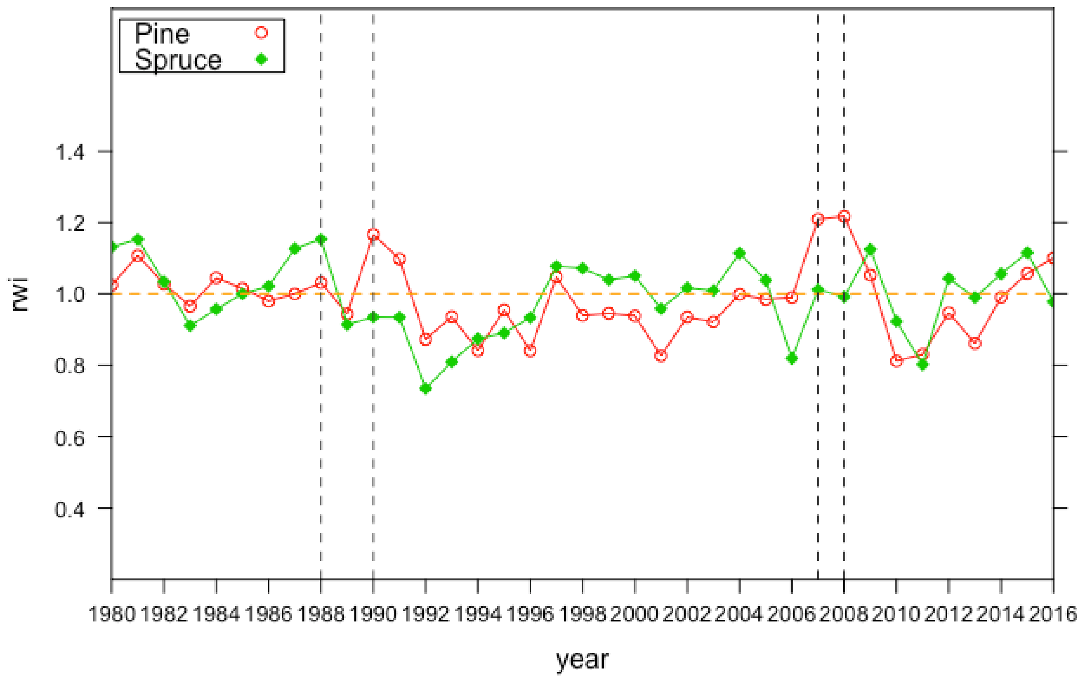
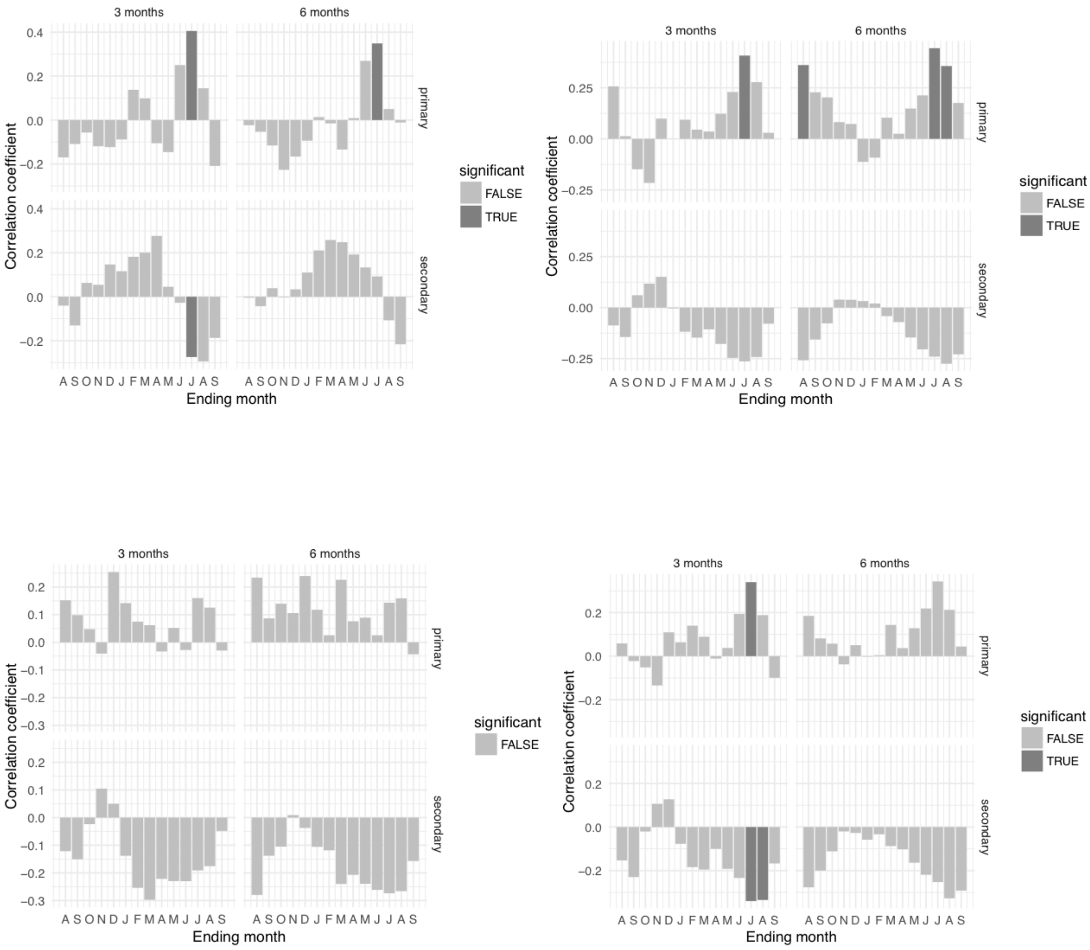


Figure 10*: Ring width indices of Norway spruce (green curve) and Scots pine (red curve) from 1980 to 2016 with interesting years marked with grey dotted lines.*

Correlation analysis for radial growth to precipitation and temperature

For all Norway spruce stands, significant positive correlation for precipitation in May to July was found and significant negative correlation for mean temperature in May to August (Figure 11). Young stands showed significant positive correlation for precipitation in May to July for the 3-months interval, and February to July for the 6 months interval. A significant negative correlation could be seen for mean temperature in May to July in the 3-month interval (Figure 11). Middle-aged stands also showed a significant positive correlation for precipitation in May to July for the 3-months interval. In the 6-months interval there was an addition of positive correlation in precipitation also for February to August, including last year's precipitation in March to August. However, no significant correlation to mean temperature could be seen for this age category (Figure 11). Old stands of Norway spruce showed no significant correlation for either precipitation or mean temperature (Figure 11).

For all Scots pine stands, significant positive correlation for mean temperature in October to December was found in the 3-months interval (Figure 12). Young stands of Scots pine showed a significant positive correlation for precipitation in January to March in the 3-months interval and significant positive correlation for mean temperature in October to January, while the 6-months interval showed significant positive correlation for mean temperature in previous years August to same years April (Figure 12). Middle-aged stands showed significant positive correlation for mean temperature in October to April in the 6-months interval (Figure 12). Old stands showed no significant correlation for either precipitation or mean temperature (Figure 12).



***Figur 11**: Radial growth correlation for **Norway spruce (young stands upper left, middle-aged stands upper right, older stands bottom left and all age categories bottom right)** to precipitation, as the primary variable in the upper panel, and monthly mean temperature, as the secondary variable in the lower panel. Ending month represents an average for the either 3 or 6 previous months. Significant correlations are shown in dark-grey colour.*

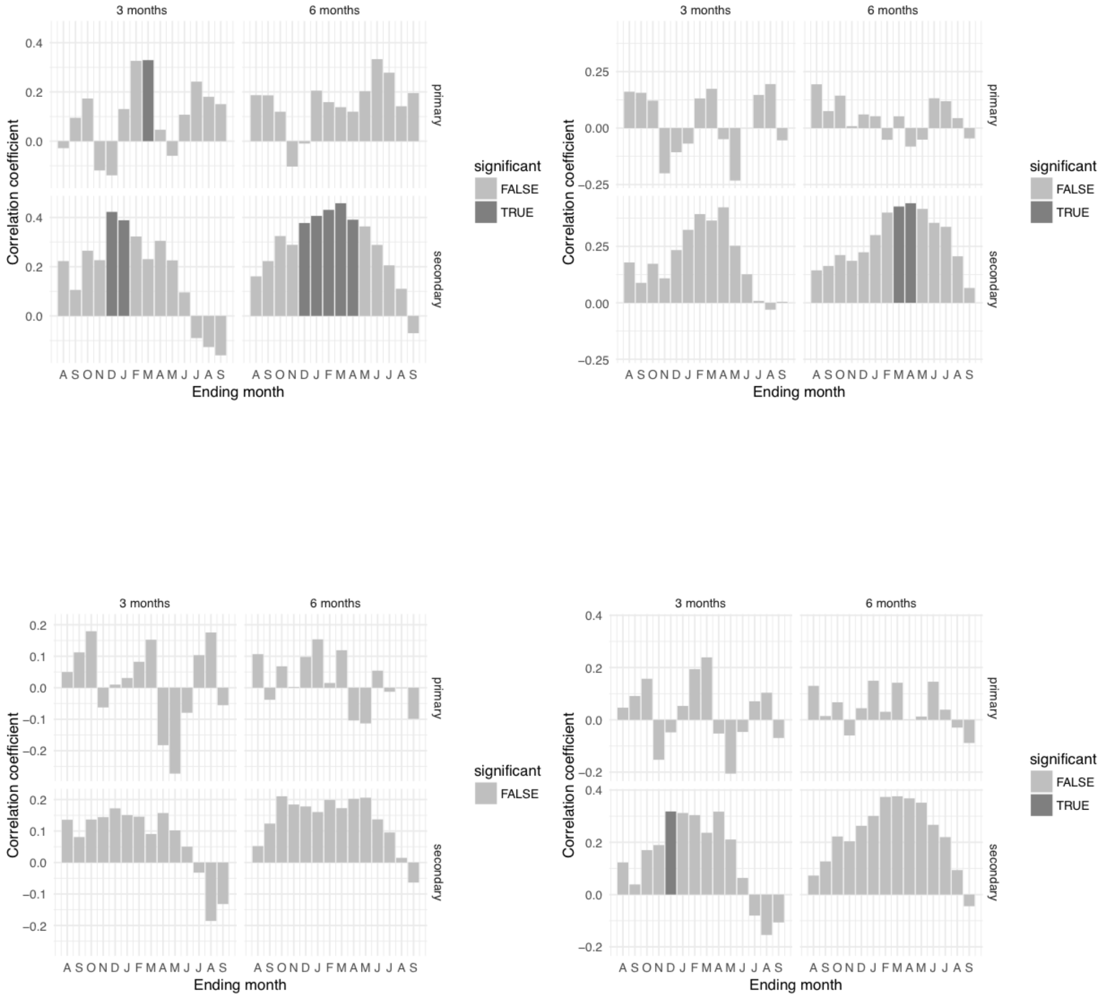


***Figure 12**: Radial growth correlation for **Scots pine (young stands upper left, middle-aged stands upper right, older stands bottom left and all age categories bottom right)** to precipitation, as the primary variable in the upper panel, and monthly mean temperature, as the secondary variable in the lower panel. Ending month represents an average for the either 3 or 6 previous months. Significant correlations are shown in dark-grey colour.*

RWI and weather variables as indices

The summer precipitation sum of May-August was calculated for each year and rescaled to a summer precipitation index (SPI) where the value 1=67,39 mm value 0.8≈40 mm and value 1.2≈95 mm. The coinciding trendlines of RWI and SPI over the time period 1980-2016 correspond to the findings from the correlation analysis. However, the dramatic drop in SPI and RWI 1992 is then followed by four years of low RWI for Norway spruce (Figure 13). It also seems as the growth of Norway spruce corresponds slightly better with precipitation during the growing season than the growth of Scots pine does, which was also verified by the correlation analysis (Figure 14).

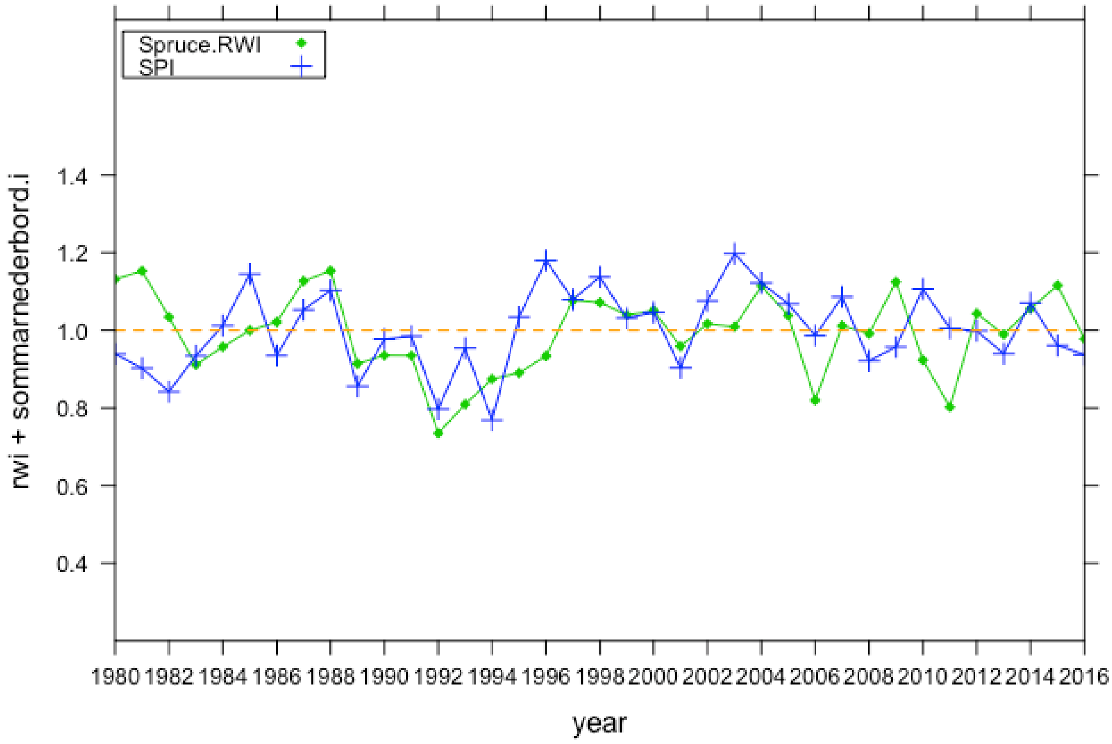


Figure 13:*Ring width index of Norway spruce (green) and Summer precipitation index (blue).*

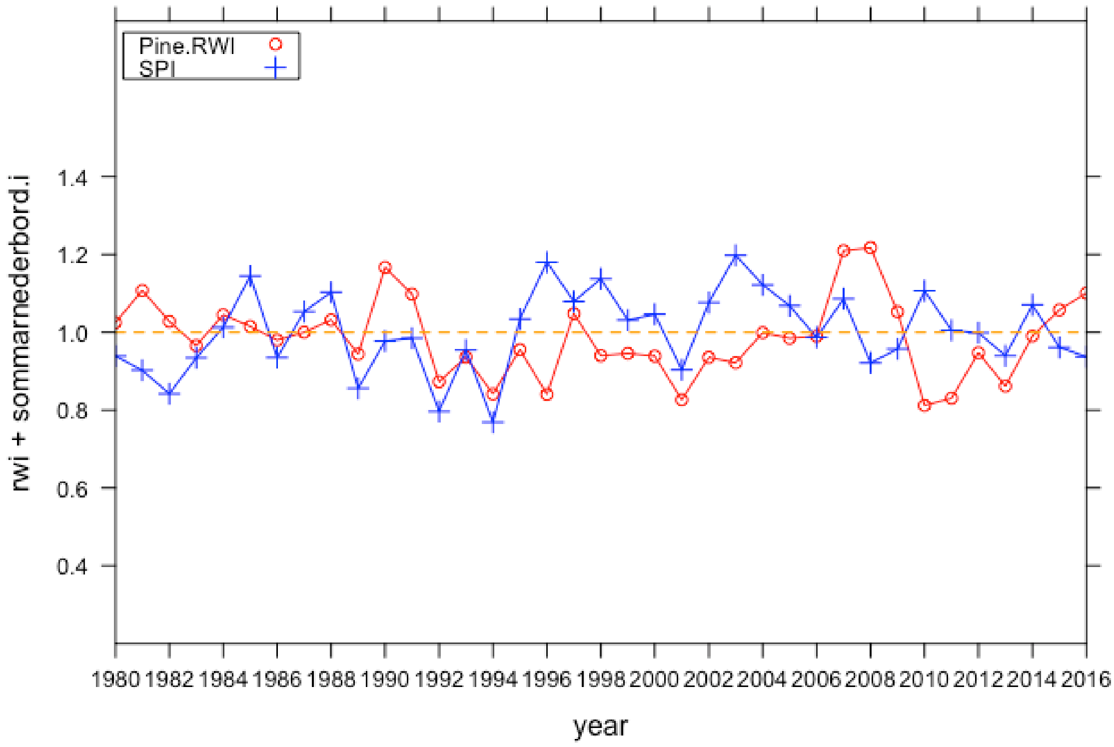
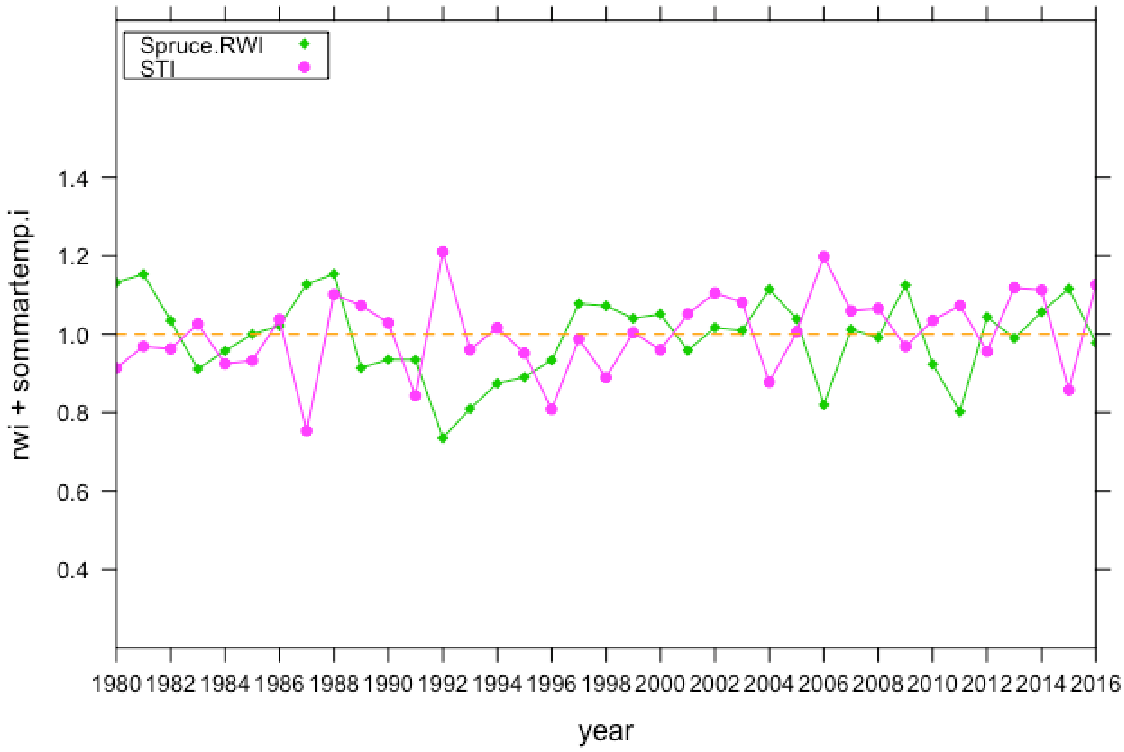


Figure 14: *Ring width index of Scots pine (red) and Summer precipitation index (blue).*

The mean temperature sum of May-August was calculated for each year and rescaled to a summer temperature index (STI) where the value 1=13,34 °C, value 0.8≈11,70 °C and value 1.2≈15 °C. The diverging trendlines of RWI for Norway spruce and STI over the time period 1980-2016 corresponded to the findings from the correlation analysis (Figure 15). For Scots pine, it was harder to see either a correspondence or divergence between RWI and STI. (Figure 16). This was also in agreement with the correlation analysis.



Figur 15: Ring width index of Norway spruce (green) and Summer temperature index (pink).

Based on the findings in the correlation analysis for Scots pine, the mean temperature sum of October-December was calculated for each year and rescaled to an Autumn temperature index (STI) where the value 1=2,52 °C, value 0.8≈-0,25 °C and value 1.2≈5,5 °C. Although, the overall correspondence is not strong it is possible to see a steep decline in growth coinciding with well below average Autumn temperature in 2010, but no substantial increase in growth can be seen in 2000 despite well above average Autumn temperature (Figure 17).

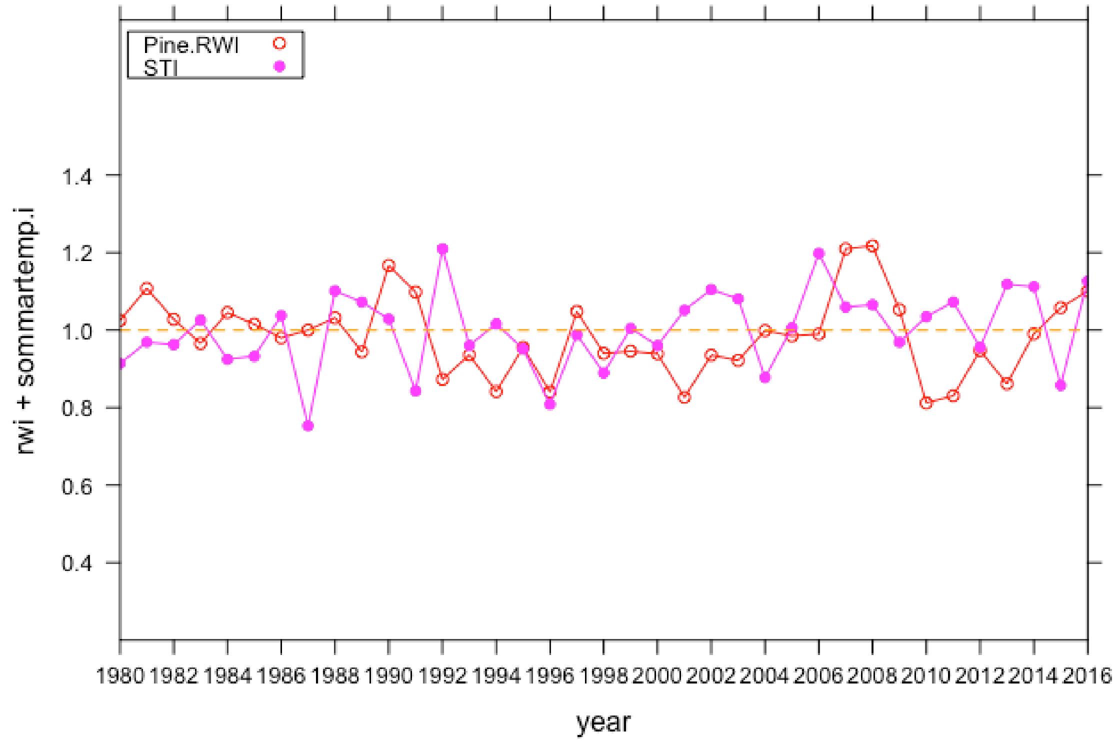


***Figure 16**: Ring width index of Scots pine (red) and Summer temperature index (pink).*

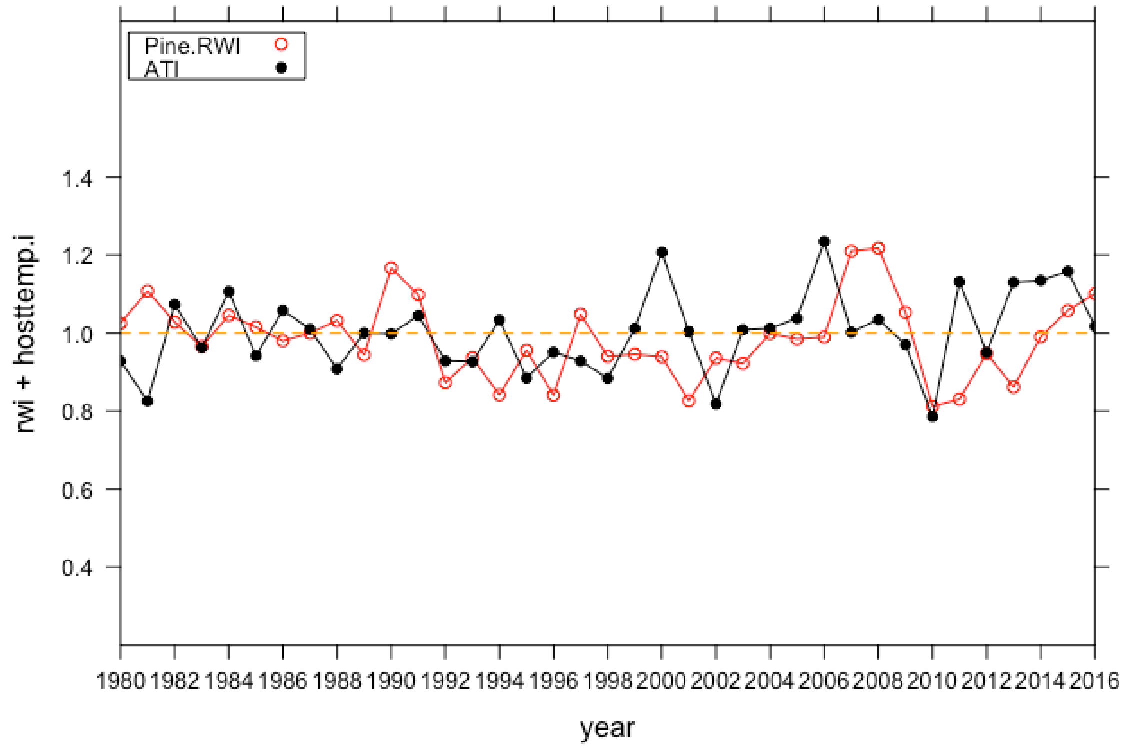


***Figure 17**: Ring width index of Scots pine (red) and previous Autumn temperature as an index (black).*

Discussion

By running correlation analysis on detrended ring-width chronologies from young, middle-aged and old stands of Norway spruce and Scots pine from Kronoberg and Kalmar county on monthly precipitation and monthly mean temperature, several significant correlations could be identified.

The results from the correlation analysis showed that precipitation in May to July had a positive correlation to radial growth in Norway spruce, while mean temperature in May to August had a negative correlation. This indicates that the Norway spruce stands may be susceptible to drought stress which corresponds well with previous studies concerning drought stress and its effect on radial growth in Norway spruce *(Zang, Pretzsch, & Rothe, 2012; Aakala & Kuuluvainen, 2011;Pichler & Oberhuber, 2007)*. Water deficit during the growing season causes physiological stress and reduces photosynthetic production *(Theodore T. Kozlowski and Stephen G. Pallardy, 1997).* By influencing the soil moisture availability and increasing evapotranspiration, high temperature during the growing season can induce drought stress *(Barber, Juday, & Finney, 2000; Aakala & Kuuluvainen, 2011).* This study further substantiates the thesis that growth of Norway spruce in the southern boundary of the boreal zone is more limited by precipitation than by temperature by showing positive correlation for precipitation and negative correlation to mean temperature *(Cook & Peters, 1997)*

Regarding the age categories of Norway spruce, the result showed significant correlation to precipitation and mean temperature for the young and middle age stands but not for the older, indicating that radial growth in younger trees are more sensitive to precipitation and temperature than older trees. This also corresponds well with some previous studies investigating the relationship between tree age and climate sensitivity of radial growth *(Zhang et al,, 2018).* A possible explanation for this could be that older trees have a more well developed root system which allows them to extract water from the soil more efficiently *(Rozas, DeSoto, & Olano, 2009).* Also, the competition between trees for water and other resources may be greater in younger stands *(Primicia et al., 2015)*. It should be noted that there have been some contradicting findings regarding the responsiveness of different age classes of Norway spruce to drought. Ding et al, (2017) found that young spruce trees were more resistant than older spruce trees to drought years and Zang et al.,

(2012) found that larger Norway spruce trees are more limited by hot and dry summers than smaller spruce trees.

For Scots pine, the correlation analysis for all stands showed significant positive correlation only for mean temperature in October to December previous year. This result proved harder to explain. It's possible that a warm winter prevents winter embolism by preventing the roots from freezing *(Lintunen et al., 2014).* The most logical explanation to growth correlation to winter temperature would be its influence on snow cover which is known to influence fine root mortality by protecting them from freezing *(Hardy et al., 2001).* However, in areas with inconsistent snowpack, an increased winter temperature may mean less damage to fine roots, leading to better radial growth *(Pederson et al., 2004).*

When observing the fluctuations of ring-width index for Scots pine, it becomes clear that the radial growth does respond to something although it does not seem to be precipitation or mean temperature to the same extent as Norway spruce. Several previous studies comparing growth to climate response between Norway spruce and Scots pine, have found that Norway spruce is the most responsive to climate of the two species *(Levesque et al., 2013; Zang et al., 2012).*

When observing the ring-width indices, it is interesting to see that after the hot and dry summers of 1992 and 1994, the radial growth of both Norway spruce and Scots pine trees does not fully recover until 1997. This indicates that the trees may have suffered substantial damage which affected their growth capacity for the succeeding years. One possible explanation is the potential loss of fine feeder roots caused by dry soils for an extended amount of time, which thereby puts the root system out of balance with the amount of foliage found above ground. Prolonged growth reduction can also be caused by needle and branch dieback and xylem cavitation *(Orwig & Abrams, 1997).* Drought stressed trees show an increased risk of being attacked by secondary agents such as pests and pathogens which may inhibit growth further *(Netherer et al., 2015)*. After a drought, trees may prioritize below ground growth in order to regain root function *(Hagedorn et al., 2016).* Meaning, less important tree growth processes such as stem growth are reduced. Something that may further complicate the relationship between radial growth and climate is the tendency of trees to allocate resources for reproduction following warm and dry summers *(Selås, Piovesan, Adams, & Bernabei, 2002).* This allocation of already scarce resources due to suboptimal growing conditions can reduce radial growth additionally *(Pukkala, 1987; Mencuccini & Piussi, 1995).* For further investigations, historical data of masting years, could reduce noise in response to climate or detect interactions between resource allocation and climate response.

The fact that it may take several years for a tree to recover after a drought event should also influence the possibility to find growth-climate correlations due to the trees inability to fully utilize potentially favorable growing conditions the years immediately after a drought. In this study, monthly average temperature was used for the correlation analysis which means that influential weather events such as frost may be present but are hidden in the monthly averages. To only use precipitation as measurement of drought, as was done in this study, may be quite uncomprehensive. In further studies estimations of e.g. available soil water, as the difference between precipitation and evapotranspiration in the stands could be used.

In contrast to ring-width data from the NFI, the data gathered and used in this study offered a large number of samples from each stand, tree species and from a specific area in Sweden. This fact should decrease the potential for noise in the climate response.

In the backdrop of the record-breaking heat and drought event that hit Sweden in the summer of 2018, the demand for knowledge concerning the relationship between tree growth and climate has gotten even more immediate. Coping with an uncertain future climate, where extreme weather and prolonged drought events are expected to increase is something that has to become carefully considered when it comes to forest management decisions. The results from this study suggests that Scots pine is more adapted for the potential increase of drought events in the future. Considering the current trend of a "sprucification" of southern Sweden, where Norway spruce increasingly has been the favored regeneration species over Scots pine, and the predicted increase of drought events in the future, concerns can be raised regarding the implications of this shift.

Conclusion

This study investigated the species-specific tree-ring width response to monthly precipitation and monthly mean temperature between Norway spruce (*Picea abies)* and Scots pine *(Pinus sylvestris)* growing on sites with similar fertility in Kronoberg and Kalmar county for the time period of 1980 to 2016 by the means of dendrochronological methods. Precipitation in July showed a positive correlation to radial growth in Norway spruce, while mean temperature in July and August showed a negative correlation. Radial growth in Scots pine showed a positive correlation for mean temperature in December. Both tree species showed a prolonged growth reduction following the drought of 1992 and 1994. Hopefully, this study will contribute to and substantiate previous findings regarding the climate-growth relationship in Norway spruce and Scots pine.

Regarding future forest dynamics in the area, an important question is whether or not the expected increase in temperature will be compensated by a sufficient amount of precipitation in the future. The relationship between climate and radial growth is complex and further research with more refined climatic variables is necessary to draw more comprehensive conclusions.

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